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AMSAT
RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE AMSAT-NA

17th Space Symposium,
and **AMSAT-NA** Annual Meeting

October 8-10
1999
San Diego,
California

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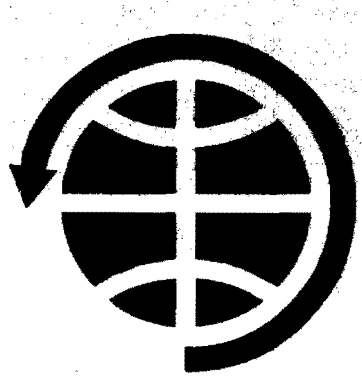

Welcome

It is with great pleasure that I personally welcome each of you to the 1999 AMSAT-NA Annual Meeting and Space Symposium. This meeting continues a proud tradition that AMSAT started in the early 1980s to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas among like-minded friends and colleagues. And share they have. For it was at many such previous meetings that the very first ideas that would later be incorporated into a number of our AMSAT satellites were exchanged. Many of the designs for these satellites were initially sketched out at previous Space Symposiums, often on the back of hotel napkins or envelopes (and usually in the "wee hours" of the morning!) In short, it is at AMSAT's Space Symposia where the true creative sprit of our organization really flourishes.

I am doubly proud to welcome you to San Diego this year because 1999 also marks AMSAT-NA's 30th anniversary. The Radio Amateur Satellite Corporation (AMSAT's full corporate name) was formed over thirty years ago, in March 1969, to carry on the work begun by Project OSCAR. And, by any measure, AMSAT's work since its founding has had a *major* impact on our world as we know it, not just as Radio Amateurs, but as citizens of Planet Earth. For it was AMSAT's experimenters that helped the rest of the world's communication engineers perfect the idea of a "satellite transponder", a device that, in its modern day form, now relays television pictures, telephone calls and, yes, even that modern-day miracle, Internet traffic, from faraway places via satellite (and in near-real time) into our homes and offices.

It was also AMSAT's experimenters (largely out of necessity because our organization couldn't afford anything else!) who were among the first satellite builders to discover that "off the shelf" electronic components often worked just as well (and in some cases, *better!*) in space than those components tested to near destruction in the expensive pursuit of a "space rated" label.

And, it was the Radio Amateurs at AMSAT who worked with Europe's ArianeSpace launch agency to use some of the empty space on their launch vehicles for carrying additional satellites where traditionally only ballast had been placed. The result was a method to simultaneously launch a number of small, lightweight satellites AMSAT called its *MICROSATs* and *UOSATs*. In fact, AMSAT's small satellite concept has since been (quite successfully) imitated by a number of other, very well-financed commercial satellite organizations. Since its humble beginnings, AMSAT and its affiliated worldwide organizations have now built and launched nearly 40 satellites. Well over a dozen of them are currently still in orbit and operational.

And, our future is just as bright because as I write this, AMSAT's Phase 3-D International Satellite, our largest and most sophisticated satellite ever constructed, is now *fully assembled and tested!* What's even more exciting is that P3-D, along with a number of other Amateur Radio satellites, are currently awaiting launch, hopefully in the not-too-distant future.

So, whether you are just getting started, or have been on the "birds" for awhile, the information you will obtain here at these meetings will help you unlock the sheer fun and excitement of the Amateur Radio Satellites. And, don't be afraid to share your own learning with others while you are here.

Thanks again for joining us in San Diego and have a *great* weekend!

73,

Keith Baker, KB1SF
President, AMSAT-NA

Greetings from San Diego,

I am pleased to be able to host this year's Space Symposium and AMSAT-NA Annual Meeting in San Diego, California. This is a special year as AMSAT-NA celebrates its 30th anniversary. As I reflect on the accomplishments of AMSAT and Project OSCAR I am very impressed at the successes that have been achieved on very tight budgets and the dedication of all those who worked on each of the projects.

This year we have the opportunity to present papers on satellites scheduled for launch the week after our meeting. As always there is the possibility of delay in the launch schedule, but the information exchanged will help us all to understand the missions of the various payloads as we observe the launch activities.

Enclosed within this document is a very broad spectrum of topics related to Amateur Radio Satellites. Whether you are interested in orbits, operation, flight hardware, antennas, software or other related topics you should be able to find a paper here that suits your interests. If you are interested in discussing a topic further, all of the authors have provided their email addresses for direct correspondence.

In the last 2 years there have been at least half a dozen amateur radio satellites launched and there are an equivalent number waiting to be launched in the next year. These satellites are being built by organizations all over the world which gives us the additional challenge of keeping current with the information necessary for scheduling and operating these new birds. I hope this document will assist you in your pursuit of this goal.

73,

Duane Naugle, KO6BT
1999 AMSAT-NA Symposium Chairman

The Apogee at Constant time-of-day Equatorial (ACE) Orbit for Amateur Radio Satellites

By Ken Ernandes, N2WWD
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ABSTRACT

This paper analyzes the utility of the Apogee at Constant time-of-day Equatorial (ACE) orbit for amateur radio spacecraft. The ACE is an elliptical orbit with a bounded altitude range. This orbit was developed by A. Turner (see **references 1** and **2**) as a candidate communications satellite orbit. The interesting property of the ACE is the way it uses perturbations due to Earth oblateness in a unique manner to produce an equatorial sun-synchronous orbit. This property offers some interesting power management advantages to the spacecraft. Furthermore, the altitude range provides a Molniya-like orbit with an excellent balance between a large footprint at high altitude and the possibility of magnetorque attitude control and low free space "path loss" at low altitude. The elliptical orbit also makes ACE and ACE-like orbits within reach of low inclination space launches.

INTRODUCTION

The amateur satellite community has continuous discussions and debates about orbits for future spacecraft. Since there is no single orbit that accommodates the needs and desires of all mission objectives or satellite operators, I have been presenting analyses of various candidate orbits, showing what goals they satisfy and to what degree.

The ACE orbit is the third orbit for which I've done such an analysis. In the 1997 and 1998 AMSAT Symposiums, I presented a 19,000 km circular orbit (see **reference 3**) and an 8,000-10,000 km Intermediate Circular Orbit (ICO) (see **reference 4**). The ACE orbit is a special case of an elliptical orbit in which apogee occurs at the same local time on the Earth's surface below the spacecraft. The ACE orbit achieves this property with an equatorial inclination by using techniques similar to those for achieving traditional sun-synchronous orbits.

EQUATORIAL SUN SYNCHRONOUS ORBITS

Traditional sun-synchronous orbits use the perturbative gravitational forces resulting from the Earth's non-spherical mass distribution to cause orbital plane precession. (The planar precession is a change only to the right ascension of the ascending node and is also known as nodal regression.) By setting the nodal regression rate equal to the Earth's motion around the Sun, the orbital plane maintains a constant solar illumination angle. To achieve synchronization, the orbit must have a 360° per year (365.25 days) nodal regression rate or about 0.9856° per day. The nodal regression is mainly a function of orbital altitude versus inclination as illustrated in **figure 1**, with traditional sun-synchronous orbits having [slightly retrograde] polar inclinations. Some advantages of the sun-synchronous orbit include consistent scene illuminations for imaging missions and predictable pass times since the orbit follows constant local times for the ascending and descending halves of its orbit. Sun-synchronous orbits also allow for simpler spacecraft thermal control and sun-tracking solar panel designs. **Reference 5** has more information about sun-synchronous orbits.

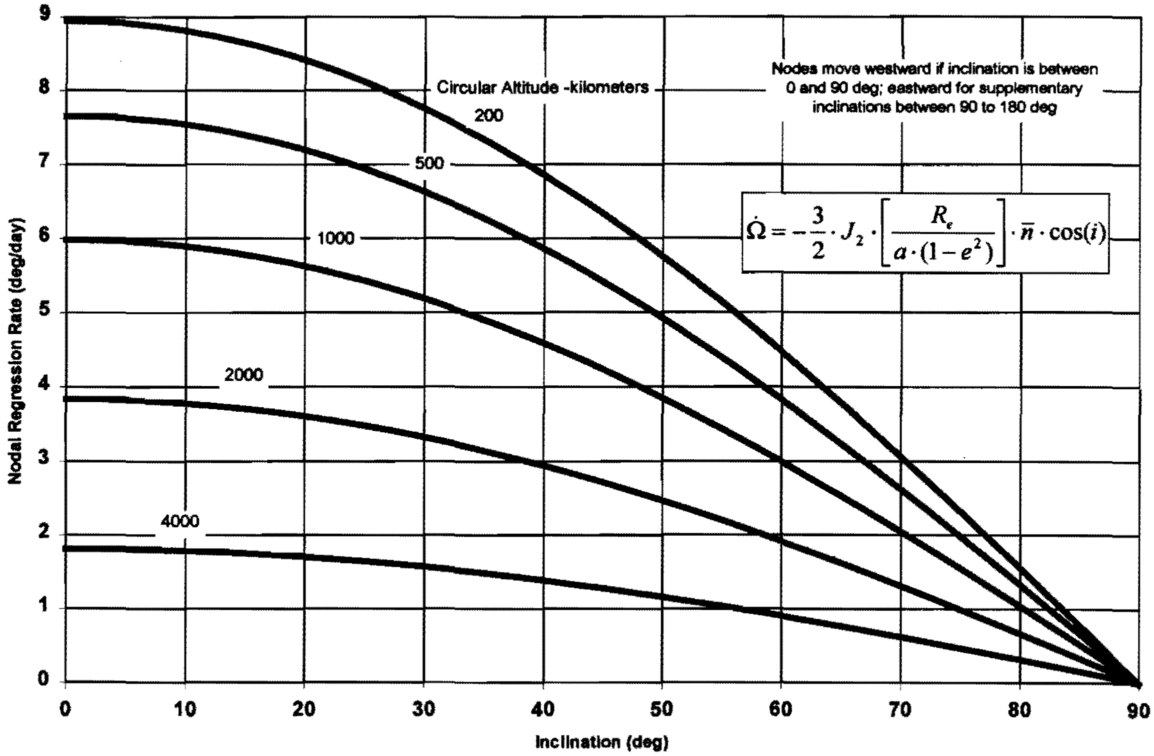

Figure 1., Nodal Regression Rate versus Inclination for Various Altitudes

The equatorial sun-synchronous orbit combines the planar precession perturbation from **figure 1** with the apsidal rotation perturbation illustrated in **figure 2.** The sum of the planar precession and the apsidal rotation rates is the sun-synchronous orbit's 0.9856° per day.

Unlike a traditional polar sun-synchronous orbits however, the ACE orbit is equatorial. This lets us add the nodal regression and apsidal rotation rates directly to form a single rate since they both lie in the equatorial plane. Furthermore, since the orbit's inclination is 0° (or nearly 0°), the equations for the nodal regression and apsidal rotation rates (shown in **figures 1** and **2**) are simplified.

To achieve an ACE orbit, the semi-major axis (i.e., half the longest distance across the orbital ellipse) needs to be balanced with the eccentricity (a dimensionless parameter that describes how elongated the orbit is). By forcing the sum of the apsidal rotation and nodal regression rate equations to equal the 0.9856° per day Earth orbital rate, the semi-major axis depends only on the eccentricity by the following equation (from **reference 2**):

$$a = k \cdot \left[1 - e^2\right]^{-\left(\frac{4}{7}\right)}$$

where:
a is the semi-major axis
e is the eccentricity
k = 1.23513 x 10^4 km

Reference 2 indicates the maximum eccentricity for an ACE orbit is (e = 0.566), with a corresponding semi-major axis of 17740 km, based on a minimum perigee altitude. As the eccentricity decreases to zero, the semi-major axis decreases to "k" (12351.3 km), defining the altitude for the circular case of an ACE orbit.

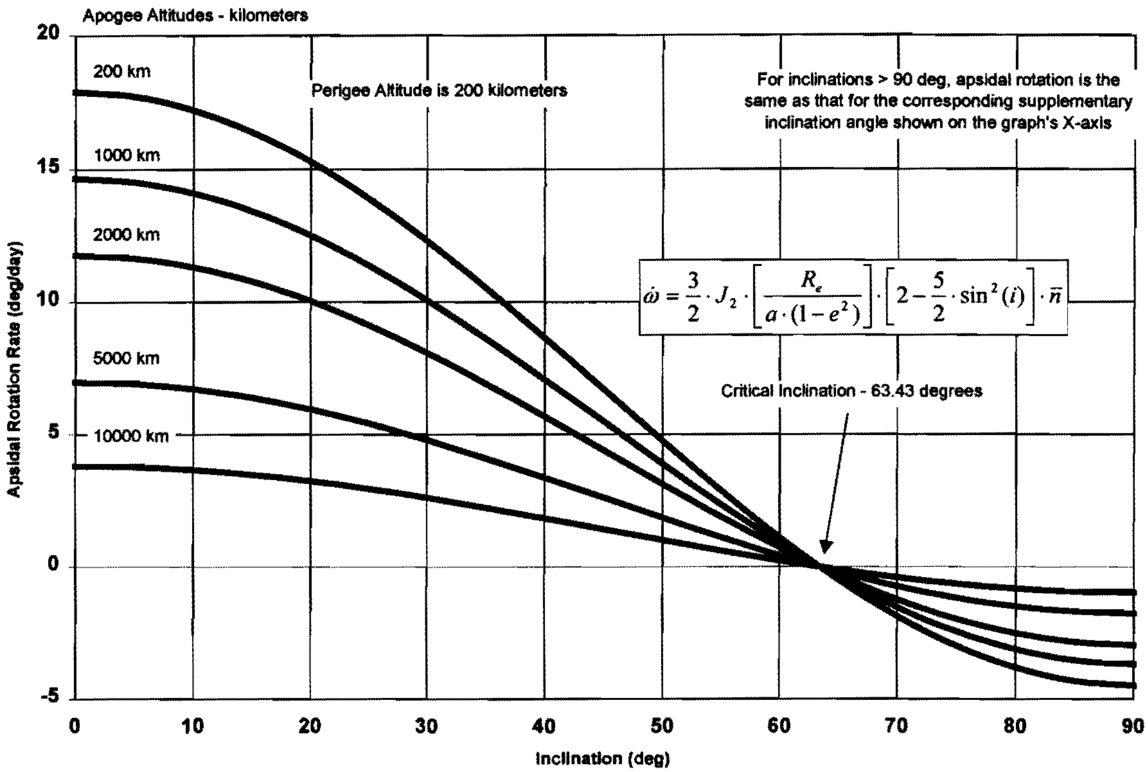

Figure 2., Apsidal Rotation Rate versus Inclination for Various Elliptical Orbits

EXAMPLE ACE ORBIT

This paper will evaluate an example ACE orbit with the following [approximate] characteristics:

Semi-major Axis: 14439 km
Period: 288 minutes (4 hours 48 minutes)
Eccentricity: 0.489
Apogee Altitude: 15120 km
Perigee Altitude: 1000 km
Inclination: 0.1°

While I make no claim that this is the optimum ACE orbit for an amateur radio satellite, I chose these particular parameters because they do a reasonably good job of satisfying the desirable orbital characteristics in the following section.

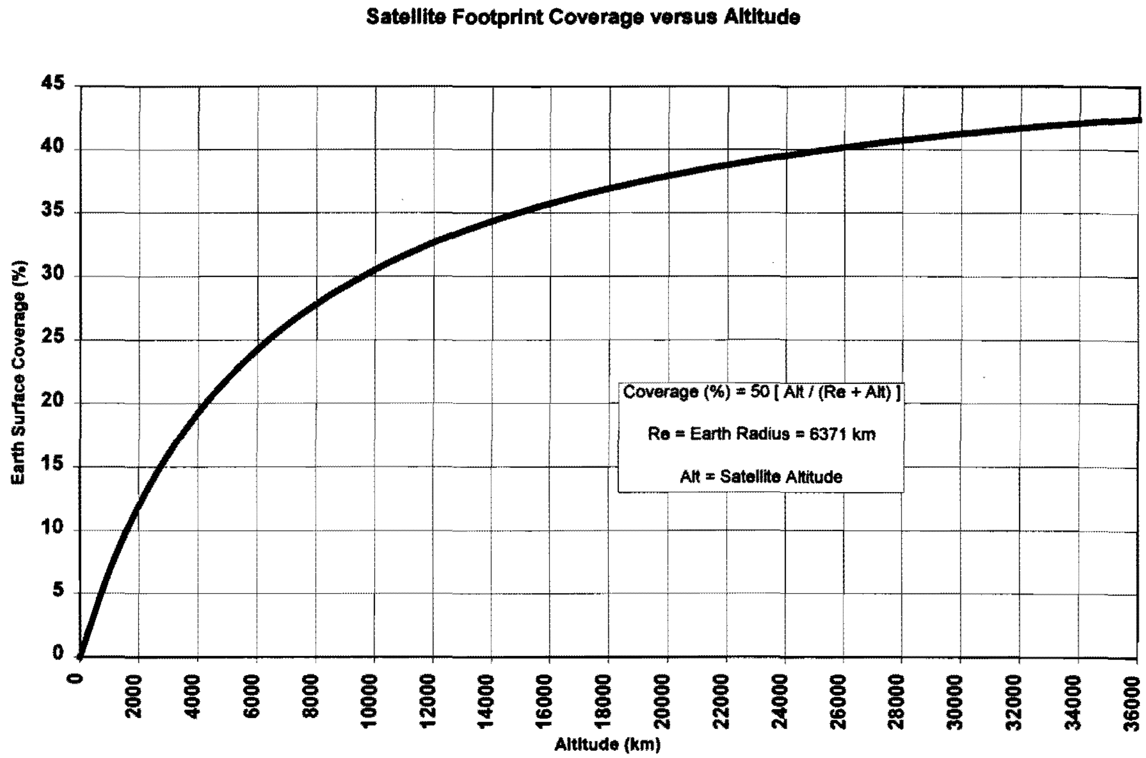

Figure 3., Earth Surface Footprint Coverage as a Function of Altitude

DESIRABLE ORBITAL CHARACTERISTICS

One key part of evaluating candidate orbits is determining the desirable characteristics of that orbit. The desirable characteristics I use for orbital evaluation are attributes that promote quality satellite communications. These include:

- Large Ground Coverage Footprints
- Low "free space" signal path loss
- Frequent accessibility
- Accessibility at convenient times
- Ability to close coverage gaps with additional satellites in the same type of orbit

How well these attributes satisfy the mission of a satellite that's in the conceptual stage might cause the designers to either (A) reject the candidate orbit or (B) to modify or further refine the spacecraft design.

Ground Coverage

Large ground coverage footprints are desirable because they let us communicate with distant stations directly, using the satellite. Orbits with large footprints usually give us longer pass time intervals and more satellite access time per day. As you would expect, higher altitude satellites have larger footprints than lower altitude satellites. However, as shown in **figure 3** the footprint size grows more slowly as altitude increases above 24000 km. This is because the Earth is roughly spherical, so the biggest possible footprint is one half (50%) of the surface. The example ACE orbit listed previously has 7% surface coverage at perigee and 35% surface coverage at apogee.

Path Loss

As the satellite's altitude increases, the slant range (i.e., the distance between stations on the surface and the satellite) also increases. For a circular orbit, the satellite is at its minimum possible range when the satellite is directly overhead and at its maximum possible range when the satellite is on the horizon.

Elliptical orbits are a little more complicated. For an elliptical orbit, the minimum possible range is when the satellite is directly overhead *and* at perigee (its lowest altitude). Likewise, the maximum possible range for a satellite in an elliptical orbit is when the satellite is on the horizon *and* at apogee. Since either one of these conditions is rare for any ground station, path loss is most reasonably evaluated for elliptical orbits at low to middle elevation angles at middle to high satellite altitudes. A good typical elevation angle for evaluation is 30°. Middle to high altitudes are more important for elliptical orbits since, by Kepler's Third Law, the satellite spends most of its time at the higher altitude region of its orbit.

The free space "path loss" increases with the square of the range. **Figure 4** shows the relative path loss between the extremes for the satellite in the example ACE orbit and also includes a curve for the more typical 30° elevation. (Note: the "relative" path loss ignores the frequency-dependent component and only considers the range component.)

Accessibility

Like traditional sun-synchronous orbits, the ACE orbit offers the user predictable pass times – the satellite is available for contact at approximately the same times every day.

It turns out that the example ACE orbit is only approximately sun-synchronous and there's a drift of about a minute per day on the pass times. Since this is a postulated orbit based on the provided computations, it appears that the sun-synchronous nature of the orbit is sensitive to small changes. Fortunately a drift in the orbit is advantageous in an amateur radio satellite to provide variety in contact times and locations and to give the most equitable access to the users. Unfortunately, the drift is so slow that you might have to wait several months for the geometry to suit you at a convenient time so you can communicate with a station in a desired location. For comparison purposes, I have always considered it desirable that an orbit has enough variety in pass times that all hours of the day are covered in a one week span. The lack of short-term variety for the ACE orbit is thus a negative if there's only one satellite.

As far as North and South coverage, the example ACE orbit provides some coverage to latitudes as high as 70°. I also modeled one middle latitude station and found that the satellite typically had two 3-hour passes per day with about seven hours of separation between the centers of the two passes.

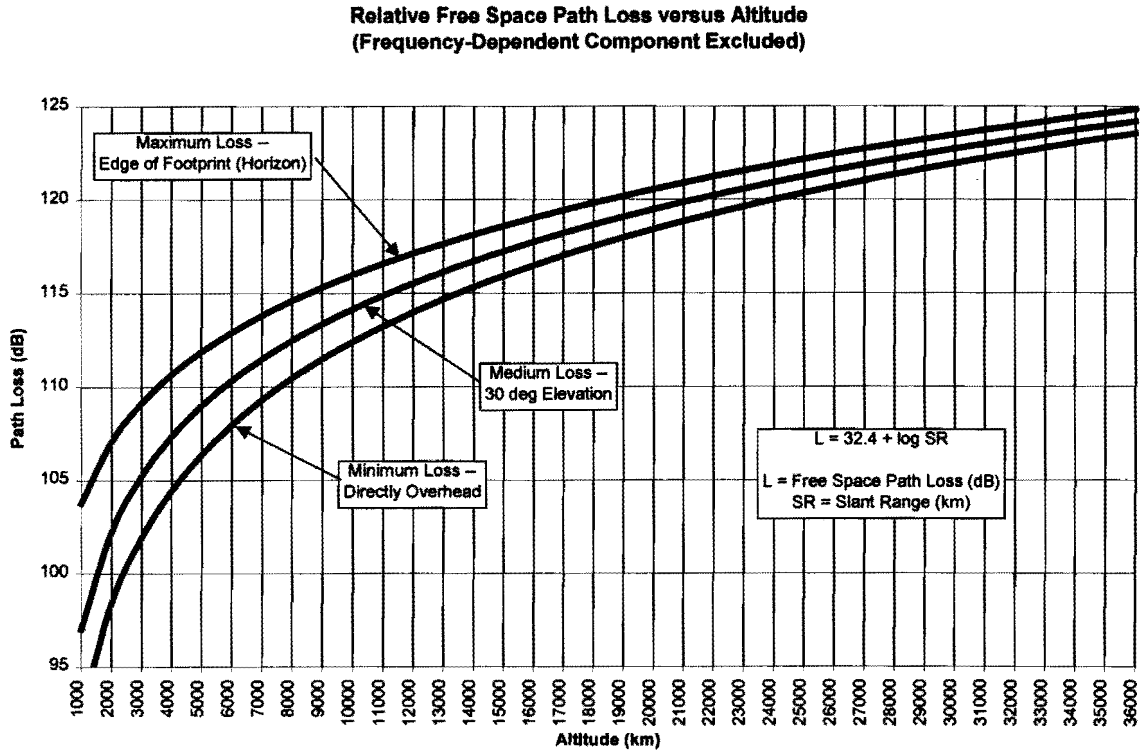

Figure 4., Relative Free-Space Path Loss as a Function of Altitude

Closing Coverage Gaps

A common desirable characteristic is to be able to place two or more satellites in similar but coordinated orbits so there is a tendency for one satellite to be entering a user's coverage as another satellite is leaving. This is known as *constellation design*; a concept I introduced in **reference 3.**

Constellation design is more complicated for elliptical orbits than it is for circular orbits since the spacecraft's speed varies in an elliptical orbit. The three-satellite constellation design for the ACE orbit uses a single orbital plane since the orbits are equatorial. The phasing between the orbits is 120° in argument of perigee and also 120° in *mean anomaly* to get the best timing arrangement. **Table 1** lists the Keplerian elements for the three-satellite ACE constellation; **figure 5** is a "snapshot" of the constellation. In this snapshot, the ACE-2 satellite is approaching apogee with its footprint over North America. ACE-2 replaced the coverage of ACE-1 in this area, which is approaching perigee. After ACE-1 passes through perigee and begins ascending in altitude, its footprint will begin replacing ACE-3's coverage over Europe.

Table 1. Example ACE Constellation Keplerian Elements			
Satellite:	ACE-1	ACE-2	ACE-3
Epoch	99260.0	99260.0	99260.0
Inclination (deg)	0.1	0.1	0.1
R.A. of Node (deg)	0.0	0.0	0.0
Eccentricity	0.489	0.489	0.489
Arg. Perigee (deg)	240.0	0.0	120.0
Mean Anomaly (deg)	0.0	120.0	240.0
Mean Motion (rev/day)	5.004988	5.004988	5.004988

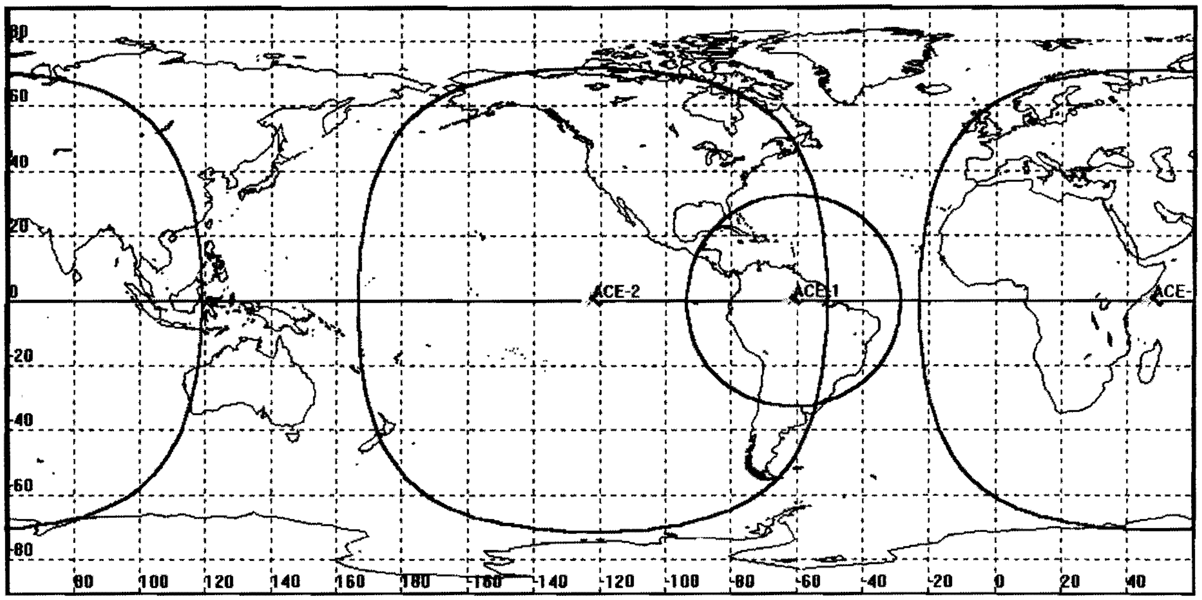

Figure 5., Example ACE Orbit Constellation Snapshot

ESTABLISHING THE ACE ORBIT

The launch profile is important for all satellites and amateur satellites usually have far less flexibility than organizations that can pay for a dedicated launch. It's unlikely that a booster would launch an amateur spacecraft directly into the ACE orbit, so the spacecraft would need to be equipped with a robust propulsion system.

Preliminary analysis considered spacecraft deployment into a Geosynchronous Transfer Orbit (GTO) with a 500-km perigee altitude and a 35000-km apogee altitude. To achieve the example ACE orbit shown in this paper, we need to do two burns. The first burn occurs at apogee, raising perigee from 500 km in the GTO to the desired 1000 km. The second burn occurs at a subsequent perigee and lowers apogee from 35000 km to the desired 15120 km. The total speed change (delta-V magnitude) for the two burns is approximately 658 meters per second.

GTOs are typically inclined to approximately the launch site's latitude, with some inclination change normally provided during the perigee "kick" maneuver prior to spacecraft deployment. Achieving the desired zero inclination for the ACE orbit would be very expensive in terms of delta-V unless the initial inclination were small. The preferred approach would be to adjust the ACE orbit's apogee altitude as needed so that the sum of the nodal regression rate (see **figure 1**) and the equatorial component of the apsidal rotation rate adds up to the required 0.9856° per day of sun-synchronous advance. This change to the orbit design could be solved numerically once we know the GTO's inclination. The inclined variant of the ACE orbit provides better coverage to high latitude stations than does the zero inclination orbit. However, a low inclination cannot provide over-the-pole apogee visibility that allows antipodal contacts, as does Phase 3D's planned orbit.

ISSUES AND CONSIDERATIONS

The issues and considerations with using any orbit include any undesirable orbital characteristics or other problems that should be considered. For the ACE orbit, there are two such issues that I haven't already identified. These are the possibility of catastrophic orbital decay (due to relatively high orbital eccentricity) and a potential licensing issue.

Many of us in AMSAT have first-hand familiarity with the catastrophic orbital decay of an eccentric orbit from OSCAR 13 (AO-13). Nobody can guarantee the safety of a high altitude eccentric orbit without extensive computations that consider the geometry of the Moon and Sun relative to the orbit. However, there are a few rules of thumb when considering the severity of the effects of lunar and solar perturbations:

- Higher altitude orbits are affected more severely than lower altitude orbits
- Higher eccentricity orbits are affected more severely than lower inclination orbits
- Higher inclination orbits are affected more severely than lower inclination orbits

Since the ACE orbit is moderate (at best) in any of these categories, catastrophic orbital decay would probably not be a problem. However, the perturbative effects of the Moon and Sun will make it difficult to maintain the 0.9856° per day precession rate needed for a sun-synchronous orbit.

The potential licensing issue was raised when I was re-reading **reference 2**. The author indicates his employer (Ford Aerospace Corporation – subsequently the Loral Corporation) filed a U.S. Patent to cover the use of artificial satellites in the ACE orbit. While I am inclined to believe that a patent would not be granted regarding the use of an orbit design, that would need to be verified and if the patent was indeed issued, the orbit would likely be unavailable for amateur satellite use until after the patent expired.

SUMMARY

The ACE orbit and its low inclination variants could be used to provide a Molniya-like (i.e., high eccentricity) orbit that is relatively safe from catastrophic decay. Since the ACE orbit is virtually sun-synchronous, the day-to-day pass times are very predictable and they change very slowly. Achieving an ACE orbit from a GTO requires the spacecraft to have a robust propulsion system to achieve the prescribed apogee and perigee altitudes. However, two or three spacecraft could be placed in a constellation of coordinated ACE orbits to provide the amateur community with a high percentage of Earth surface coverage at all times.

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Detroit Area Satellite Gateway

Jerry Smyth, K8SAT
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ABSTRACT

Amateur (ham) radio satellite communications is a very specialized and somewhat complex mode of communications. This mode provides worldwide communications capability to ham radio operators who have only met basic licensing requirements set forth by Federal Communications Commission (FCC). There are some inherent problems with this communications mode however. First, the equipment is relatively expensive, around $3,000 to set up a satellite station. Second, setting up a satellite station can be technically challenging for those who do not have a fairly extensive technical background. Finally, in order to build and finance future amateur radio satellites, this communications mode needs public exposure. This exposure will help solicit contributions for the Radio Amateur Satellite Corporation (AMSAT), a non-profit organization which builds and launches amateur radio satellites. The purpose of this project is to provide an inexpensive means of access to ham radio satellites. A satellite gateway would provide access to ham radio satellites without the need for local area ham radio operators to buy, setup, and operate their own satellite station. This would save the local hams thousands of dollars as well as acclimate them to the advantages of communications with other hams worldwide via satellite. The gateway would also be an excellent vehicle to demonstrate satellite communications to a mass audience. This demonstration would help further promote AMSAT and their work.

INTRODUCTION

Background

The Detroit Area AMSAT Net has generated a large interest in amateur radio satellite operations. There is a basic need to provide a way to demonstrate the capabilities of amateur radio satellite operations. This is currently being done by running a weekly on the air meeting, the AMSAT Net. The purpose of the net is to disseminate amateur radio satellite related information. An AMSAT Area Coordinator, in addition to running these weekly nets, also gives presentations to local amateur radio clubs, publishes internet web pages, and sets up tables at amateur radio swap meets. All these methods of information dissemination have proven helpful but usually result in requests for even more information and most often, requests for one-on-one demonstrations. This involves a personal invitation for the individual or small group of individuals to visit the area coordinator's satellite station.

A satellite gateway is "a facility where a terrestrial network interfaces a space network" (ARRL, 1994, p.106). The purpose of the gateway is to provide a means to demonstrate the potential of amateur radio satellite communications to a relatively large audience at one time. Also, the satellite gateway will provide Detroit area ham radio operators the ability to make contact with other ham radio operators worldwide via satellite. They can do this with equipment as meager as a handheld radio costing less then $200.

Acting in the capacity of Michigan AMSAT Area Coordinator, I have designed an automated voice satellite gateway. I am using my existing satellite station and a local high profile repeater in addition to the other gateway components.

GOALS

The satellite gateway design and implementation concentrated on achieving the following goals:

- To promote AMSAT
- To provide an inexpensive means to demonstrate satellite communications
- To reach as large an audience as possible at one time

ADVANTAGES

Keeping the previous goals in mind, the following advantages should result:

- To promote AMSAT to a large audience
- To provide worldwide communications to the local ham radio community
- No need to spend in excess of $3,000 for satellite equipment
- No complex station setup

The following final report explains the design and implementation of the proposed satellite gateway. The report includes details of the setup, implementation, and costs.

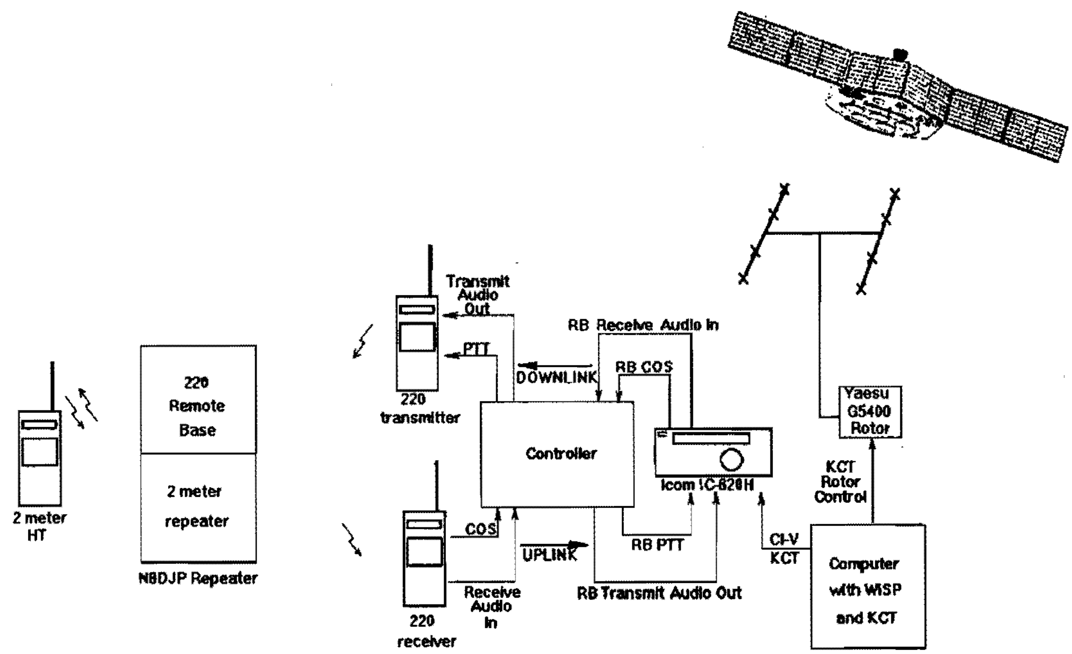
TECHNICAL DISCUSSION

Satellite Gateway

A satellite gateway system is an amateur radio satellite station, which is interfaced to a repeater and consists of the following components:

- A computer capable of running WiSP for Windows 95/98
- Kansas City Tracker/Tuner Card
- Yaesu G5400B Azimuth/Elevation Rotor
- 2-meter & 70-cm cross yagi antennas (M2, KLM, or other satellite antenna)
- All mode dual band 2-meter/70-cm satellite transceiver (ICOM IC-820H)
- Repeater Controller (Micro Computer Concepts model RC-100)
- 220 MHz mobile radio (Clegg 220 MHz mobile transceiver)
- 220 MHz antenna

To optimize the gateway configuration, the satellite station must be fully automated and require little to no intervention from the satellite station owner. There must be a means to transmit the satellite station audio to a high profile repeater system without interfering with the satellite station or the repeater. The block diagram (see block diagram 1 below) shows how the gateway is configured and how it interfaces with the local 2-meter repeater.



Block Diagram 1: Satellite Gateway System

Station Control

One challenge of satellite communications is the fact that a pair of antennas must track the satellite (see figure 1 below) while it is passes across the sky. Also, the frequencies the satellite user is talking on and listening to are constantly changing, the Doppler effect which is "the observed frequency difference between the transmitted signal and the received signal on a link where the transmitted and receiver are in relative motion". (Davidoff, 1998, Glossary p. 1) This means someone must control the station. The satellite operator controls the station by moving the antennas and tuning the uplink and downlink frequencies on the satellite transceiver.

There are several programs available to automate these functions. A program called WiSP (see figure 2 below), which is distributed through AMSAT, is probably the best suited to this task. WiSP is a Microsoft Windows based program designed by Chris Jackson G7UPN for use on the digital (packet) satellites. This program is very useful for gateway operations since it will control the antenna tracking of the satellite and tune the radio automatically. WiSP controls an ISA buss card, called the Kansas City Tracker/Tuner, that plugs into your computer and has a cable that runs to the Yeasu G5400B azimuth/elevation rotor control box. This cable also connects to a computer controlled satellite transceiver. This will allow the computer to control frequency tuning on the satellite transceiver.

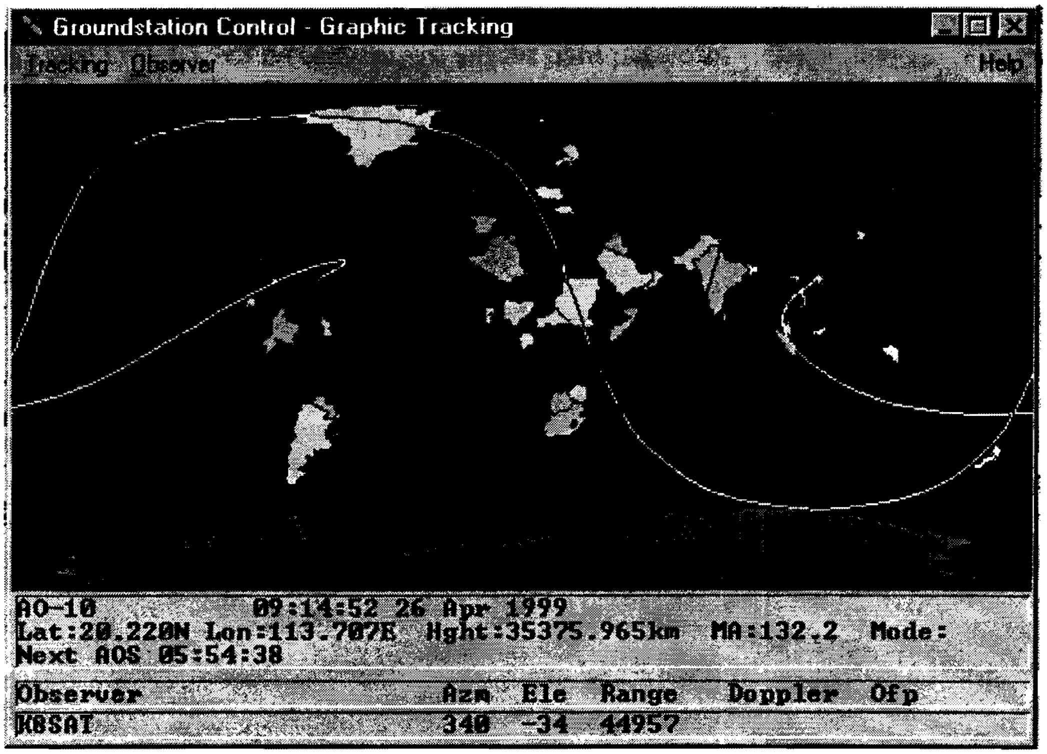


Figure 1: Satellite Mapping Display in the WiSP Suite

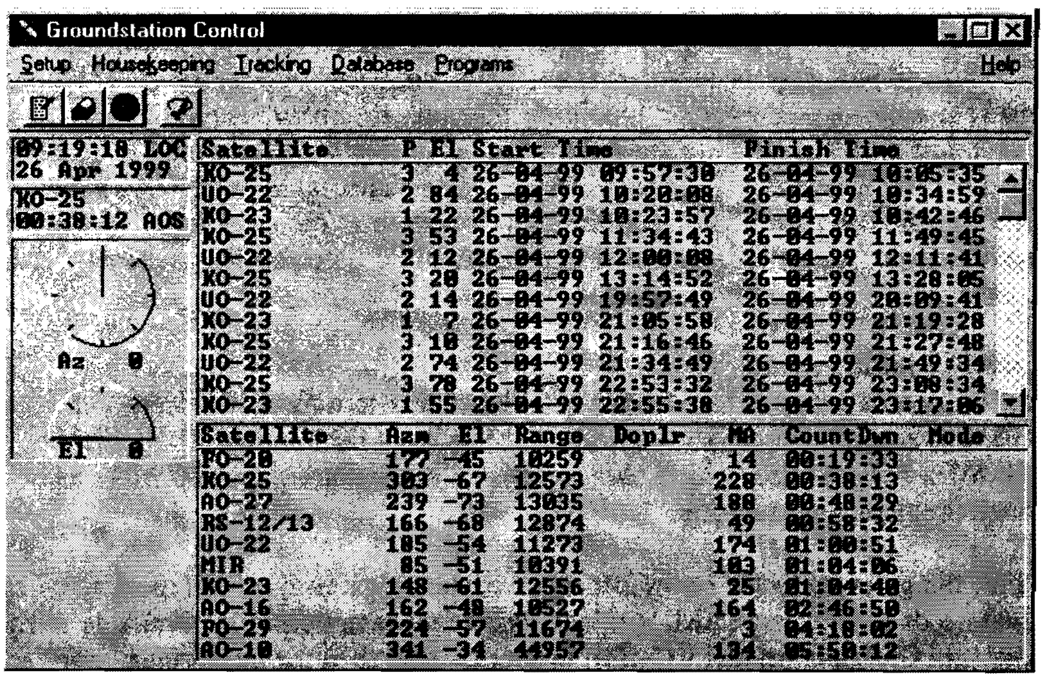


Figure 2: WiSP Main Ground Station Control Screen

By entering the satellites' uplink and downlink frequencies in WiSP's satellite setup menu, WiSP will use this information to set the frequencies on the satellite transceiver for each satellite. WiSP will also calculate and correct for the Doppler effect (see figure 3 below). This will ensure the gateway transceiver will always be on the correct uplink and downlink frequencies as the gateway users are making their contacts.

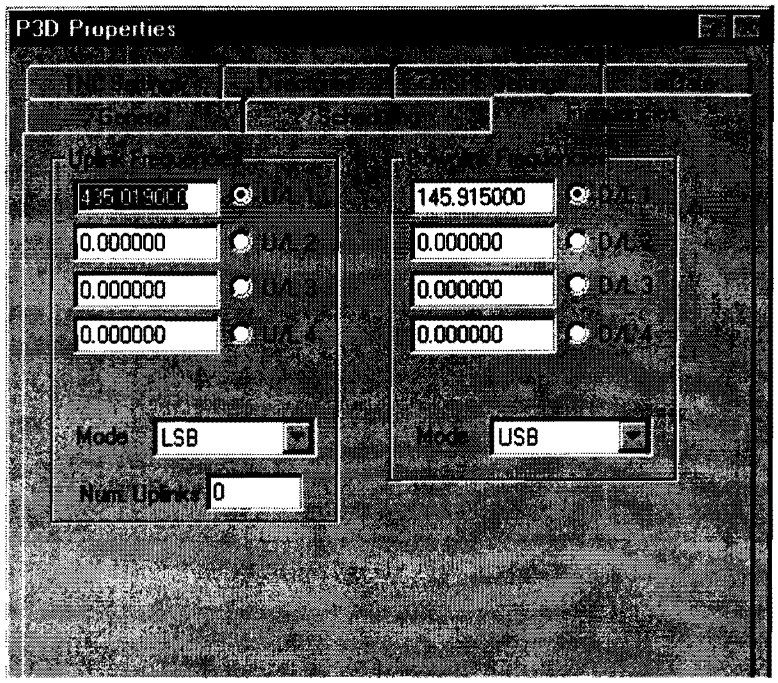


Figure 3: WiSP Radio Frequency Control Screen

If the satellite station is configured to operate on the digital (packet) satellites, the time on the computer will stay accurate and keplerian elements will be update automatically. These are two very important functions that are automatic to WiSP and require no intervention from the satellite station owner. It is also very important to make sure the computer time is accurate and the keplerian elements are up to date. This is necessary to insure the antennas are pointing in the right direction at the right time. With WiSP, all these functions are automatic and important satellite gateway housekeeping efforts are removed from manual intervention.

Repeater Linking

The Detroit area gateway interfaces a satellite station to a local two-meter repeater. This interface is accomplished by using the 220 MHz band for linking. The local repeater has a 220 MHz remote base, which allows any audio originating on 220 MHz to be passed through the two-meter repeater.

To link the gateway to the main 2-meter repeater, a gateway mini-repeater type linking system needs to be constructed. An inexpensive repeater controller available from Micro Computers Concepts (model RC-100) in Florida was used for the gateway mini-repeater. This controller is available for $130 and is ideally suited to this system because it includes remote base capability built into the controller. The satellite station will act as the remote base while a 220 MHz transmitter and receiver will act as the gateway mini-repeater. An old used Clegg 220 MHz mobile radio was dismantled to be used as the 220 MHz gateway mini-repeater (Adams, 1983, April). This radio was found at a ham radio swap meet for $120. The process of dismantling the 220 MHz radio includes removing the receiver board, the exciter board, and the PA (power amplifier) board from the mobile radio. The receiver, exciter, PA and repeater controller are placed into separate Bud aluminum project boxes (see figure 4). This is necessary to provide RF (radio frequency) shielding for each subsystem.

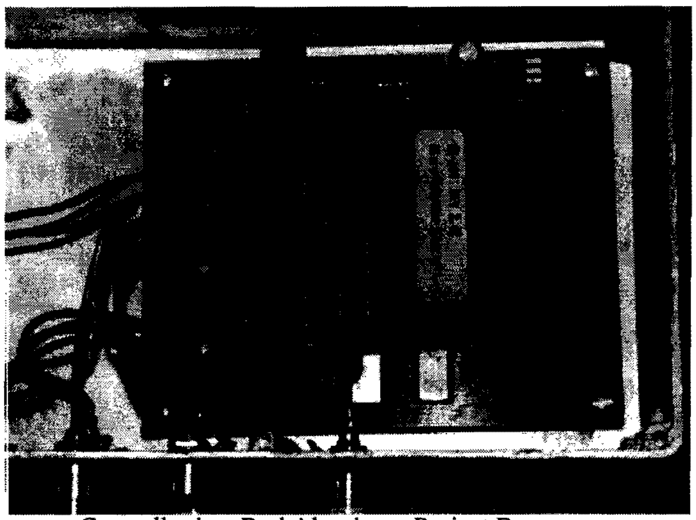


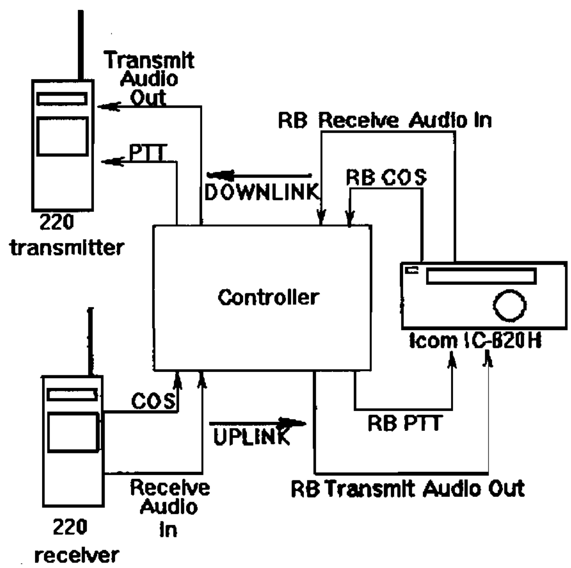
Figure 4: RC-100 Repeater Controller in a Bud Aluminum Project Box

The receiver and exciter board is interfaced to the repeater controller. The exciter board is interfaced to the PA board and the power output was set to one watt. The satellite station was only located four blocks from the main 2-meter repeater so low power output was adequate for this application. It was also unnecessary to add filter cans to the 220 MHz gateway mini-repeater because of the low power output. Separate antennas were used for the receiver and transmitter. By using the 220 MHz band, linking is possible without the satellite station and repeater interfering with each other.

Once the gateway 220 MHz mini-repeater is assembled, the satellite station must be interfaced to the RC-100 repeater controller remote base input (see block diagram 2 below). The remote base transmit audio is interfaced to the satellite transceiver (ICOM IC820H for this application) using the microphone input on the microphone jack. The repeater controller's remote base push-to-talk (PTT) logic signal needs to be connected to the PTT input on the satellite transceiver microphone jack. The RC-100 repeater controller will now control when the satellite transceiver transmits and pass the audio from the gateway user through to the satellite.

For the downlink receiver, the satellite radio's audio out (which is also available on the microphone jack on the satellite transceiver) was connected to the RC-100 controller remote base receive audio input. The remote base carrier-operated-squelch (COS) logic signal is available on the data jack on the back of the satellite transceiver. (The receive

LED indicator lamp on a satellite radio could also be used to supply this logic signal.) Once these connections are made, the audio levels on the satellite transceiver and the gateway repeater controller can be set.



Block Diagram 2: Interface of 220 Mini-repeater and Satellite Station

Cost
The total cost for this project was $380, which fell within the estimate. These cost also assume that there is no additional costs are incurred by the main 2-meter repeater or additional equipment for the satellite station itself. For this application, no further costs were incurred.

Actual Costs
- RC-100 Repeater Controller.......... .$130
- Used Clegg 220 MHz mobile radio....$120
- Bud Aluminum Project Box........... $25x4
- Misc. Parts............................... $30

Results
The satellite gateway was a very involved project. It was challenging in both design and implementation. There were some technical problems while first testing out the system. Several ham radio operators commented the audio from the gateway users was too loud and somewhat distorted at times. This report was verified and required a potentiometer to be added in line between the repeater controller remote base audio out and the microphone input on the satellite station. The level then could be adjusted to an acceptable level. The gateway has also been a success with local ham radio operators.

Several local ham radio operators have become very enthused about this new mode of communications!

Evaluation
The satellite gateway has been a great success in the local Detroit area. As a result, several local ham radio operators have joined AMSAT and donated funds through the purchase of satellite tracking programs and other items. Some have also donated money to support new satellite construction. There has been at least four hams in the Detroit area who have set up their own satellite stations as a result of using or listening to the gateway.

CONCLUSION

The implementation of the Detroit area satellite gateway system has been a resounding success. All the goals have been realized. There have been several local hams who have joined AMSAT, donated monies to support AMSAT projects, told others about AMSAT and satellite communications, and built and operated their own satellite stations as a result of using the gateway.

The implementation of the Detroit gateway has been relatively inexpensive, $380, because most of the expensive components were already in place. The 2-meter repeater owner was very cooperative in allowing me to link my satellite station to his repeater and has assisted in the final checkout of the gateway.

The gateway has reached a large audience. There have been hams from Windsor, Livonia, Detroit, Dearborn, Sterling Heights, Allen Park, Ypsilanti, Ann Arbor, and several other areas who have used the gateway. Also, the enthusiasm has been noted by hams from around the world who have talked to the gateway users here in the Detroit area. As a result of the Detroit area gateway, a group in Toronto, Ontario in Canada have set up a similar gateway and they are currently operating it successfully.

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Converting Surplus Qualcomm OmniTrack Microwave Assemblies For Use With Amateur Satellites

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The San Diego Microwave Group has been successfully using modified surplus Qualcomm OmniTrack microwave assemblies for terrestrial communications over the last seven years. The primary uses up to this time have been: Modified PLL board producing 1152 MHz LO for 1296 MHz operation with 144 MHz IF. (Also as marker for 2304 MHz through 24192 MHz) Modified PLL board producing 2160 MHz LO for 2304 MHz operation with 144 MHz IF. Modified PLL board producing 2556 MHz X4 for use as 10224 MHz LO for 10368 operation. Modified assembly producing a synthesized LO transverter for 10368 MHz with 144 or 432 MHz IF. Modified assembly producing a synthesized LO transverter for 5760 MHz. Modified assembly providing a stand alone LNA for 10368 MHz. Source of 10 MHz TCXO reference oscillators suitable for use with synthesizers up through 10 GHz.

Detailed conversion procedures for these applications have been well documented by the San Diego Microwave Group as well as a number of other users. Hundreds of the synthesizers 10 GHz power amplifiers and some tens of transverters have been put into Amateur service all over the wold. As a considerable number of the various Qualcomm surplus units have been and should continue to be available, the ongoing effort being put forth to produce detailed conversion documentation should not meet with a dead end as has happened with many conversion projects based on a very limited quantity of available material.

Application of converted assemblies to Amateur Satellite use.

The primary applications for Amateur Satellite operation up to the time P3D is in operation are the synthesizers, which are used as local oscillators for 1.2 GHz and 2.4 GHz. As well as weak signal test sources for all microwave bands through 24 GHz. Once P3D becomes operational, possible applications then expand to include the synthesizers and transverters for 5.7 Ghz (4 Watt uplink) and 10.4 Ghz (1.5 dB NF downlink). The PLL boards are also useful as building blocks for local oscillators for 24 GHz (downlink).

Conversion versus building from kits or from scratch.

There are several advantages to converting surplus equipment over building kits or from scratch. The cost of the surplus assemblies is usually far below that of individual components or kit. The many tiny surface mount components on a surplus assembly have already been professionally mounted and in most cases the circuitry has been tested or operational at one time. The components and circuit boards are normally of the high quality required to provide reproduceable results in high volume. This is also true for the circuit design, which is typically quite conservative to eliminate or reduce component value adjustments and tuning. Just as with most other approaches, some access to test equipment is required to verify performance before attempting to operate over the air. In most cases some form of frequency measurement (to verify proper synthesizer frequency programming) and possibly spectrum analyzer (to check for clean output) is desired.

Synthesizers –

The Qualcomm Omnitrack synthesizers are readily modified to suit most combinations of operating and IF frequencies. The advantage of using synthesizers in general is that no special crystal must be purchased and the frequency stability is that of the 10 MHz reference. Another advantage is the capability to change the synthesizer output frequency easily when it's desired to operate the same radio on both the terrestrial and satellite portions of the band.

For terrestrial use, local oscillator phase noise is of concern as there are often strong local stations or beacons which may be many tens of dB stronger than and only tens of Kilohertz away from a very weak signal to be worked. In this case, poor phase noise will appear to raise the noise floor and some interference from the strong station will be heard. For Satellite work, the difference in received signal strength between the weakest and strongest signals is apt to be less than 20 dB for which the phase noise of the converted Qualcomm synthesizers should not be an issue. Synthesizer phase noise becomes more pronounced with higher orders of frequency multiplication creating more of an issue at the higher microwave frequencies (10 GHz and 24 GHz). Typical phase noise of the Qualcomm synthesizer is around –80 dBc/Hz 10 KHz from the carrier at 10 Ghz where a Frequency West Brick is around –110 dBc/Hz.

Synthesizer conversion consists of modifying the programming of the internal frequency dividers and adding reference frequency rejection filter capacitors, Rf & power connectors, and enclosure. The conversion project is a about a one or two evening project depending on experience. The synthesizers are used in the parallel input mode, which requires tying the appropriate synthesizer IC pins to a logic 0 or 1. Spread sheets have been developed which readily display the modifications required as a function of VCO and internal reference comparison frequencies. The output of the spread sheets include a display of the logic level required at each IC pin number.

10 MHz reference oscillator –

The frequency stability, and to some extent the phase noise of the synthesizer is dependent on the 10 MHz reference source characteristics. The variation of temperature around the reference oscillator greatly affects the overall stability depending on oscillator type. Most microwave transverters or receivers are likely to be mounted outdoors near the antenna to reduce feedline loss and are exposed to outside temperature variations. A crystal oscillator with temperature compensation (TCXO) or oven control (OCXO) is normally required for adequate stability at microwave frequencies. As with the phase noise, the reference oscillator stability becomes more pronounced with higher orders of frequency multiplication making the most stable oscillator type (OCXO) desirable for 10 GHz and 24 GHz and probably necessary in areas with large temperature variation (many tens of degrees F) during the year.

The 10 MHz TCXO used in the Qualcomm assemblies are rated for better than + or – 30 Hz from –40C to +85C equates to about 0.5 Hz per degree C and 6 parts per million. Translated to microwave frequencies this is about 60 Hz per degree C at 1296 MHz and 500 Hz per degree C at 10 GHz. A good OCXO will be about 100 times more stable with a typical stability of 1 part per 100 million.

A TCXO has almost no warmup time and consumes very little power (perhaps 50 ma @ 12 VDC). An OXCO typically takes as at least 15 minutes to become reasonably stable and consumes typically 1 amp at 12VDC when cold and 0.3 amps warm. The ideal situation is to leave power applied to the OCXO continuously eliminating warm up time and drift. The TXCO is suitable for outdoor mounted use on 2400 MHz and below in most climates and in Southern California is used on 10 GHz. Temperature control of the TCXO has also been done in a few cases with very good results. The more extreme temperature variations typically require the OCXO above 2400 MHz.

Weak signal source –

Converted synthesizers are also very useful as receive frequency markers/weak signal sources. For terrestrial applications a single synthesizer programmed for 1152 MHz provides harmonic markers at major calling frequencies of 2304, 3456, 5760, 10368, and 24192 MHz. For satellite use it appears that individual markers are required as the operating frequencies are not so conveniently related harmonically. A single 2 Ghz synthesizer can be switched to provide a fundamental or harmonics for 2400 MHz and 2446 MHz. A 1045 MHz synthesizer (X10) can be used to generate harmonics for 10450 MHz. A 2672 MHz synthesizer (X9) can produce harmonics for 24048 MHz receiver testing. The fundamental and harmonic levels radiated from an unshielded Synthesizer are considerable making it possible in many cases to locate the synthesizer/marker generator indoors. At my QTH, 10GHz harmonics are useable from a synthesizer located about 30 feet behind and 10 feet below a 24" roof mounted dish. The 24 GHz harmonics are weak & may require the synthesizer to be located in front of the dish

10 GHz transverter conversion –

The Omnitracks units in their original state transmitted 1 watt in the 14.5 GHz band and received in the 12 GHz band. A dual conversion, high side LO transverter conversion design has been used with good success for terrestrial applications. The approximate specifications are listed below:

Operating frequency – 10368 MHz
First LO (high side) – 11360 MHz
First IF – 992 Mhz
Second LO (high side) – 1136 MHz
Second IF – 144 Mhz
LO type – synthesizer locked to external 10 MHz reference
Noise figure – 1.5 dB without optimization, 1.0 dB with optimization
Tx output power - +8 dBm without PA, +30 dBm with external QC PA
Power required - +12 VDC at 0.3 amps with TCXO (additional 1 amp for 1 watt PA)

A 146 MHz IF satellite version of the above unit has the following differences:

Operating frequency – 10451 MHz
First LO (high side) – 11450 MHz
First IF – 999 MHz
Second LO – 1145 MHz
Second IF – 146 MHz
For Rx only, no PA is needed

A 434 MHz IF satellite version has these differences:

Operating frequency – 10451 MHz
First LO (high side) – 11130 MHz
First IF – 629 MHz (requires IF amp mods)
Second LO – 1130 MHz
Second IF – 434 MHz

The stripline filters and synthesizer VCO range utilized in the transverter may be broad enough to allow reasonable performance on both 10368 MHz as well as 10451 MHz with only a switch for synthesizer frequency. I plan to explore this possibility in the near future.

The 10 GHz transverter conversion procedure includes the following steps:

Location & marking of connector mounting locations.
Removal of circuit boards from baseplate.
Baseplate modification and mounting of connectors.
Remounting of PCBs on baseplate.
Modification of stripline filter elements to specified lengths and addition of tuning stubs.
Cutting of three PCB traces and installation of three coupling capacitors.
Synthesizer modifications including lifting IC pins and connecting to specified logic levels for frequency programming and paralleling of 3 reference frequency suppression capacitors.
Addition of power and Tx/Rx control wires.
Modification/installation of second LO amp/mixer board.
Attachment of 999 Mhz 1st IF filter (construction of filter if desired).
Connection to 10 MHz reference oscillator.
Testing of Tx output using spectrum analyzer to check synthesizer frequency and overall output spectrum.
Testing of Rx function using weak signal source and spectrum analyzer or IF receiver.

5.7 Ghz transverters -

At this time the availability of surplus C-Band Omnitrack units is very limited and therefore the description will be brief. The approximate specifications are listed below:

Operating frequency – 5668 Mhz
First LO – 4420 MHz (4400 MHz for 1268 MHz single conversion IF)
First IF – 1248 Mhz (1268 MHz for single conversion)
Second LO – 1104 MHz
Second IF – 144 Mhz
LO type – synthesizer locked to external 10 MHz reference.
Noise figure – Not measured as of this time
Tx output power – 4 watts (+36 dBm)
Power required - +12 VDC 0.3A Rx, Amps Tx Not measured

For further conversion and materials availability information contact Chuck Houghton, WB6IGP (clhough@pacbell.net) or Kerry Banke N6IZW (kbanke@qualcomm.com) of the San Diego Microwave Group. Much of this information will soon be available on the SBMS (San Bernardino Microwave Society) web site http://www.ham-radio.com/sbms

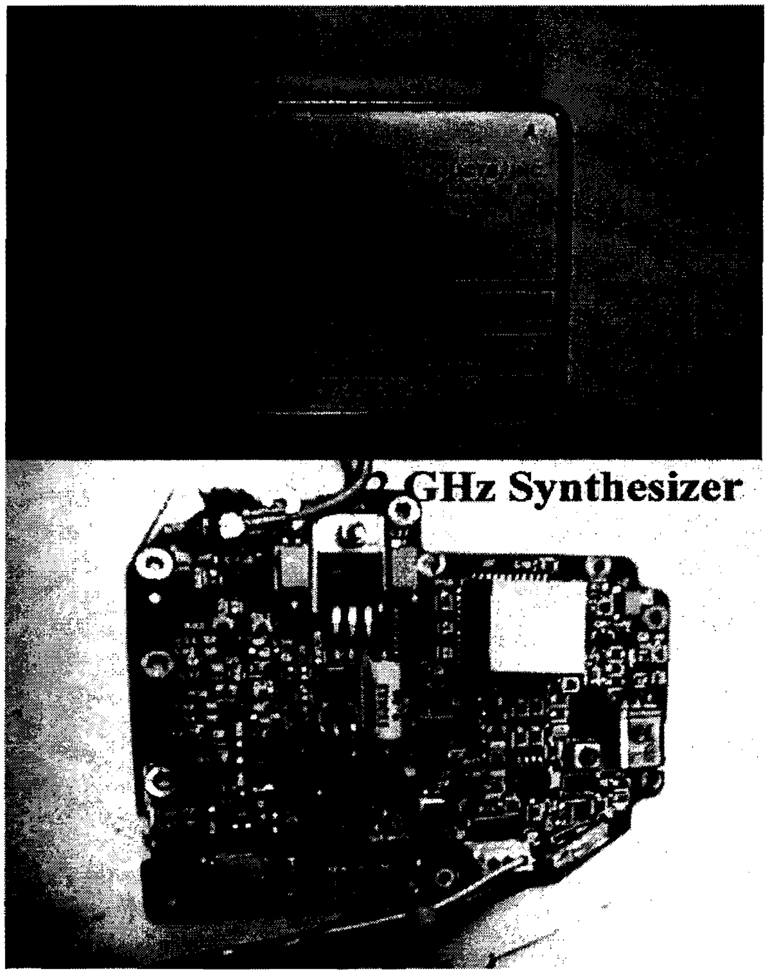
Additional conversion information articles and sources:

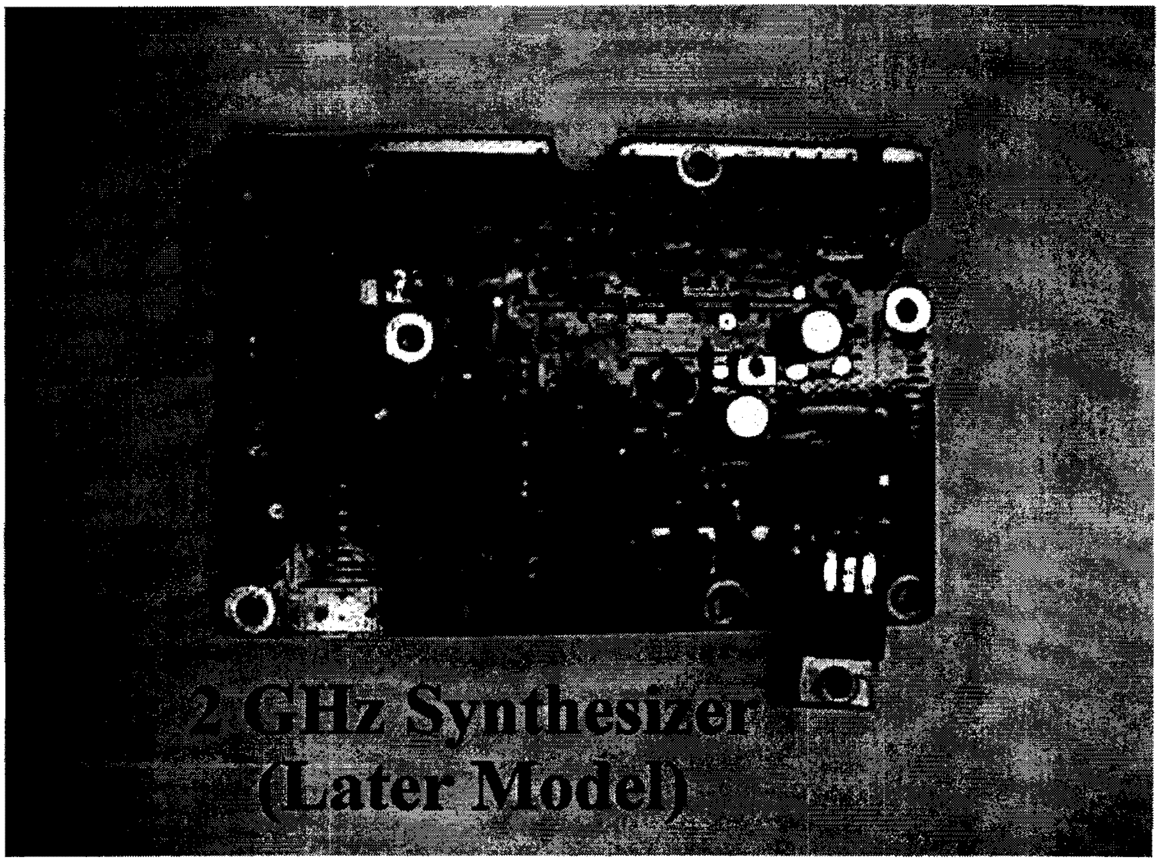
C. Houghton, WB6IGP & Kerry Banke, N6IZW, "Microwave GAAS FET Amps for Modification to 10 GHz", NTS FEEDPOINT Newsletter, December 1993.

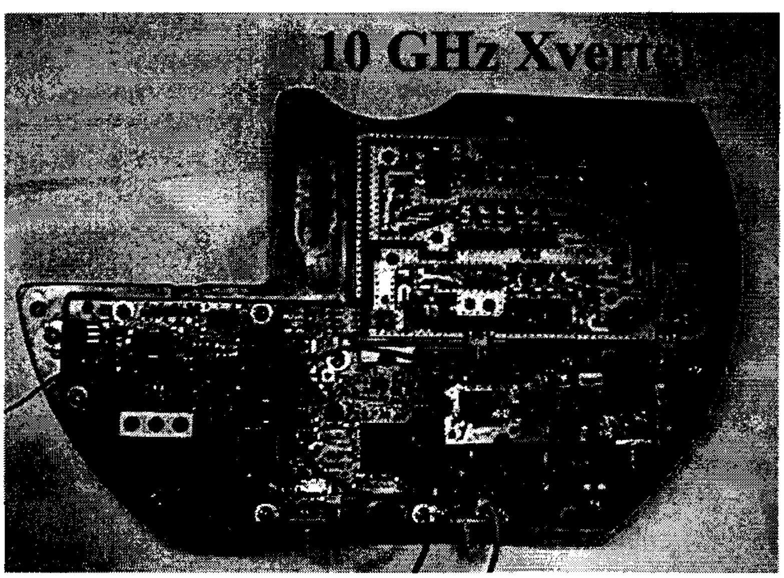
Ken Shofield, W1RIL, "Suggestions for Modifications of Qualcomm LNA Board for 10 GHz", Proceedings of the 21st Eastern VHF/UHF Conference, August 1995, Pg 63 and "Modification Update of Omitrack PA Board for 10 GHz" Pg 65. Also at http:/www.uhavax.hartford.edu/disk$userdata/faculty/newsvhf/www/w1ril.html

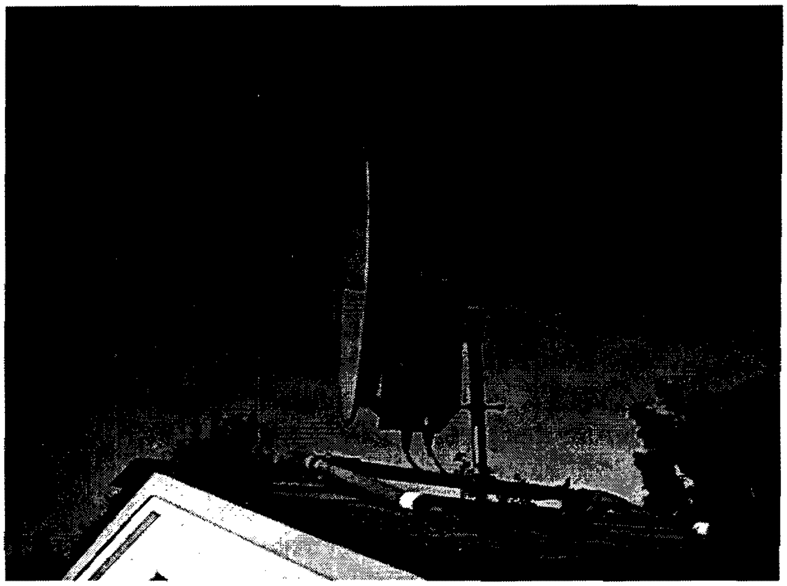
Bruce Wood, N2LIV, "UP, UP & Away to 10 GHz Semi-Commercial Style", Proceedings of the 20th Eastern VHF/UHF Conference, August, 1994, Pg 133

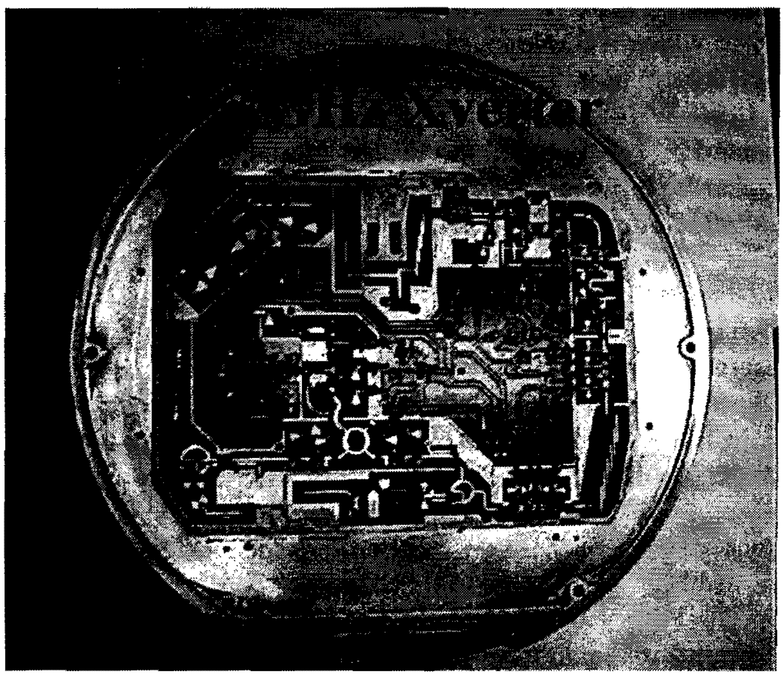
10 GHz Qualcomm Modification Notes by Dale Clement, AF1T


GHz Synthesizer


2 GHz Synthesizer
(Later Model)


10 GHz Xverte





435-438 MHz Patch Antenna

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Patch antennas have been in use for years primarily in aircraft and space vehicles. Most are "microstrip" antenna designs since a rigid dielectric is used to separate the ground plane from the radiator. Almost all are linearly polarized since the "patch" is square. Two modifications are presented in which circular polarization is obtained as well as the use of air dielectric allowing ordinary construction and some amount of VSWR adjustment through mechanical means. A great deal of experimentation resulted in a simple design for 435-438 MHz.

One of the earliest practical low profile antenna designs was presented in NASA Tech Brief in March 1996. Both crossed dipole and microstrip was used. A suggested approach to circular polarization in which unequal feedline lengths feeding square patch elements was demonstrated. These designs used multiple patchs to increase gain and provide some measure of circular polarization stability. Earlier, Harold Ward W1GE presented a circularly polarized design of a patch antenna for GPS in which a single coaxial feedpoint is used with a slightly off square radiator. W1GE used design information from a number of commercial sources including information supplied by Roger Cox, WB0DGF. Both presented information in which air dielectric was used. W1GE presented an off diagonal tap design producing right hand circular polarization. The basic concept is that both the shorter and longer sides of the patch are excited. The shortest path from the coaxial attachment point to the edge is excited first followed by the longer path to the longer dimension. This then produces circular polarization. Proving this in practice is difficult as well as demonstrating how "circular" the end result. Note how close to the 1575 MHz design the scaled 438 MHz antenna became!

One of the better patch designs was worked out by Stan Wood, WA4NFY and his efforts to optimize the antenna aboard Phase IIID. While these patches are edge fed with coax rather than "tap" fed, the many pictures in the AMSAT Journal illustrated the concept. Of the many articles reviewed regarding AIR dielectric a set of added fundamental guidelines can be listed:

1. Air dielectric has the highest gain and lowest loss since the larger patch size has larger aperture and smallest beam width.

2. The spacing between the ground plane and the radiator must be kept reasonably large, between 0.01 and 0.04 wavelength with .05 wavelength a practical maximum. The resonant frequency of the antenna can be varied considerably by small changes in spacing.

3. Bandwidth is improved by larger patch spacing since the Q is lower. The antenna is less affected by moisture and buckling. Note that in this effort, the final spacing is varied to obtain a better match to the feedline once the tap points have been determined.

4. Ground based antennas should be Right Hand Circularly polarized if only one is to be used, but both RHC and LHC is advantageous. The ability to switch between both rapidly is highly desirable.

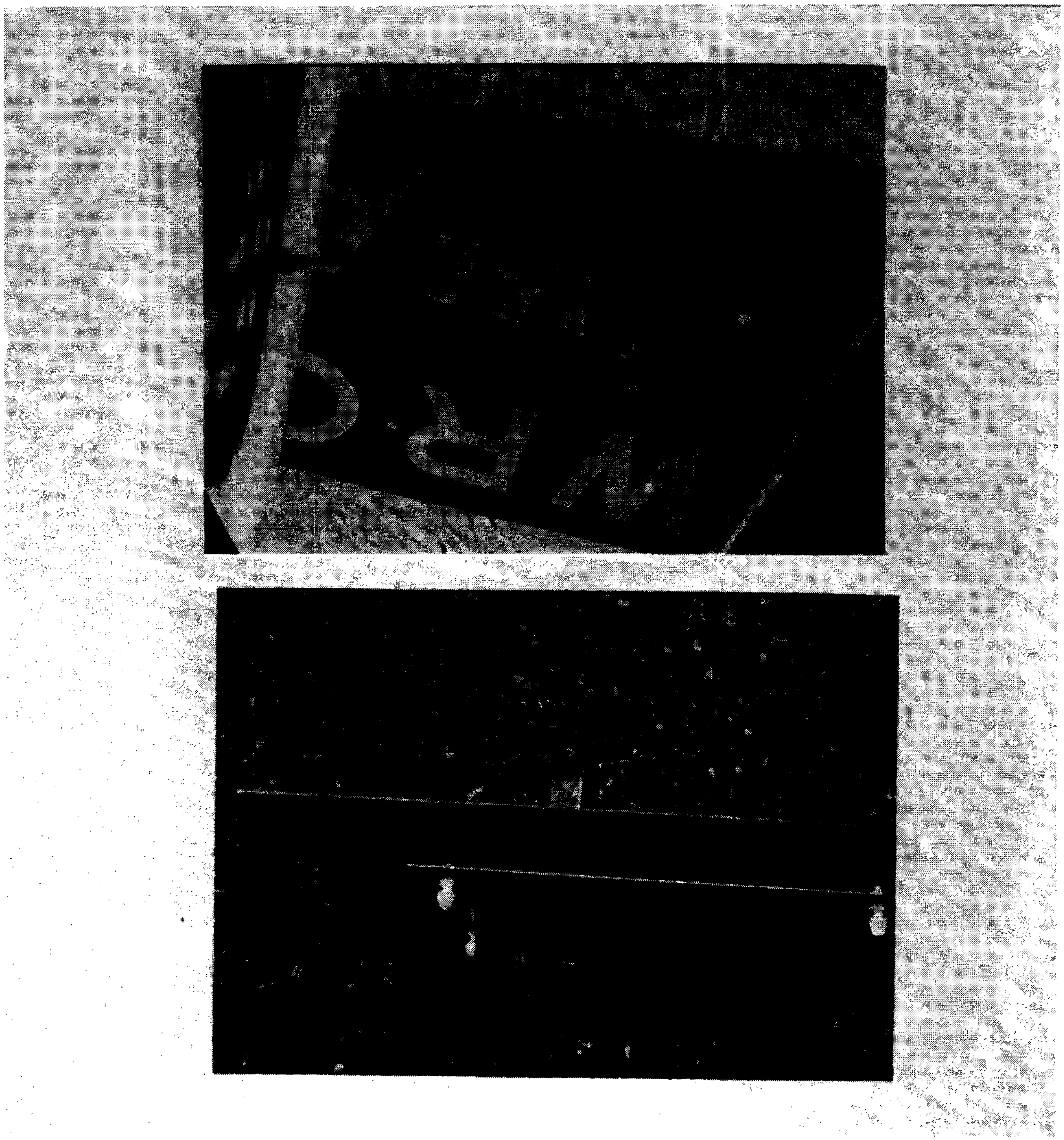


Figure one illustrates the two aluminum plates that need to be fashioned. The dimensions are CRITICAL in that best results can be gotten with care in construction. Many hours of experimentation have gone into the selection of the compromised tap points. The final antenna design benefits from hours of listening to signals and calculation which has proven the old adage that both are useful!

However the incorporation of a suitable switching system on a single patch proved difficult. Two designs resulted, the simpler using a SMA relay placed as close to the underside of the ground plane as possible. These relays are rather expensive if not obtained surplus. The advantage is that each SMA connection can be optimized before the relay system is installed. A second design uses three quarter wavelengths of coaxial cable and an ordinary type N relay. Both seem able to pass one hundred watts with ease. The stub arrangement using coaxial cable was fashioned by first placing the cable on a RF bridge, then selectively cutting to length. A free space full wave in millimeters is given by 299974 divided by the frequency in MHz, then multiplied by the velocity factor and 0.75 for an approximate final coax cable length. The result was a line of 340 mm for solid coax. Each line is then cut with an additional 30 mm of exposed center conductor for later mounting. All was easily accomplished on an Autek VHF analyzer in minutes. The bridge is selectively tuned for minimum impedance since an open odd quarter wavelength inverts impedance. The very fact that 30 mm of center conductor is left floating compensates for fringing rather well.

These photographs illustrate a rather inexpensive source of 1/16 inch aluminum sheet. Indeed they are segments of damaged road signs gotten from the highways department! More importantly, 1.6 mm material (1/16 inch) is used. Air dielectric avoids the criticality of material thickness. In the four corners, 1/4 inch nylon bolts support the patch. Each has three nuts thread so that the distance between the patch and the ground plane can be varied. VSWR can be finalized in this fashion. For those who want a better VSWR can vary the size of the wire between the SMA connector and the patch as this does affect the match slightly. Most are content with a minimum value by adjusting spacing. Do solder to the patch as a bit of effort and proper flux is required before a good solder joint can be made. In the coaxial stub design, connect the shield to the ground plane side nearest the patch radiator as the fields are largest there.

As to the proper method of determining circularity, signals from local 70 cm repeaters were used assuming that the multiple dipole collinear gain antenna produced nearly pure vertical radiation. The patch was rotated in an effort see a three db decrease at all four 45 degree points. The results were far from conclusive probably due to ground reflections. Better results were gotten from a six turn helix. Circularity was good and cross gain approximately minus ten db. No gain figures were obtained but published figures indicate between 8 and 10 dbic should be expected. It was most gratifying to note the cross modulation from local repeaters was gone due to the low gain at lower elevation angles. As a final note, radomes can be made of large salad bowls or trash cans cut off where necessary. One can also favor some satellites by noting the most desirable position in the sky and mounting the antenna directly upon a sloping roof in that direction.

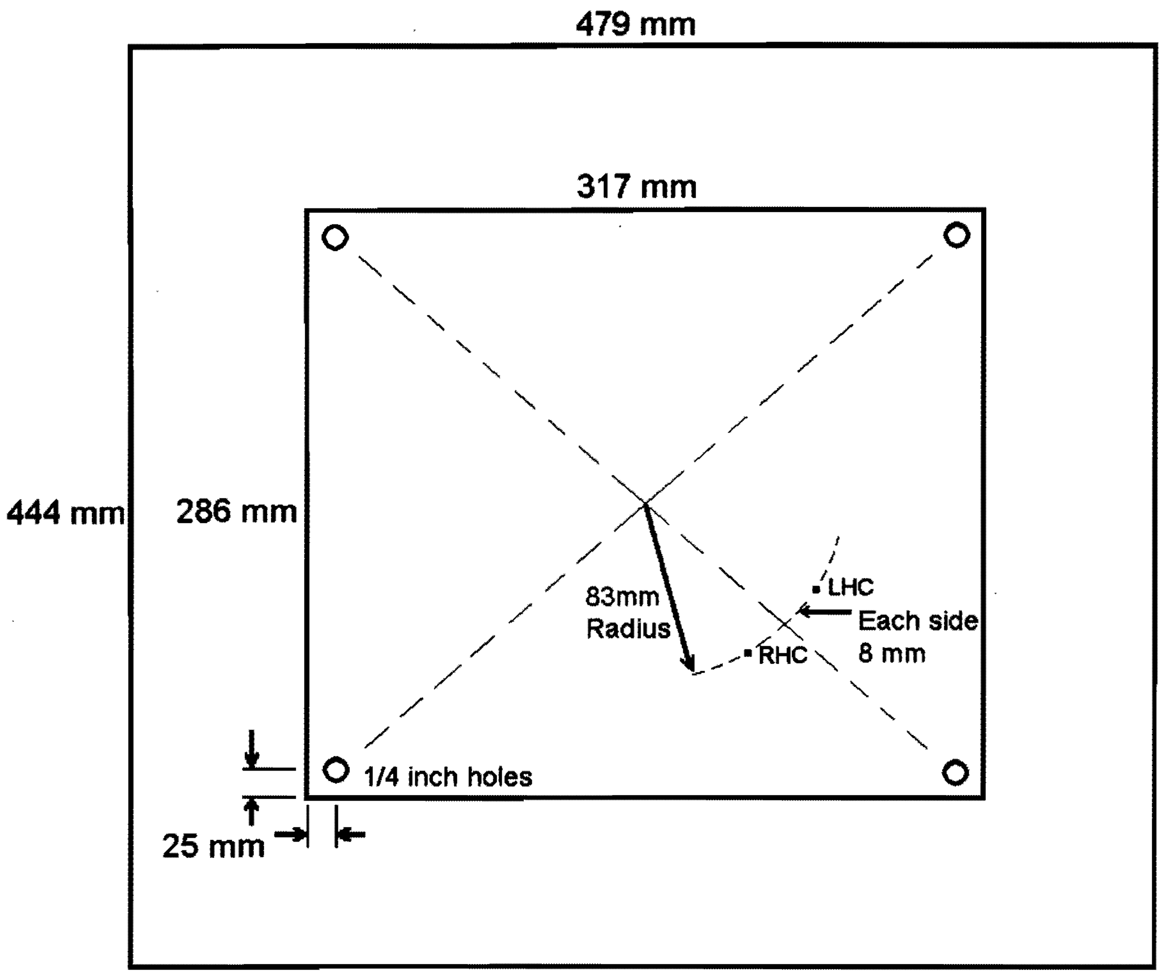
References:

[1] "Antennas For Receiving Signals Broadcast Via Satellites" NASA Tech Brief Vol 20, No.3, Item #98

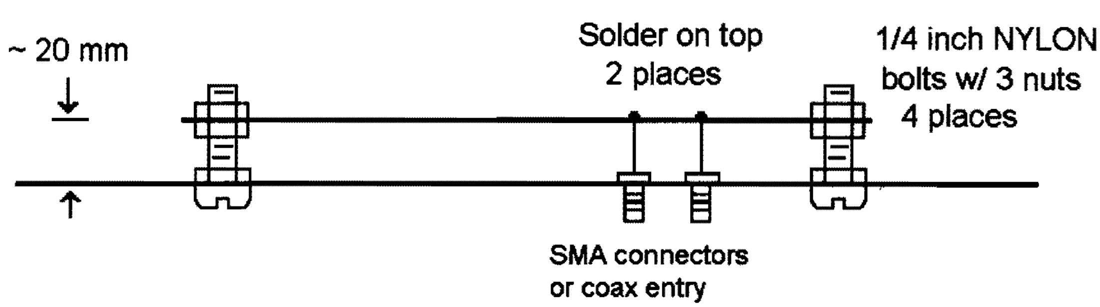
[2] "A Patch Antenna for the Global Positioning System" H. R. Ward QST Oct. 1995, page 44

[3] The AMSAT Journal Mar/April 1993, page 18, Stan Wood WA4NFY and Dick Jansson WD4FAB

Diagram: **435-438 MHz Patch Antenna**



MATERIAL: 1/16 INCH ALUMINUM



K7RR August 1999

The Applicability of CAN on Small Satellites

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Abstract:

One of the key innovations of the original AMSAT Microsat design was the use of a digital network to replace the traditional command and telemetry wiring harness on the satellite. For the Phase-3D spacecraft, AMSAT selected CAN, the Controller Area Network, to implement this function. Though the Phase-3D spacecraft has not launched yet, AMSAT now has almost five years of experience working with CAN.

This paper provides an overview of CAN including the protocol, available integrated circuits, and a survey of existing applications. We discuss the benefits and limitations of CAN in the small satellite environment including performance, reliability, and development issues. Alternatives to CAN, which may be more appropriate in some circumstances are presented and the paper concludes by discussing the factors AMSAT design teams are likely to consider when selecting command, control, and bulk data transfer busses for our future small satellite projects.

Background:

One of the key innovations in the AMSAT Microsat series was the elimination of a traditional wiring harness. Instead, a serial network bus was used to connect the various modules. Using Motorola AART controller chips, the resulting bus is often referred to as the "Microsat AART Bus." The AART chips allowed each module to have some telemetry and telecommand points, with the housekeeping processor moderating the flow of information over the bus.

For the Phase-3D satellite, a more traditional wiring harness design was chosen for the spacecraft health systems and for the primary communications payload. The AART bus was deemed inadequate to the task for a satellite of this scale and any other bus was unknown and unproven. However, DB2OS proposed the use of the fledgling CAN bus as an experiment with several experimental payload modules using it instead of, or in addition to, the traditional wiring harness. In this way, the Phase-3D satellite would not be put at risk by using an unproven bus technology, but CAN might be proven out for use on future AMSAT spacecraft.

The folks at SSTL in Surrey also became interested in CAN. They drafted a protocol specification and authored a software protocol stack to run on top of CAN called CAN-SU. At the RUDAK design meeting in Surrey in December of 1994, we agreed to use the CAN-SU protocol on Phase-3D, and SSTL agreed to provide us with their software as a starting point for our work.

CAN Overview:

The Controller Area Network (CAN) was developed by Bosch in the late 1980s as a means of connecting smart sensors and controls to the increasingly powerful computers in automobiles. The goal was a simple (1 or 2 wires), multi-drop, robust, real-time communications scheme for sensors attached to the brakes, engine, and transmission, and to control things like the lights and instrument panel gauges.

CAN is a broadcast network. The network operates in a half-duplex mode. One unit transmits and all others listen. This is the same as many other networks - ethernet, GPIB, or an amateur radio repeater. One major stated advantage of CAN over similar networks is the way it handles channel contention. On a CAN bus, any unit may send at any time. This means two or more units can transmit at the same time. In most other networks, this will cause a loss of data from all units. But on the CAN bus, addresses also serve as priority levels and the highest priority (lowest address) device will get its message through. The CAN specifications require that a device listen to the bus before and during a transmission. Thus, the lower priority device will recognize the collision and stop transmitting.

CAN is a medium speed network. It can operate at speeds up to 1 megabit per second depending on the transmission and noise environment. For Phase-3D a rate of 800 kilobits per second was selected.

A CAN message is made up of 4 fields plus framing bits (see Figure 1). There are 10 framing bits that mark the start, end and acknowledgement of a CAN frame. Inside the framing bits are the Arbitration, Control, Data, and CRC fields.

```
  | Arbitration    | Control | DATA |  CRC   |
 _|_____________  _|   _____|______|________|____________
|S|              |R|I|r|    |      |        |            |
|O|   11-bit     |T|D|0| DLC | 0-8  | 15-bit| ACK & EOF  |
|F| identifier   |R|E| |     | Bytes|  CRC  |  9-bits    |
|_|______________|_|_|_|_____|______|_______|____________|
```

CAN Version 1.2 Standard Data Frame format

```
  |             Arbitration                 | Control | DATA |  CRC |
 _|_____________  _ _  _______________      |   ______|______|______|____________
|S|              |S|I|                 |R|r|r|       |      |      |            |
|O|   11-bit     |R|D|    18-bit       |T|1|0| DLC   | 0-8  |15-bit| ACK & EOF  |
|F| identifier   |R|E| identifier      |R| | |       | Bytes| CRC  |  9-bits    |
|_|______________|_|_|_________________|_|_|_|_______|______|______|____________|
```

CAN Version 2.0 Extended Data Frame format

Figure 1. CAN Message Frame Formats

The Arbitration field contains the Message ID field (or address) and the Remote Transmission Request bit. There are two versions of the CAN protocol specifications: Version 1.2 and Version 2.0. The main difference between the versions is the size of the Message ID field. In version 1.2 the Message ID field is 11 bits. This allows for the specification of up to 2032 addresses or messages. Message IDs 0 through 15 are not allowed. In Version 2.0, the Message ID field is 29 bits allowing for over 500 million distinct messages. The Version 2.0 protocol was specified in such a way that it is fully backward compatible with Version 1.2. The total size of the Arbitration field is 12 bits in Version 1.2 and 32 bits in Version 2.0. For Phase-3D, we chose to limit ourselves to the Version 1.2 address specification so that we could take advantage of controller chips that implement only the shorter addresses.

The Control field contains a 4-bit Data Length Code and 2 reserved bits. The Data field is a variable length field for 0 to 8 bytes (0 to 64 bits) of data as specified in the Data Length Code.

The CRC field is an error-checking field. It contains a 15-bit Cyclical Redundancy Check error code and a delimiter bit. The CRC is computed over all bits in the Arbitration, Control and Data fields.

The CAN specifications do not specify the physical layer for the bus. The specifications do require that the physical layer must be able to generate and distinguish dominant and recessive bits. A dominant bit on the bus will override a recessive bit. A number of physical media are possible. Simple systems could use a 1-wire open-collector bus. On this type of bus, a recessive bit is generated by allowing the output to be pulled high by a resistor. A dominant bit is generated by pulling the output low. Using the bus this way allows the collision management functions to be easily implemented at the hardware level. On Phase-3D, CAN uses a 4-wire system, a 2-wire data bus driven with 82C250 CAN interface circuits and 2 wires for power and ground.

There are a number of parts that implement the CAN protocols. CAN was developed with the intention that most of the protocol would be handled in hardware rather than software, and the available parts reflect this. The programming of the chips to send a packet or collect a packet is only slightly more complicated than what is required to send or receive a single character with a UART. Getting the chip initialized is another story, but it only needs to be done once.

The oldest design part used was the Phillips 80C200. This chip supports only Version 1.2 of the protocol and a single message object. It is easily connected to a microprocessor and appears as 32 I/O registers.

The chip used for most of the nodes on Phase-3D is the Intel 82527. It is a bit more complex. In addition to the CAN functions, it supports a pair of 8-bit ports and an SPI-type serial microprocessor interface. The SmartNodes (discussed later) use the SPI for communications with a 68HC11 CPU. On RUDAK, standard 8-bit parallel bus interface was used. The 82527 provides 15 message objects with 8-bytes of data plus control registers. These message objects allow selective reception of messages and help keep the interrupt load on the CPU to a minimum.

A number of newer chips are now available. These include the Phillips SJA1000 with a 64-byte FIFO, the Siemens SAE81C90/91 with 16 mailboxes and 5MHz serial interfaces. And Motorola and others are producing micro-controllers with integrated CAN interfaces. Various ASIC tool vendors now include CAN blocks in their function libraries, and new micro-controllers with integrated CAN functionality have been introduced, or soon will be.

Phase-3D CAN Participants:

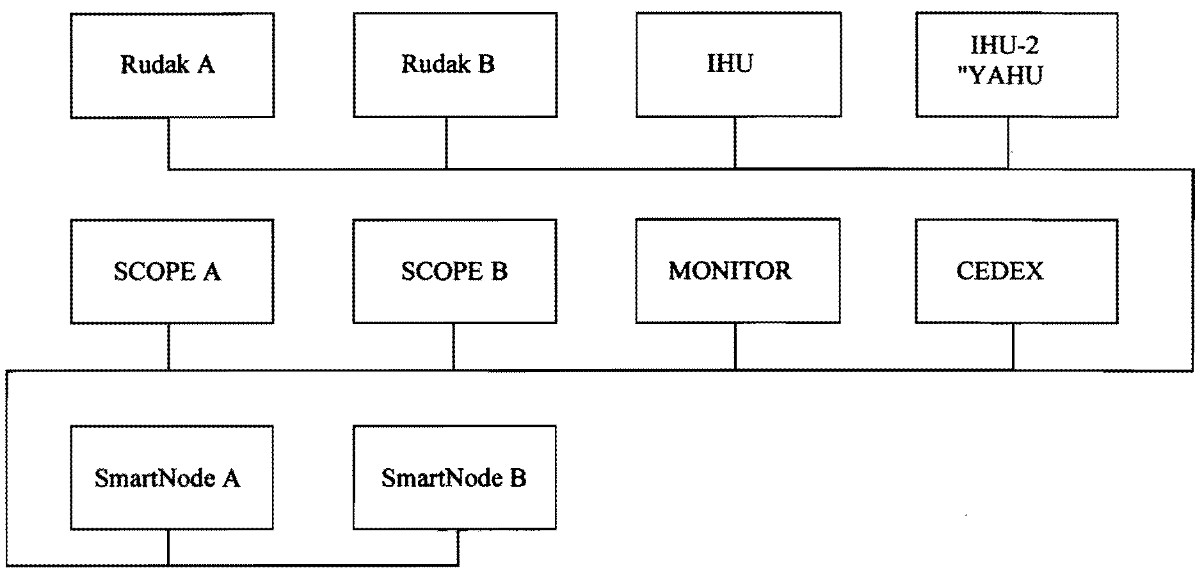

Figure 2. Participants in the Phase-3D CAN Bus

The Phase-3D IHU has a CAN interface but it has not been (and may not be) used very much. The primary controllers on the CAN bus are the RUDAK CPU's, which provide the interface between digital ground stations and various experimental payload modules on the spacecraft.

The highest-profile customer of CAN service from RUDAK is undoubtedly the SCOPE camera package from Japan. SCOPE includes two color CCD cameras that take 800x600 pixel, 24 bit-per-pixel images. The SCOPE cameras each contain a CPU that must be bootloaded from the filesystem on RUDAK, and which then controls image capture and compression, providing images to RUDAK for storage and download. In addition to the CAN interface, the SCOPE CPUs share an RS-485 serial multi-drop interface with the RUDAK CPUs as a backup. However, it is intended that all interaction with SCOPE will use the CAN bus.

The CEDEX radiation measurement experiment from SSTL lives only on the CAN bus. It was provided ready to boot and run the CAN-SU protocol from ROM at power-on. SSTL provided an example task for RUDAK to be used in capturing the data from CEDEX and a decoder program so that we can look at the resulting data. Any time it is powered on, CEDEX is live and trying to provide data to RUDAK on ten-minute intervals.

The MONITOR experiment from Hungary also lives only on the CAN bus. It also boots and runs from ROM, and supports the CAN-SU protocol. However, unlike CEDEX it operates in a polled mode where it never speaks on the CAN bus unless spoken to.

The SmartNode modules designed by DB2OS and WA7GXD also live only on the CAN bus. These modules were designed to be general-purpose CAN interface boards, in the same way that a small board housing the AART was produced for the Microsats and used in each module. For a variety of reasons, only two are being used on Phase-3D, dedicated to measuring temperatures at various places on the spacecraft not conveniently reached from the IHU. Each module contains a Motorola 68HC11 micro-controller, an Intel 82527 CAN interface, signal conditioning for up to 10 analog input channels, 8 bi-directional digital control lines, and a serial data interface. The SmartNodes can operate in either a polled measurement mode or an automatic reporting mode. On Phase-3D the digital control lines are not used and the serial data interface is used only for software development and ground support monitoring.

A late addition to the spacecraft is the IHU-2 module, sometimes known as YAHU (Yet Another Housekeeping Unit). This module includes a CAN interface. How it might be used on orbit is unclear at this time.

In addition to our experience with CAN in the development of Phase-3D, our friends at SSTL have flown, or are planning to fly, CAN on several spacecraft, so far with very good results.

Issues with CAN Bus:

In the course of developing the CAN bus for Phase-3D, we ran into a number of issues. Some of these are fundamental to the CAN design and some pertain to our early adoption of CAN before it gained wide acceptance.

First and foremost, CAN is not well suited for bulk data transfer. The design of the packets provides for only 8 data bytes per packet. Add to this the half-duplex nature of the bus and the limited support for streaming, and the data rates achievable for bulk transfer even on a 800-kilobit-per-second bus are only marginally better than on an asynch multidrop bus. For all its theoretical faults, the Ethernet protocol with a maximum packet size of 1500 bytes and similar half-duplex typical application achieves much higher throughput efficiency per unit of raw data rate.

Fortunately for Phase-3D, we do not have any real bulk data transfer needs. The closest we get is the bootloading of the SCOPE cameras, and retrieval of compressed still images from the cameras. Our CAN implementation is completely adequate for these needs, if a bit annoying at times during ground testing when we're all sitting around biting our nails, waiting to see if the cameras still work!

The second issue is that the CAN-SU protocol is relatively obscure. Only SSTL and AMSAT Phase-3D are using it at this time. The UTIAS MOST project evaluated CAN and gained agreements allowing use of the CAN-SU protocol and our protocol stack, but has since decided to implement a simpler multidrop serial bus which should be completely adequate to their needs. This is not an absolute problem and is certainly not unusual in the history of AMSAT software development. However, there are a number of other protocol stacks that run on top of CAN, one or more of which are nearing the status of industry standard.

We had a number of problems debugging our CAN implementation. At the time we adopted CAN, it was almost completely unknown in the US, except for the availability of the 82527 from Intel. We even had a hard time convincing them that they made the part when we tried to obtain programming information! Our initial application of a driver for the Intel chip tripped over a number of special case behaviors in the hardware. Then, as we developed the CAN server for RUDAK and made it work with the various experiments, we tripped over some ambiguities in the CAN-SU specification. The most notable of these was text that defined the byte ordering of data objects in terms of the processors least and most significant bytes, instead of defining a network byte order. These were all easy to resolve, but each took coordination among volunteer developers in several countries on three continents!

It also took a while to find an ISA-bus CAN interface card that we could use for software development. Our Japanese friends developed a CAN interface that attaches to a PC parallel port to facilitate their SCOPE hardware and software development, but we found it unable to handle large numbers of back to back packets, which made it difficult to trace network activity. On N3EUA's test bench, we used a Debian GNU/Linux system with a DIP 82C200 card, the Linux Lab Project CAN drivers, and some diagnostic programs written by WD0FHG to develop and test our software. In Orlando during functional testing, and again in Maryland during Thermal/Vacuum testing, N3EUA developed a packet tracing program which consumes one of the RUDAK CPUs as a diagnostic tool to observe CAN transactions to and from the other RUDAK CPU. The results are quite functional, but it sometimes felt like we needed to spend more time developing our test environment than it took writing the actual flight code!

Conclusion:

CAN is a fairly reasonable medium-speed serial network bus and is in some ways ideally suited for telecommand and telemetry gathering. Many of the harsh attributes of the automotive environment led to design decisions which should make CAN very robust in the satellite environment. However, because the data payload in each packet is tiny and each packet contains a large protocol overhead, the bus is not well suited for bulk data transfer.

For simple satellites, CAN is overkill. For modest command and telemetry needs, we would opt instead for a simpler, serial multidrop bus. For complex satellites, CAN may be an excellent solution for the command and control function. If payloads with high data rate requirements are connected by faster serial or parallel data busses, a CAN bus could quite effectively be used for controlling transactions on the simpler but faster data-transfer busses.

Since CAN seems to be growing in popularity in industry, it may be that more controller chips will be produced with integrated CAN interfaces. If that happens, CAN becomes even more attractive.

While the application of CAN on Phase-3D may be sub-optimal for things like retrieving pictures from the cameras, we feel the Phase-3D CAN experiment is already a success. Even before we launch, this experiment has taught us a great deal about CAN, and how it might be applied to future small satellite applications.

OPAL: A First Generation Microsatellite That Provides Picosat Communications for the Amateur Radio Community

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Abstract

The OPAL microsatellite built by students at Stanford University will provide a new era for unique satellite communications for amateur satellite operator and user enthusiasts. The major payload of OPAL is a launcher that allows ejection of small picosatellites into orbit. These picosatellites, weighting less than 1 kg and having dimensions of 1"x3"x4", can provide experimental platforms for forms of experimental communications that have not been possible before.

OPAL is scheduled for launch on an U.S. Air Force converted Minuteman II missile from Vandenberg AFB, California on October 1999. OPAL has a picosat launcher that is capable of carrying eight 4" long picosats or combinations of 4" and 8" lengths. This mission will be carrying six picosatellites, one amateur picosat developed satellite called Stensat developed by a team lead by Hank Heidt - N4AFL, Kevin Doherty, and Dr. Carl Wick - N3MIM. An undergraduate student engineering team from Santa Clara University built three picosatellites. The final two picosats that will be launched are built by The Aerospace Corporation carrying DARPA experimental MEMS RF switches and University of California at Los Angeles wireless radios.

This paper will describe the OPAL satellite in detail, the payloads that can be used by the amateur radio community and the new collaboration model by the Stensat team between the academic and amateur community.

Introduction

OPAL is Stanford University's second Satellite QUIck Research Testbed (SQUIRT) satellite. As part of the Space Systems Development Laboratory (SSDL) the SQUIRT project exposes graduate level students to all aspects of satellite design, construction, testing, and operations.

The goal in the SQUIRT programs is to construct a microsatellite in one year and for only $50,000. The design for OPAL was started in early April of 1995. However, since this is only SSDL's second satellite, the development time was extended. OPAL obtained a flight opportunity in March 1998 and the satellite was delivered in May 1999 to Weber State University for final integration with the launch platform.

OPAL's (Orbiting Picosatellite Automatic Launcher) primary mission is to demonstrate the feasibility of launching multiple picosatellites from a mothership satellite. The satellite's secondary payloads are an accelerometer testbed and a magnetometer testbed, which will perform component characterization

Background

The Stanford SSDL was established in 1994 in the department of Aeronautics and Astronautics to provide project based programs for the Stanford engineering graduate students. The laboratory goals are to provide graduate students the opportunity and facilities for research and development and operation of space satellites. The program is based on using the simple, low-cost design philosophy pioneered by the AMSAT community and having a student managed program. This program provides students with "real world" experience in the life cycle of a project. This life cycle is to conceive, design, implement and operate real spacecraft in a low earth orbit.

The major challenges in this program are to keep the satellite design simple and yet provide enough capability to fly space experiments for customers; to design using commercial components and keep the total purchased materials cost less than $50,000; and complete the project with the normal term of a master's degree student (1 to 1-1/2 years). The physical size and weight design goals were 18" in diameter, 12" high and approximately 25 lbs.

The first satellite in the program was started in March of 1994 called SAPPHIRE was completed in June 1998 --- much longer than the initial goal, but realistic considering it was done in conjunction with establishing a new laboratory, acquiring equipment and developing a student managed program.

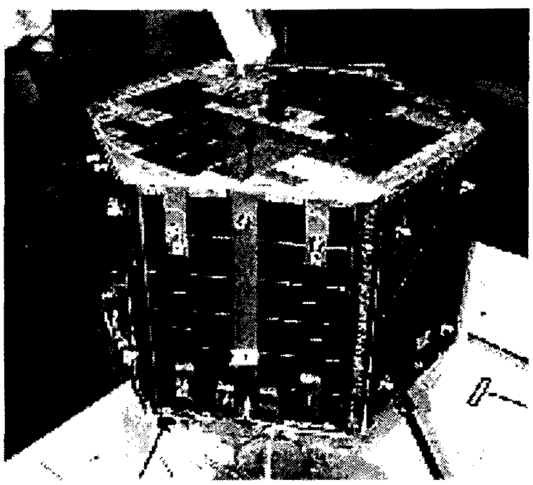

Figure 1 SAPPHIRE

The completed SAPPHIRE is shown in Figure 1 and is awaiting a possible NASA space shuttle launch in 2000.

This second satellite called OPAL original concept is shown in Figure 2 and is presented in detail in this paper.

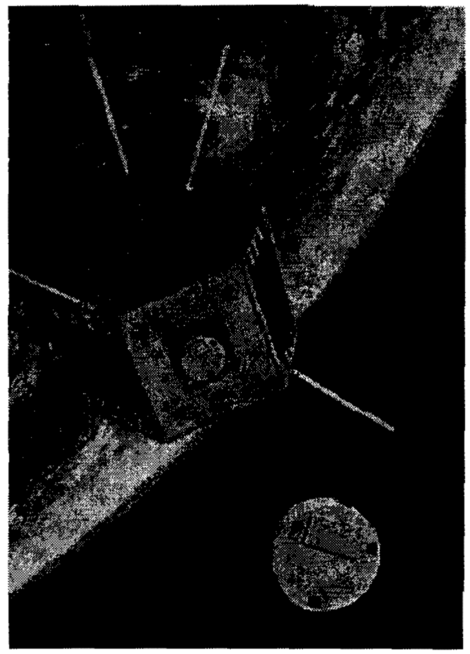

Figure 2 Original OPAL Concept

Mission:
Mothership-daughtership Architecture

Recently, a new mission architecture has been suggested to perform distributed sensing in space. In this architecture, a main satellite, or "mothership", deploys a number of smaller satellites, or "daughterships", to remote locations of interest to perform the required sensing. To date, several missions have placed one or two sensors in interesting locations, but placing dozens or hundreds of them remains a challenge. Due to increased interest in distributed sensing in space, new technologies need to be developed. The mothership technologies include picosatellite storage, deployment, communication, and retrieval or disposal. The daughtership technologies include all the necessary miniaturization of current satellite technology to meet the picosatellite scale.

The primary mission of the OPAL picosatellite payload is to validate the mothership mission architecture and provide a basic testbed to develop the mothership and daughtership technologies.

The Mothership

The OPAL design team focused on mothership technology development. A picosatellite launcher developed addresses the storage and deployment technologies. The launcher is designed for scalability, manufacturability, and reliability. It is capable of launching at eight 1"x3"x4" picosatellites.

Spacecraft Bus

OPAL is a hexagonal prism, made of quarter-inch aluminum honeycomb panels. The spacecraft uses a modular, three-tray approach. Each tray contains a different subsystem. In addition, all major components are shielded from EM interference inside sheet aluminum boxes. Shown in Figure 3.

Bus Height (without antennas): 23.5 cm (9.25 in)
Magnetometer Boom Length: 1.2 cm (3 in)
Outside Radius: 21.0 cm (8.25 in)
Mass: 25Kg (56 lb.)
Volume Envelope: 27,300 cm^3 (1660 in^3)
Usable Volume: 21,300 cm^3 (1300 in^3)

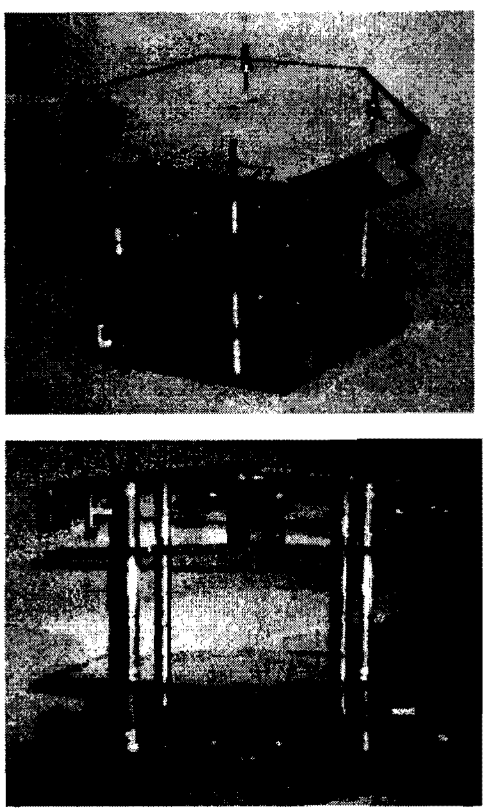

Figure 3 Honeycomb Stacked Structure

Power Subsystem

OPAL is powered by seven solar panels. Ten rechargeable Nickel-Cadmium batteries provide the secondary power source.

Solar Cells: GaAs
Batteries: Sanyo KR5000DEL, D-size rated at 1.2 Volts and 5 Amp-hours

Onboard Computer

OPAL's computer consists of a primary CPU board and two peripheral data acquisition boards. Vesta Technologies produce all three boards. The computer controls all aspects of the satellite's operation, including picosatellite launch, sensor data collection, ground communications, and engineering telemetry.

Primary CPU board: SBC332 based on the Motorola 68332 microcontroller, running at 8.38 MHz with 1 MB of onboard RAM.

Peripheral boards: Two SPI332 boards based on Motorola's Serial Peripheral Interface bus and protocol. Each board contains 16 digital I/O channels and eight 12-bit analog-to-digital converters.

Communications Subsystem

OPAL communications uses packet radio AX.25 protocol over amateur radio frequencies. The terminal node controller (TNC) and radio transceiver are off-the-shelf units provided by NavSymm Inc.

Uplink: 70 cm band (430.1 MHz)
Downlink: 70 cm band (430.1 MHz)
Data rate: 9600 baud

The Daughtership

The daughterships are called picosatellites because of their low mass (less than 1 kg). To satisfy OPAL's end-to-end mission demonstration, the picosatellites are capable of communicating data to the ground.

Picosatellite Payload

The Orbiting Picosatellite Automated Launcher (OPAL) project has the following top-level objectives:

- Develop SSDL as a laboratory. Provide educational opportunities.
- Conduct OPAL payload experiments.

The primary mission of the OPAL picosatellite payload is to provide an end-to-end mission demonstration of mothership and daughtership technologies. A storage, deployment, and communication scheme will be designed and implemented on the OPAL satellite. The OPAL mothership will store and deploy six picosatellite daughterships. Upon deployment, the picosatellites will establish a link with an earth-based ground station and transfer its mission data.

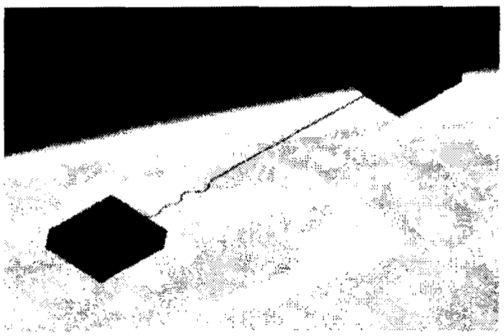

Figure 4 Aerospace Picosats

Three teams designed and constructed the daughterships. A team from The Aerospace Corp. and UCLA will test MEMS technology and an intersatellite communication network. An undergraduate engineering team designed and built three picosats. An amateur radio (HAM) team built a transponder picosatellite.

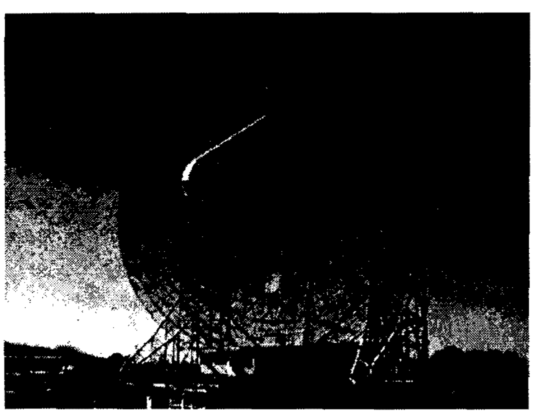

Figure 5 50 Meter Antenna

Primary Picosatellites Provider:

The DARPA Team - DARPA sponsored The Aerospace Corporation, UCLA, and the Rockwell Science Center, to develop a battery powered picosatellite to test an intersatellite communication scheme and to characterize a MEMS RF switch. Wireless radios (shown in Figure 4) from UCLA will be used in these two tethered picosats for cross-link communication and communications with a 50 meter ground antenna (shown in Figure 5) at Stanford University.

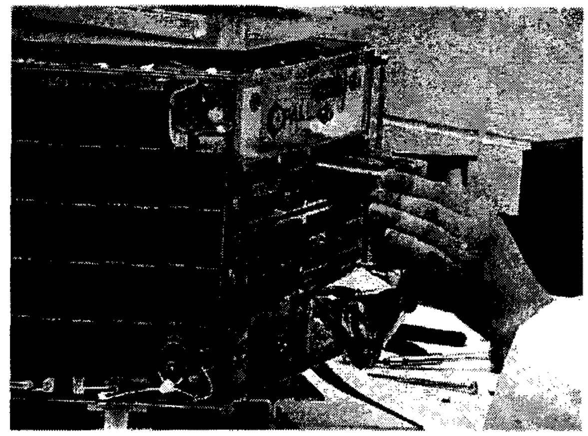

Figure 6 Inserting Artemis Picosat

Secondary Picosatellite Providers:

The Artemis Team - The undergraduate team from Santa Clara University designed and built one 4" battery powered picosat that will be a short life beacon and two 8" battery powered picosats. The two 8" picosats that will be used to measure the EM energy generated in the VLF band by lightening storms of the US Midwest area.

STENSAT - Stensat is a small (12 cubic inch, 1 pound) solar powered picosat intended for use by amateur radio operators world wide and will operate as a single channel mode "J" FM voice repeater. It was built by a group of HAMs from the Washington, D.C.

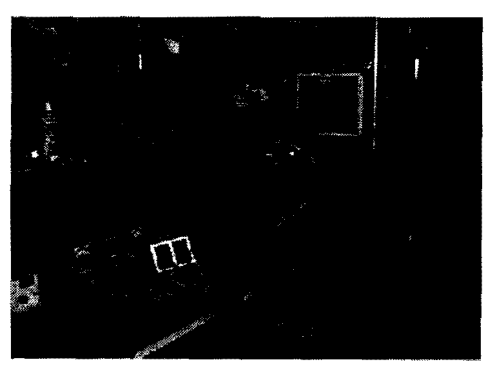

Figure 7 Stensat Picosat

area by a team lead by Hank Heidt - N4AFL, Kevin Doherty, and Dr. Carl Wick - N3MIM. This opportunity of having an amateur group build a picosat was presented to the audience at the 16th Space Symposium and AMSAT-NA Annual Meeting at Vicksberg, MS in October 1998. Through the extended efforts of Hank, Kevin, Carl and others, the amateur community will be launching the smallest, most capable OSCAR satellite ever put into space.

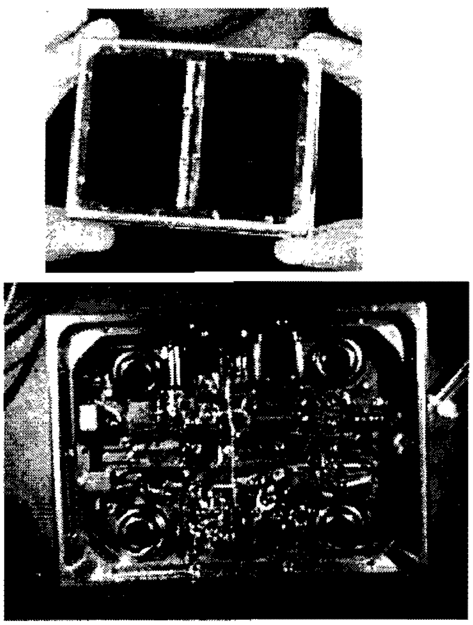

Figure 8 Stensat Details

Accelerometer Testbed

The accelerometer testbed will characterize the functionality and operation of several commercial-off-the-shelf (COTS) accelerometers. Accelerometer technologies that will be flown include a MEMS capacitive sensor, piezoelectric sensor, an inductive sensor, and a piezoresistive sensor. Since there are no measurable forces on OPAL except during launch of the picosats, the accelerometer sensors will be activated by pulsing a solenoid to provide vibration of the spacecraft.

Figure 9 Accelerometer Test

Magnetometer Testbed

This testbed consists of a magnetometer made by Applied Physics Systems, and is sponsored by the Relativity Mission, Gravity Probe B, a NASA project directed by Stanford University at Stanford. The testbed will characterize the functionality and operation of the magnetometer and used for OPAL attitude information.

Figure 10 Magnetometer

Attitude Control

OPAL is a free-flyer and performs no attitude control. The spacecraft includes ballast so its major moment of inertia is optimal for picosatellite launch.

Mission Operations

OPAL will be operated from the SSDL ground station at Stanford University, which is fully equipped to carry out satellite contacts over the amateur radio satellite bands.

The initial launch in a southern direction from Vandenberg AFB will allow the opportunity for one contact pass on the next orbit to the west of California. The contact for this pass will be with the help from Bob Harrison and Cliff Buttschardt-K7RR in Santa Maria, California. After the first contact pass at Santa Maria, the next pass will not occur until abut nine hours later when the Stanford students can return to use the ground station at Stanford.

Since this is a polar orbit, it is advantageous to have a very high latitude ground station in the first few days after launch to get maximum contact. Arrangements are being made to have the Stanford student Greg Hutchins in Alaska for the first few days of operation using Mike West's - WL7BQM station at Sterling Alaska.

After the on-orbit checkout period, the picosatellite payload will be the focus of operations followed by an evaluation of the testbed payloads. Once all the experiments are completed operations will turn to an extensive analysis of vehicle performance. This will provide valuable information for future SQUIRT-class satellite development.

Launch Arrangements

A launch opportunity was acquired for the OPAL satellite in March 1998. It was to be launched from Orbital Science's OSP Spacelift Vehicle while piggy backing on JAWSAT satellite from the United States Air Force Academy (USAFA) and the Center for Aerospace Technology (CAST) at Weber State University.

JAWSAT

The JAWSAT mission is collaboration between the USAFA and the Center for Aerospace Technology (CAST) at Weber State University in Ogden, Utah. The JAWSAT concept of and operations prescribes Weber State the design and development responsibilities and USAFA the integration, launch, and on-orbit operations responsibilities.

JAWSAT shown in Figure 11 with OPAL attached is scheduled for launch on an Orbital Science's OSP Spacelift Vehicle in the October of 1999 from the Vandenberg AFB. The primary objective of the JAWSAT mission is to provide a satellite that can be used to train cadets in satellite command and control operations. Since orbit maneuvering and attitude determination and control are fundamental to this cadet JAWSAT will be equipped with several systems for attitude determination, two pulse plasma thrusters, and a 3-axis stabilization system.

OSP Spacelift Vehicle

The standard Orbital Sciences OSP launch vehicle configuration is a four-stage, all-solid-fueled, launch vehicle, capable of placing up to an 800-lbs spacecraft into low earth orbit. OSP offers the user the ability to launch multiple payloads during the mission profile, spreading the cost of the launch vehicle among several different programs. The Orbital OSP vehicle utilizes the Minuteman II stages 1 and 2, with the Orion 50XL as the third stage. The Orion 38, avionics structure, and Pegasus based shroud complete the vehicle stack. Both Orion motors have extensive flight experience from the Pegasus and Taurus programs.

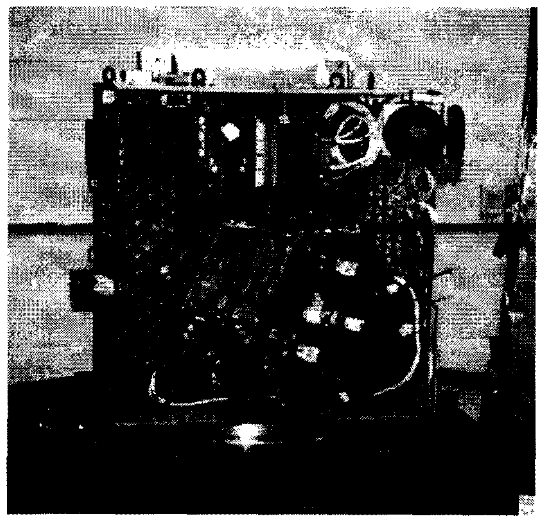

Figure 11 OPAL Integrated on JAWSAT

Orbit Description

OPAL will be placed on the terminator in a circular sun-synchronous orbit with an altitude of 750 km. This orbit will leave all of the payloads in a continuous sunlight condition. This provides maximum power for the spacecraft but may also present a challenge in adequate thermal management not normally experienced in LEO orbits with eclipse time.

OPAL Radiation Environment

The expected radiation environment of OPAL's orbit was modeled using the Space Environment Information System, SPENVIS. SPENVIS is a web-based tool providing space engineers and scientists with information on the environment and its likely effects on space systems.

Conclusion

The development of the OPAL satellite has shown that it is possible to develop viable spacecraft at a low cost. Of course, the use of graduate students working on the satellite for several years as part of their degree program and "we're going to get this done" attitude has negated the labor costs.

The use of COTS parts has played not only an important role in reducing costs but has provided a valuable lesson in the design role of the student. The use of the COTS parts allowed the students to have broad range of components to use in the trade-off studies for the design. In selection of these COTS parts, however, now forces the student designer to be very aware of the environment in which these components must survive and operate. The components must withstand the launch environment, the thermal environment of space (no more convection cooling), and effects of space radiation on electronic components. The student designer must incorporate into the design ways of mitigating these effects.

The program also introduces many new learning aspects into student education that cannot be taught or simulated in the classroom. This student managed projects now requires the students to deal with establishing group dynamics for a productive program which is not always easy with peers. The students select a project manager, systems engineer, subsystem leads and other positions to support the program. The management of a project in this situation produces many challenges. What can the student peers do if some students do not perform their required tasks on time? What motivation do they use to keep the project on time line? Students in an educational setting such as this operate in a distributed engineering environment since students have other classes, jobs, etc. than this project and are not all working in the same area at the same time as in most industry projects. Here, the faculty provides the framework to get the project done with some management advice, getting the physical and funding resources required and working more as a coach than a line manager.

The students survive all of this and many excel in gaining new capabilities technically and maturing in a working environment. It is estimated that more than 100 students have significantly participated in this program with about 20 that will have gained broad experience that would have taken many years in industry to get.

The faculty goal of educating the students has been achieved at a 95% level before launching this student built satellite.

Acknowledgment

For a project of this nature to be successful, it takes a broad range of resources and conditions to be present. This is evidenced by the small number of university programs working on student built satellites that have reached the point of being launch ready.

Stanford University has provided the opportunity for a single faculty member to be entirely dedicated to this program. Stanford, although not providing any direct funding for the program, provides the facilities and most importantly promotes working these programs as interdisciplinary programs across department boundaries.

Being in Silicon Valley is a great asset. Having access companies such as Lockheed Martin, Space Systems/Loral, Deskin Research and the government laboratory, NASA Ames Research Center provided many resources with use of facilities, access to engineering specialists and the availability of surplus materials.

The additional following companies have provided invaluable support and advice: Amp, Analog Devices, Analytical Graphics, Dow Corning, Eagle Picher, Harris Semiconductor, ITT Cannon, Motorola, National Semiconductor, PacComm, Pads Software, Penstock, Raychem, Shur-Lok, Space Electronics, Stanley Tools, and the TiNi Alloy Company.

SSDL has established a mentors program to assist the students. This has been primarily through the use of HAM radio enthusiast. These mentors are to assist the students in their design and testing work but are not allowed to do the work for the students. These mentors meet with students at Stanford every Monday evening and are compensated with pizza for their efforts.

Students often work at the mentor's homes where some have equipment that is far better than exists in program laboratory. The HAM mentors gain the opportunity to help some very capable and ambitious students and primarily get to work on spacecraft that will actually get into space. Many thanks go to Lars Karlsson, John Ellis, David Lin, Dick Kors, Richard Anderson, David Joseph and many more for their help.

Also, it should be acknowledged the efforts of Ernie Robinson from The Aerospace Corporation for his efforts in getting DARPA interested in launch picosats to test MEMS components. Al Pisano from DARPA has supported Ernie is his efforts and has been an enthusiastic and financial supporter of Stanford in this program.

Jay Smith from Weber State University kept Stanford in mind as a payload for JAWSAT to fly on the Orbital Sciences OSP expendable launch vehicle.

Finally there is a special thanks to all of the Stanford students that put many long hours of the volunteer time to get this project done be a part of the space program.

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Emerald: University Built Satellite Extending Communications Experimentation for the Amateur Community

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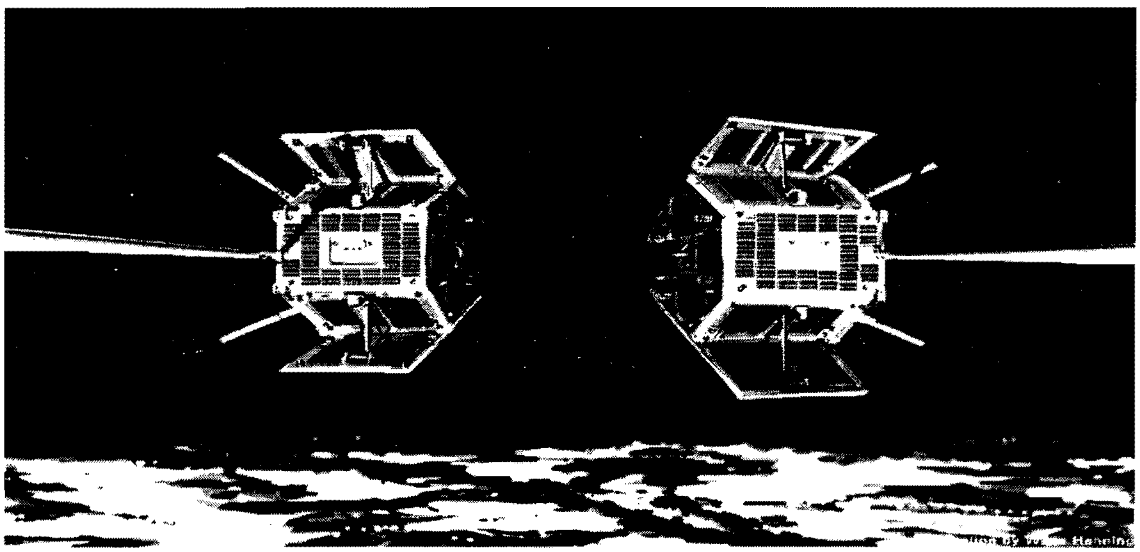

Figure 1 Emerald Satellite Formation

Abstract

The Emerald microsatellite being built by students at Stanford and Santa Clara University is the next generation of university satellites that will provide a potential model of communications for amateur satellite operator and user enthusiasts. The Emerald microsatellites, 18" hexagonal in diameter, 12" high and weighing less than 20kg will provide the first opportunity for amateur radio operators to experiment with two formation flying satellites that have a radio cross-link capability. It also carries a compliment of other payloads that will be of interest to both the science and amateur community.

The Emerald program is two satellites of the University Nanosat Program being sponsored in the Techsat 21 program by the Air Force Office of Space Research and the Defense Advanced Research Projects Agency. The University Nanosat Program funds are providing universities the opportunity to build ten nanosatellites in two years and a launch in 2002.

This paper will describe the Emerald mission in detail and the proposed payloads that can be used by the amateur radio community.

Introduction

The Emerald nanosatellite program is a joint effort between Stanford University at Palo Alto, CA and Santa Clara University in Santa Clara, CA. The program is to develop two nanosatellites in a collaborative effort between the Stanford graduate students and Santa Clara undergraduate students.

The Space Systems Development Laboratory (SSDL) at Stanford in the department of Aeronautics and Astronautics and the Santa Clara Research in Extreme Environment Mechanisms (SCREEM) laboratory in the school of engineering were awarded contracts in September 1998 for the University Nanosat Program in response to Broad Area Announcement (BAA) in July 1998 for the TechSat 21 program. This is a program funded by the Air Force Office of Space Research (AFOSR) and the Department of Advanced Research Agency (DARPA).

This program provides $100,000 for each university over a two-year period to develop, launch and operate a nanosatellite. The initial desire, but not requirement, of the BAA was to develop nanosatellites that could demonstrate collective experimentation that may not be possible with a single satellite.

The definition of "nanosatellite" was a satellite <10kg. Stanford and Santa Clara proposed using the existing heritage in microsatellites from Stanford to build a 15kg microsatellite. The following small satellite size designations was proposed at the Micro/Nanotechnology Workshop in Albuquerque, New Mexico in March 1998:

Microsatellite <100kg
Nanosatellite <10kg
Picosatellite <1kg

Background

The Stanford SSDL was established in 1994 in the department of Aeronautics and Astronautics to provide project based programs for the Stanford engineering graduate students. The laboratory goals are to provide graduate students the opportunity and facilities for research and development and operation of space satellites. The program is based on using the simple, low-cost design philosophy pioneered by the AMSAT community and having a student managed program. This program provides students with "real world" experience in the life cycle of a project. This life cycle is to conceive, design, implement and operate real spacecraft in a low earth orbit.

The major challenges in this program are to keep the satellite design simple and yet provide enough capability to fly space experiments for customers; to design using commercial components and keep the total purchased materials cost less than $50,000; and complete the project with the normal term of a master's degree student (1 to 1-1/2 years). The physical size and weight design goals were 18" in diameter, 12" high and approximately 25 lbs.

The first satellite in the program was started in March of 1994 called SAPPHIRE was completed in June 1998 --- much longer than the initial goal, but realistic considering it was done in conjunction with establishing a new laboratory, acquiring equipment and developing a student managed program.

The second satellite called OPAL was started in March 1995 and was delivered for launch integration in May 1999. OPAL is scheduled for launch in October 1999. OPAL is unique in that it is going to launch six picosatellites as part of its payload.

Emerald Mission

The main objective of the EMERALD project is to promote Robust Distributed Space Systems:

- To demonstrate Robust Distributed Space Systems through engineering, design, tests and verifications of the satellite bus, subsystems, and experimental subsystems

- To validate Robust Distributed Space Systems through on-orbit experiments using the satellite bus, subsystems, and experimental subsystems

Mission Objective and Requirements

The core of the EMERALD mission is demonstration of Robust Distributed Space Systems. The mission uses a building-block approach, where the ultimate mission is actually built upon the success of individual experiments.

Lightning Detection Experiment

This atmospheric science experiment utilizes a set of VLF receivers, one on each spacecraft, to detect electromagnetic radiation from lightning storms.

This payload is designed by Stanford's STARLAB and will be implemented by the Santa Clara University students. The ability to control the formation of the spacecraft will be used to enhance this experiment.

Formation Control Experiment

Both EMERALD spacecraft will attempt controlled formation flying by combining the individual experimental payloads. The GPS receiver will determine the relative position, using the inter-satellite link. The drag panels will be commanded as needed to maintain the relative position between spacecraft.

Formation Flying Experiment with Orion

This experiment will be to use the Emerald satellites to demonstrate precision formation flying with a Stanford built satellite called Orion, which will be launched with the Emerald spacecraft.

Orion is a project funded by the NASA Goddard Space Flight Center to build a 50kg class satellite to demonstrate precision formation flying. Orion has been under study and development at Stanford as a joint project between the Formation Flying Laboratory directed by Professor Jonathan How and the SSDL since late 1997. Both laboratories are in the Department of Aeronautics and Astronautics.

This microsatellite is an advance SQUIRT type satellite that is a 1/2 meter cube that has attitude control and orbiting maneuvering capability with a cold gas propulsion system and torquer coils.

Colloid Thruster Experiment

One of the EMERALDS will be demonstrating the Colloid Thruster technology to confirm ground experimental data and to validate its technology and its application in Distributed Space Systems architecture. It is currently being developed at the Stanford Plasma Dynamic Laboratory.

GPS Receiver Experiment

Stanford-modified Mitel 12-channel 2-antenna receiver will be tested to compute orbital attitude and relative positions of the spacecraft.

Inter-Satellite Crosslink Experiment

Evaluation of Inter-Satellite crosslink communication systems for autonomous data exchange between spacecraft supporting Distributed Space Systems architecture.

Advance Amateur Radio Communications Atmospheric Experiments

The use of the cross-link between the two Emerald satellites and the Orion satellite will provide a new test capability for radio experimentation in the amateur radio bands.

The Emerald satellites will begin to drift apart as the mission progresses. This will allow initial experiments to characterize the use of amateur frequencies for cross-links between to amateur satellites. It will also provide the opportunity to perform other experiments in atmospheric propagation. The satellite separation will become great enough that the cross-link will occur in path that is a grazing angle to the earth and will pass through most of the earth's the atmosphere. The AMSAT community will be asked to help specify these experiments and participate in their execution.

Radiation Testbed Experiment

The testbed is being developed jointly with Boeing, Naval Research Laboratory, The Aerospace Corporation, Lawrence Livermore Laboratory, and University of California at Berkeley. Its primary mission is to assess the on-orbit performance of advanced microprocessor, MEM technologies and COTS parts that are considered vital to enabling high-performance, low-cost, distributed space systems.

NASA Shuttle Launch

The Emerald and Orion satellites are scheduled for a NASA shuttle launch in mid to late 2002. The launch mechanism on the shuttle will be the SHELS launcher that attaches to the side of the orbiter bay. This launcher will hold a platform that will contain the two Emerald satellites and the Orion Satellite. This configuration will allow simultaneous launching of the satellites to start with an initial close formation to perform the formation flying experiments.

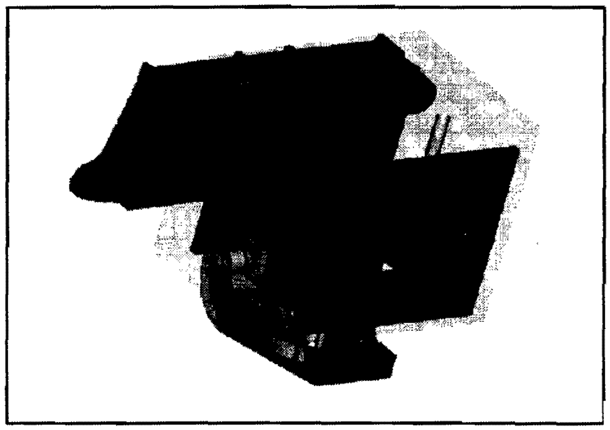

Figure 2 SHELS Launcher

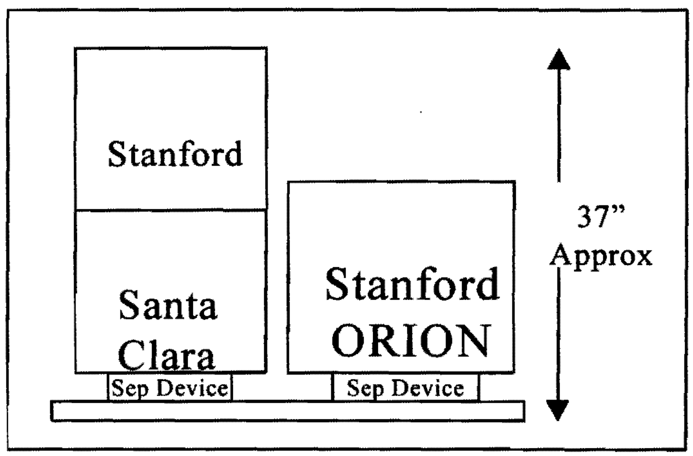

Figure 3 Stacked Emerald/Orion on SHELS

The two Emeralds will be stacked on one side of the platform and the Orion will be mounted next to them as shown in Figure 3.

Emerald Spacecraft Design

The Emerald design will draw heavily on the experienced gained with the SAPPHIRE and OPAL spacecraft developed in SSDL.

Structure

The structure will be the basic hexagonal design with stacked trays made from aluminum honeycomb sheet. These structures get their main structure strength with the axial longeron rod technique used on the AMSAT microsatellites that were launched in 1990. The attachment of the side panels add additional stiffening. There is a new design of the attachment mechanism between the two satellites. The stack will be attached to the platform with a Marman clamp mechanism developed by McDonnell Douglas and used by many previous AMSAT satellites on Delta launches.

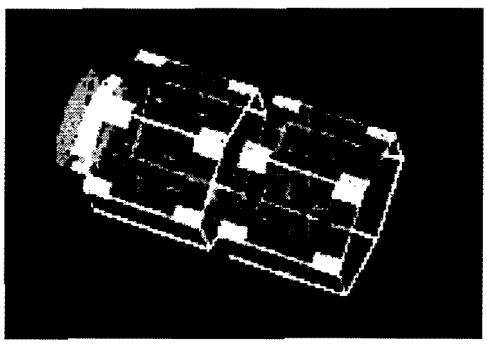

Figure 4 Stacked Emeralds

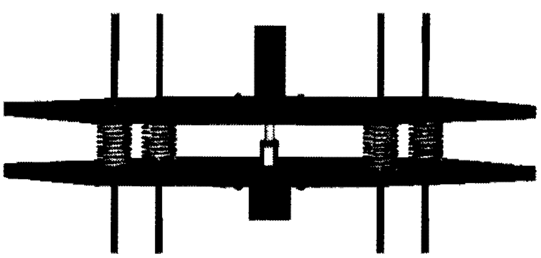

Figure 5 Satellites Interconnect Assembly

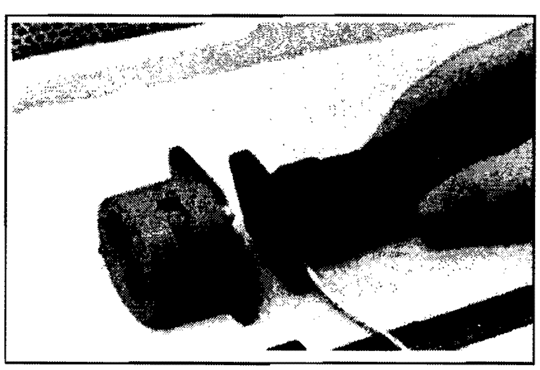

Figure 6 QwkNut Release Assembly

Power System

The present baseline on the power system is to use NiCd type batteries that were used on previous SSDL programs. The present plans are to us triple junction 24% experimental solar cells provided by AFOSR from Spectrolab and Tecstar. The panels will be fabricated by students at the supplier's facilities and under their direction.

Communications System

The Emerald and Orion satellites will use a 70cm band transceiver used for both crosslink and ground communications. Emerald will also use an additional backup command receiver at the 2m band.

A Space Quest modem will be used. The AX.25 amateur radio protocol will be used, but is now in software on the processor as compared to a hardware TNC used on the previous SSDL satellites.

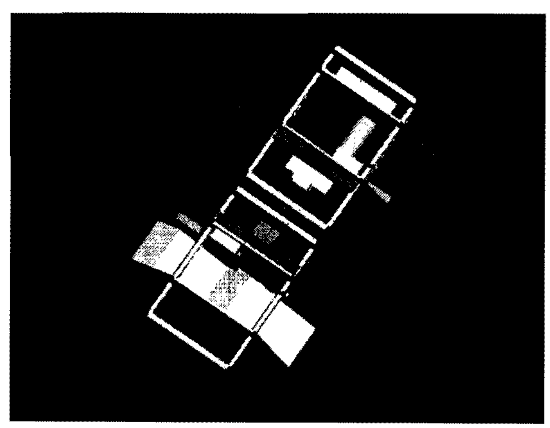

Figure 7 Stacked Assembly Drawing

Processor System

The processor and software used for both the Emerald and Orion will be the Space Quest V53 processor and the BekTek software used on the AMSAT microsatellites and many of the University of Surrey UoSats.

Having more funding than for previous SSDL projects has allowed this combination to solve many of the previous reliability problems. The previous used Vesta 68332 had no EDAC memory and did not allow uploads of developed software after launch and required a hardware TNC in order to use the AX.25 protocol.

The combination of Space Quest hardware with the EDAC memory and the BekTek software, which has a software TNC, has solved both of those design concerns.

Distributed Control

The Emerald and Orion designs will use a distributed control architecture by using the I^2C two wire communications bus. PIC processors will be used for subsystem controllers. The Dallas single wire bus will be used as an auxiliary bus and back up to the I^2C bus.

Operations Mode

Throughout the mission, EMERALD will have the several operational modes, in which there will be a set of sub-modes. These operational modes are outlined below.

- Launch-Verification Mode
- Downlink Mode
- Stacked Mode
- Separation Mode
- Non-Distributed Experiments Mode
- Colloid Thruster
- VLF Science
- Orion Formation Flying Mode
- Safe Mode

Conclusion

This program provides many new challenges to SSDL as compared to past projects. It requires the completion of two microsatellites in a period of about two years. It requires more coordination outside Stanford for coordinating the development with Santa Clara University. It requires the certification for the launch on the NASA shuttle and must meet much higher requirements that previously SSDL built satellites.

The addition of a primary part of the mission in doing formation flying with the Stanford Orion project requires that the two programs must have close development and interface coordination.

This programs also takes SSDL into a new era. It is the first program started in SSDL that has committed funding to use at the start of the development. It has a scheduled, defined launch. These are conditions that were not present during the two previous SQUIRT programs.

Acknowledgment

For a project of this nature to be successful, it takes a broad range of resources and conditions to be present. This evidenced by the few number of university programs that have produced student built satellites that have reached the point of being launch ready.

Stanford University has provided the opportunity for a single faculty member to be entirely dedicated to this program. Stanford, although not providing any direct funding for the program, provides the facilities and most importantly promotes working these programs as interdisciplinary programs across department boundaries.

Being in Silicon Valley is a great asset. Having access to companies such as Lockheed Martin, Space Systems/Loral, Deskin Research and the government laboratory, NASA

Ames Research Center provided many resources with use of facilities, access to engineering specialists and the availability of surplus materials.

This program is funded through the University Nanosat program from the Air Force Office of Space Research. Maurice Martin directs the program at the Air Force Research Laboratory at Albuquerque, New Mexico.

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ASUSat1 – On-Orbit Operations and Satellite Profile

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Introduction

Over the past six years, the students at Arizona State University have been working on their first satellite, ASUSat1. In early October of 1999 the project will assume a new phase when students begin on-orbit operations of the satellite.

The ASUSat1 project began in October 1993 as an innovative attempt to build a nanosatellite able to perform meaningful science in space while maintaining strict mass and volume constraints. Over the years, ASUSat1 has undergone several major design changes as launch opportunities have changed. In mid 1998 a firm launch was secured on the maiden voyage of the "Minotaur". On May 13, 1999, the ASUSat1 team delivered the flight-ready satellite to the launch integrator, and the satellite was integrated to the payload adapter on June 23, 1999. ASUSat1 weighed in at a svelte 12.9 pounds. Currently, launch is scheduled for early October from Vandenberg Air Force Base in California.

This paper will discuss the final configuration of ASUSat1, with an emphasis on operational capability. In addition to that, the current flight commissioning and operations plan will be discussed.

Launch Characteristics

The launch, currently scheduled for October 4 from Vandenberg Air Force Base, will be the maiden voyage of Orbital's newest rocket, the Orbital/Sub-Orbital Program (OSP) Space Launch Vehicle "Minotaur". The satellite will be the first deployed from the JAWSAT multiple-payload adapter (MPA) approximately 7 minutes after takeoff.

The planned orbit of ASUSat1 will be sun-synchronous (3:30am-3:30pm), with an inclination of 100 degrees and altitude of 750km. Since this is the maiden voyage of the rocket, some deviation from the planned orbit can be expected. With this insertion, the satellite should nominally perform 14 orbits per day. Most ground stations will be able to access 5 to 6 of those orbits with an average pass time of 12 minutes per orbit.

Satellite Characteristics

Command and Data Handling (C&DH)

The on-board computer (OBC) is based on the Intel 188 CPU. It has 1MB of EDAC-protected RAM. This memory is shared between code and data. Upon launch, the OBC is loaded with a bootloader only. The bootloader maintains the satellite in a power-safe mode, and awaits commands from the ground station. During the operations phases, the Bektek multi-tasking operating system will be uploaded to the satellite. Once operational, the operating system will enable operators to take full advantage of all the resources on the satellite.

Electrical Power System (EPS)

Power availability is the primary factor in determining the mission profile. Due to the small size of the satellite, the available power from the solar array is limited. Solar panels are mounted on all 14 sides and the top bulkhead of the satellite. Power from the solar array is transferred directly to the battery pack. The battery pack is a six-cell Sanyo NiCd pack with a capacity of 5Ahr and a nominal voltage of 7.2V. From the battery, power is transferred to a high-efficiency DC/DC 5V voltage regulator. The last part of the power system is the switching network, which feeds all the subsystems. Since power management is so important, all payloads have power switches - except the OBC. Current calculations estimate that the system should have 6W average available for mission operations.

Communications

To enable the amateur radio community to participate in satellite operation, the communication system is fully compatible with amateur radio standards. The communications system will be a common VHF uplink, UHF downlink (mode B) system. The digital system will use 9600 Baud FSK, which is compatible with UO22/KO25 and similar satellites. AX25 will be the main communications protocol, making use of a KISS TNC possible.

While being similar in modulation technique to UO22/KO25, the downlink will not be active continuously. This is needed in order to conserve power and enable data/audio multiplexing on the same downlink. Telemetry beacons will use standard formats which are supported by WISP. Telemetry configuration files will be available to the public shortly before launch.

FM Repeater

One of the most important contributions of ASUSat1 to the amateur radio community will be the addition of another easy-sat to the fleet. The satellite will have a mode B FM repeater similar to the popular AO-27. It is estimated that the repeater mode will be enabled only when the satellite is in sunlight. This is again to maximize the time that the transmitter can be driven at full power. The repeater will be PL-tone activated. In addition, the downlink is shared between both the digital and analog payloads. The digital payload always has priority over the FM repeater. If a QSO is taking place while the satellite needs to send a beacon, the downlink will be captured before the transmission and released back to the repeater after the transmission is over. All in all the performance of the FM repeater is expected to be slightly better than that of the AO-27, with 6dB more power and less spin modulation.

Cameras

Two similar cameras are mounted inside the satellite to point nadir. The spectral range of one camera is visible blue, and the other is visible red and near infra-red. The cameras are independent of each other. Working together, the cameras will provide images useful for vegetation indexing. Used separately, the visible blue camera will provide general earth observations. The field of view of both cameras is 18 degrees and the resolution is 496 x 365 pixels. From the planned orbit, the expected resolution will be about 0.5km/pixel. The cameras do not have a specific mission and the students at ASU will entertain interesting challenges for scientific observations. The images will be available for download via the Web.

GPS

Another interesting experiment involves the implementation of a terrestrial Trimble GPS unit mounted on board. The data gathered periodically will be used for orbit determination. Moreover, closed-loop tracking and location event scheduling is also planned.

Gravity Gradient Boom

ASUSat1 will use a gravity-gradient boom as the main mode of stabilization. The boom will deploy immediately prior to the satellite's deployment. Current estimations show that the boom will keep the satellite pointing to about 10 degrees from nadir. Means of attitude determination and finer control were added: namely, dynamics sensors and a fluid damper, respectively.

Dynamics Sensors

The student-designed dynamics sensors are an array of sun/earth sensors to be used for attitude determination. This is important for proof of concept of the fluid damper and for camera operations. If successful, these low-cost sensors will be useful for many other future LEO missions.

Fluid Damper

Fine 3D stabilization on a nanosatellite is not a trivial challenge. Due to power constraints, elaborate systems are not possible. The fluid damper is a new concept for passive 3D stabilization. The damper utilizes a ball with four mass concentrations (two per axis). This results in a smooth sphere with three distinct moments of inertia and that "floats" in fluid. The outer casing of the damper is attached to the satellite bus. The internal ball should align itself with the gravity-gradient vector and the velocity vector of the satellite. Since it is expected that the satellite will oscillate around the equilibrium state, this energy should be dampened by friction in the fluid layer between the ball and the outer casing. The effect of the fluid damper is expected to be very subtle. It is estimated that the satellite should reach a steady state after about 600 orbits.

Z-Coil

One Z-axis magnetorquer is mounted on ASUSat1. Even though no attempt for active attitude control is planned, this magnetorquer will be used if the satellite is pointing zenith instead of nadir. This could occur during initial deployment, for example. Using the magnetorquer, the satellite could be flipped back over into the correct orientation. Also, the device can be used to compensate for gravity-gradient-boom pumping action.

Mission Phases

The operational lifetime of ASUSat1 is divided into four phases, each with a specific logical sequence. The purpose of Phases 1 through 3 is to commission the spacecraft bus and experiments. Phase 4 will be the last phase in which the spacecraft will go into steady-state operations.

Phase 1, Power-On Systems Checkout

The first phase is the initial satellite acquisition and system checkout. Since no operating system is loaded onto the satellite, the checkout of only basic bus status is possible. This phase relies heavily on the telemetry beacon sent by the satellite. ASUSat1 operators hope that the amateur radio community will be able to provide telemetry reports from all over the world during this important time. This phase is expected to last a few days.

Phase 2, Whole-Orbit Systems Checkout (OS)

In the second phase, whole-orbit system analysis software will be uploaded to the satellite to enable the operators to monitor the satellite over several orbits. This phase will provide a sense of how successful the electrical and thermal design was. This phase should last less than two weeks. At the end of this phase the operators should know and understand the status of the satellite bus.

Phase 3, Payloads Checkout (OS)

After the satellite bus has been tested in previous phases, the three main payloads will be commissioned: the amateur FM repeater, both cameras, and the GPS receiver. This phase is of great importance since the mission operations (Phase 4) will rely on the results of the payload commissioning. This phase should last about 3 weeks.

Phase 4, On-Orbit Operations

Phase 4 is the most exciting phase for everyone, as the satellite operators and users will be able to access the experiments. Since the power budget is very limited, a detailed and optimized profile will be created for maximum benefit from the payloads. This phase will last for the rest of the satellite's lifetime, which is estimated to be 2 years. It is hoped that with proper battery management, the operators will be able to extend the lifetime of the satellite to about 5 years.

Planned Timeline

Below is a brief summary of the phase timeline:

Table 1. ASUSat1 Mission Operations Phases – Planned Timeline

Phase	Start Time	Duration	Purpose
Phase 1	Launch	3 days	Initial system checkout
Phase 2	Launch+3 days	7 days	Whole orbit data collection
Phase 3	Launch+10 days	31 days	Payload testing
Phase 4	Launch+41 days	Lifetime	Normal operations

On-Orbit Operations – Suggested Profile

On-orbit operations will be the longest (hopefully) and most exciting phase of ASUSat1 operations. Due to the fact that new software can always be uploaded to the spacecraft, this phase can change dynamically as the students gain proficiency in spacecraft operations. The following description refers to the initial mode of operation as conceived by the ASUSat1 team.

Power Management

Power will be the limiting factor on the operating profile of ASUSat1. Since the satellite is power-negative with all experiments turned on, only some can be used at any given time. In addition to this, battery maintenance will be of concern to the operators. In order to properly cycle the pack; the experiments will be used to enable deep discharge.

FM Repeater: Operation Mode and Availability

The FM repeater will be the primary operation mode of interest to the amateur radio community. The repeater will be enabled during sunlight periods of the orbit. This is necessary due to the high power consumption of the transmitter. A day-of-week schedule may also be used in order to facilitate operations with other payloads. The team will be happy to receive comments and preferences to modes of operation.

GPS Data Collection

GPS data collection will occur intermittently in order to collect position points over several orbits. The data will be used to calculate the satellite's orbit and compare it with data provided by NORAD. Since orbital perturbations are not expected to be significant, it is expected that this mode will not be used on regular basis. Future operations modes include closed-loop tracking and position-related event scheduling. For closed-loop tracking, the satellite will transmit its location to the ground station. The ground station can use that information to actively track the satellite. A position-related event is an event that is scheduled to take place when the satellite has achieved a certain position in space.

Camera Image Capture

The cameras on ASUSat1 can be used together or independently. At present two modes of operation are planned. The first is vegetation indexing. For this mode, both cameras will be used to create multi-spectral images. For this mode, interesting targets will be selected, such as rain forests and agricultural areas. The images could be used to analyze trends in vegetation growth or decay over time.

The second mode of operation will be general earth imaging. Only one camera is needed for this mode. General targets will be selected and photographed. For both modes, the team will accept requests from the public and post the images on the web for general use.

Summary

The ASUSat1 team is anxiously awaiting launch in October. ASUSat1 will provide a great experience for the students to test and operate the payloads they have developed. With this, the team is wide open for suggestions from the amateur radio community. All the information collected by the team will be made available through the ASUSat home page. The team hopes that by the time this paper is presented, the students will be busy collecting data from the initial orbits of ASUSat1.

Acknowledgements

Support for ASUSat1 has been provided by:

- Orbital Sciences Corporation
- National Space Grant College & Fellowship Program (NASA Space Grant)
- AMSAT Organization
- Honeywell Space Systems Group

- Lockheed Martin Management & Data Systems – Reconnaissance Systems
- National Science Foundation Faculty Awards for Women in Science and Engineering
- Cogitec
- SpaceQuest
- Hughes Missile Systems,
- ORCAD
- Solid Works Corporation
- Zilog
- Microchip
- Dycam
- Motorola (Satcom & University Support)
- SunCat Solar; PhotoComm, Inc.
- Eagle Picher Industries
- Intel (University Support)
- Maxon
- Universal Propulsion Company, Inc.
- ICI Fiberite Composites
- DynAir Tech of Arizona (SabreTech)
- National Technical Systems
- SpectrumAstro
- Trimble Navigation
- Bell Atlantic Cable
- Lee Spring Company
- Astro Aerospace
- BekTek
- Jet Propulsion Laboratory
- Rockwell
- Sinclabs, Inc.
- Applied Solar Energy Corporation
- Gordon Minns and Associates
- Communication Specialist
- Advanced Foam and Packaging
- XL Specialty Percussion, Inc.
- Simula, Inc.
- KinetX
- Equipment Reliability Group
- Arizona State University Center for Solid State Electronics Research

New ASUSat Projects for Fall 1999: Three Corner Sat and Distributed Ground Station Network

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Introduction

This past year has seen students of the ASUSat Program completing the final assembly and acceptance testing of their first project, ASUSat1. With ASUSat1's launch scheduled for this October, this project will transition into its operations phase, also to be performed on campus by the students. The ASUSat Program continues to set its sights high however, as in addition to the transition of ASUSat1 into operations, the students are also embarking upon a number of additional projects. Two of these, Three Corner Sat (3⩓Sat) and the Distributed Ground Station Network (DGSN), are the subject of this paper.

The 3⩓Sat project is a constellation of three satellites being developed jointly by Arizona State University (ASU), the University of Colorado at Boulder (CU), and New Mexico State University (NMSU). This project began in response to the AFOSR / DARPA University Nanosatellite Program, a special topic of AFRL's TechSat 21 Initiative. Primary mission objectives of 3⩓Sat are stereoscopic imaging, virtual formation operations, innovative communications schemes via LEO telecomm constellations, and innovative command and data handling. Additionally, each spacecraft will include a generic payload envelope to provide each school an opportunity to conduct a unique experiment after the constellation objectives are met. ASU will be flying a micropropulsion experiment in this volume.

The DGSN project is in its infancy, as ASU began research in the area of distributed ground stations earlier this summer. We hope to begin a lasting dialog with the AMSAT organization that generates vital feedback, and develops partnerships, to together formulate and implement the optimum strategy. Your input now is critical to a useful product for both the AMSAT and university communities.

Three Corner Sat

We will begin by providing a brief overview of the initial opportunity resulting in the formation of the 3▲Sat project. We'll then give a detail of the 3▲Sat Mission Goals. Further information may be found in References 1-3.

Overview

3▲Sat is a constellation of satellites to be built by ASU, CU, and NMSU. A proposal requesting Air Force Office of Scientific Research / Defense Advanced Research Projects Agency funding for this project was submitted under the University Nanosatellite Program, a Special Topic of the Broad Agency Announcement on the Air Force Research Lab (AFRL) TechSat 21 Initiative. The TechSat 21 concept 'involves satellites flying in formation that operate cooperatively to perform a surveillance mission'.

The University Nanosatellite Program is funding ten university 'research projects centered on the design and demonstration of nanosatellites', defined as sizes from 1 – 10 kg. The awards are 'for universities to design, assemble, and conduct on-orbit experiments for these satellites.' Technological innovations and demonstrations are needed in nanosatellite design, communications schemes, and distributed processing.

The 3▲Sat team has chosen to divide leadership responsibilities by subsystem, rather than by spacecraft. However, this division only applies to the 'leadership' of each subsystem, not to the individual students. Interested students at a given school can participate on any given subsystem, but they still have to coordinate their efforts through the lead, independent of which school at which the leader resides. The leadership assignments are as follows:

ASU

Management; Electrical Power System; Structures, Mechanisms, Thermal, and Radiation; Attitude / Orbit Determination and Control; Micropropulsion Experiment; and Integration.

CU

Commands & Data Handling, Distributed Operations, Stereoscopic Imaging, Science Operations, and Spacecraft Operations.

NMSU

Communications, LEO Telecommunication Services, Intersatellite Communications, and Ground Stations and Network.

Mission Goals

The 3▲Sat consortium will perform research and development of a number of nanosatellite and constellation technologies by the design, construction, and operation of a three-satellite constellation. Student education will be emphasized by involvement in all aspects of the project.

Stereo Imaging

The primary science objective of the 3Asat constellation is to stereo-image small (< 250 meter), highly dynamic (< 1 minute) scenes including deep convective towers, atmospheric waves, and sand/dust storms. These stereo images will enable the computation of range to within 100 meters giving accurate data regarding the shape, thickness and height of the observed phenomena.

Virtual Formation Operations

To accomplish the science objectives, a 'virtual formation' is proposed and will be demonstrated as part of our program. The virtual formation is a cooperative effort between satellites operating as a network where targeting and data acquisition are accomplished and results transmitted to the ground segment and to the other satellites via communications links without the need for strict physical proximity of the satellites. In this mode, the communications links carry the command and control data necessary to accomplish the mission regardless of the physical location of the satellites. For the mission to be accomplished the locations of the satellites will need to be 'in range' and mutually known in order for each to support its portion of the mission, but physical proximity is not a requirement for the formation network.

For stereo imaging, a nominal spacing of tens of kilometers between the satellites is sufficient. With a controlled deployment to achieve this initial spacing, the satellites will remain within range for the suggested four-month lifetime of the mission. Therefore propulsive capability is not needed.

Communications

The communications system on board the satellites will include three innovative schemes. The first will be a traditional ground-to-satellite link utilizing innovative technology. The second will be a satellite-to-satellite communicator, and the third will be a satellite-to-commercial Low Earth Orbit (LEO) communications network communicator.

The ground-to-satellite will be the only traditional type of communications system. Even so, the team intends to develop new technologies for the traditional communications modes. With the tremendous growth in the communications industry, newer low-cost implementations are possible for systems that previously required significantly more hardware.

The satellite-to-satellite communicator will be one of the highlights of the mission. The communicator will have an impact all the way from hardware implementation to mission operations profile. It is expected that this mode will enable new and exciting ways to make use of spacecraft for advanced communications schemes.

The third communications scheme utilizes a commercial communications network in LEO that supplies the communications links. This will allow each satellite to be contacted via the LEO network regardless of the position of the satellite relative to the ground station. Because each satellite in the network will be visible to the LEO communications constellation, there is the ability for satellites to perform their mission coordination without the need for visibility from the ground station or with each other. The LEO communications network knits together the virtual formation.

LEO satellites utilizing cellular telephone constellations is a new concept but one in which there is considerable interest in the government and private-sector space communities. This natural extension to the use of ground-based systems will be explored not only to demonstrate the utility of this mode of communications but also to act as an experiment to characterize the constellation itself and the limits on operations. A technology goal of 3⩓Sat is to perform the first steps in this characterization.

Command and Data Handling (C&DH) System

The C&DH for the 3⩓Sat constellation is designed as a distributed and simple system. As part of this distributed arrangement, each satellite uses a Satellite Processor Board that serves as its local controller, data interface, on-board memory, and processor. The three-satellite constellation can be controlled and managed by a processor on any of the three satellites via the communication links. The Satellite Processor can be responsible for supervising the operation of the three spacecraft and managing their resources. This supervision can be automatically accomplished within the constellation by the selected satellite processor which can initialize and distribute commands and which can monitor and react to science and engineering data from the three spacecraft.

ASU Micropropulsion Experiment

Micropropulsion systems can offer a wide variety of mission options, all relevant to formation flying: attitude control, station keeping, altitude raising, plane changes, and de-orbit. For its University-specific experiment, ASU is collaborating with AFRL and industry to design and fly a micropropulsion system. The objective of ASU's research is to take a systems point of view and develop a safe and simple micropropulsion system for nanosatellites. In particular, the ASU satellite will demonstrate orbit raising and de-orbiting once the 3⩓Sat virtual-formation/stereo-imaging mission is completed.

Current Status

The University Nanosatellite Program received some very good review board ratings, practically guaranteeing a launch aboard the shuttle. Expected launch date is in late 2001 or early 2002. We are continuing to pursue a launch aboard an expendable launch vehicle (preferred over shuttle).

Distributed Ground Station Network

In this second section, we will introduce our intent to research and develop a distributed ground station network product. We present the factors that will enable success and the advantages of such a system. Our hope is to begin a dialog with the AMSAT community and generate feedback, as well as encourage partnerships with anyone who is interested as we further formulate and implement a strategy. Your input now is critical to producing a useful product down the road.

Introduction

Orbital mechanics dictate that any satellite not placed in Geo-Synchronous Orbit (GEO) will not have constant visibility windows with a given ground station on earth. Traditionally, this forces the mission characteristics to adapt to the available visibility windows. The extreme case occurs for satellites in LEO. For example, a LEO satellite in a near polar orbit will circle the Earth an average of 14 times per day. For a typical ground station, the satellite will be visible for only 5 of those orbits and have available only about 12 minutes of communications time per orbit. This results in an availability duty cycle of about 5%. These are, of course, nominal figures, as the numbers may vary slightly with the location of the ground station and the inclination of the orbit.

The main point is that a single ground station has only a very limited opportunity to communicate with the satellite. The traditional approach for satellite communications is to establish a ground station and maximize the efficiency of the limited time available for communications. Another solution for satellite operators who need more communication opportunities is to establish and link several ground stations. At present, this approach is no small undertaking. The required personnel, resources, and complexity of the systems are major issues.

Even though present implementations are very complex, the concept of linking ground stations is a good one. If the above '5%' figure is considered, then every ground station added in non-overlapping footprints can add 5% to the total communications availability. For instance, if 10 ground stations are established at population centers around the world, total availability could rise to 50%.

Enabling Factors

There are several influencing factors that combined can lay the foundation for a networked ground station within the amateur radio community. The first factor is equipment availability. It is estimated that at present, there are some 200 satellite ground stations worldwide. Even though not all have the same modes, with such a large number of stations cut sets could be easily established. Second, many ground stations are semi or fully computer controlled. This technology will help fully automate station operations. Third, the communications medium has already been established. Almost everyone has Internet access nowadays. A small number of ground stations even have constant Internet connectivity. A larger number have dialup capability to the Internet. These factors provide the pieces of an interconnected network. All that remains is to establish the connectivity scheme that will enable a large number of ground stations to collaborate to enhance the communications capability over that available from each individual station acting alone.

Advantages of a Distributed Ground Station Network

Aside from the main advantage of increasing raw communications time, a ground station network offers several additional advantages:

Redundancy

In a single station system when the station fails, the entire system goes off the air. When multiple stations are involved, one impaired station would only slightly reduce the capability of the network without bringing it down entirely.

Link Efficiency Improvement

Ground stations with overlapping footprints have the ability to increase the efficiency of the link by combining the data received from all the ground stations. By combining multiple streams, frames missed by some of the ground stations can be received by others. Another aspect of improving link efficiency is the reduction of command redundancy. A satellite in LEO usually implements some form of store and forward operation. In many cases, users in different regions of the world download the same data. By storing the data once in the ground network, different users will not have to request the same data from the spacecraft over and over again.

Application Portability

By networking ground stations together, the hardware is separated from the application. There are two implications: the first is that satellite operators are no longer dependent on a ground station 'location' for communication. An operator only needs a computer with some form of Internet access for operation. The second is that newcomers can more easily join and participate in the amateur radio hobby.

Multiple Access

When a few ground stations are available with several satellites of interest, access to multiple satellites is possible.

Satellite to Satellite Gateway

Ground stations can be used for satellite to satellite communications. This could enable real-time data transfer from regional satellites to satellites that cover other parts of the Earth. It is obvious that a ground-station network could enhance today's satellite communications modes. There will undoubtedly be more applications as it evolves with time.

Stakeholders

Both current and new operators could potentially find interest in such a project, including:

Satellite Command Stations

These are the operators with the most urgent needs, because they maintain the satellites. Consequently, the more opportunity they have to access the satellites, the better the job they can perform.

Satellite Operators

This is the vast majority of satellite operators who simply enjoy using the various modes available.

Space Technology Enthusiasts

These are not necessarily hams, but ordinary people who are interested in the telemetry and science information collected by the ground stations. This could serve the interest of the amateur radio community well by establishing a meaningful relationship with scientific groups.

K-12 and Educational Institutions

Education is a major aspect of our hobby. At present only those schools that manage to find the resources for ground stations can participate in space experiments. On the other hand, more and more schools are establishing computer labs with Internet access. This could eventually enable ALL students to join in and learn from space projects using these available resources.

Expected Modes

The most obvious answer to this is digital; but on second thought, we already have the technology to support both audio and digital. The amateur satellites split almost evenly between analog and digital. Therefore, it would make sense to start such a network with the digital satellites due to the large impact it would have. But it would also make sense to integrate the voice over IP technology into it, making a truly multi-mode system.

DGSN Summary

Networked ground-stations have been around for a while. The only organizations that could establish them have kept them as closed networks due to the level of complexity and costs associated with them. At present technology has laid the hardware infrastructure needed to establish a dynamic network that can further enhance the gain of amateur radio satellite technology. The students in the ASUSat program are investigating such a network for amateur-radio use. The students desire this project to be based on dynamic interaction among students and amateur radio operators. The students are open to any suggestions and ideas regarding this project and its progress and implementation.

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- Honeywell
- Lockheed Martin Astronautics
- Motorola
- Cogitec
- Space Quest
- Microchip
- Ball Aerospace
- Spectro Lab
- JPL

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Amateur Radio On-board the International Space Station

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Abstract

Amateur radio has had a substantial presence in human space flight since the mid-1980s. For over 16 years, amateur radio space enthusiasts in the U.S., Russia, and Germany have worked diligently to develop, deploy and coordinate operations of on-orbit amateur radio stations on the U.S. Space Shuttle and the Russian space station Mir. Human space flight is expected to change in the near future as the aerospace community rapidly evolves its focus towards operations on the International Space Station (ISS). The international amateur radio community is working with the aerospace community to make amateur radio a permanent fixture on ISS. This update of last years paper will summarize the status of the ISS program, the development of an initial station for use on-board ISS, and the opportunities and plans for implementing a permanent amateur radio station on-board the ISS.

Ham Radio and the Human Space Flight Connection

Amateur radio has had a significant human presence in space starting with a flight on board the space shuttle orbiter Columbia on the STS-9 mission late in 1983. At that time, astronaut Owen Garriott, W5LFL, provided an unprecedented level of excitement to the amateur community by talking to hams on the ground using a 2-meter FM transceiver. This modest beginning 16 years ago has led to a significant, nearly continuous presence of ham radio in human-tended space vehicles today.

With twenty-five flights, the Space Amateur Radio Experiment (SAREX) has become the most flown payload on board the Space Shuttle. The primary goal of SAREX is to pique student's interest in science, technology and communications by allowing schools around the world to talk with the astronauts during Shuttle missions. The crew also uses the equipment for a limited number of personal chats with close friends or family members and to talk to hams on the ground during their break times. SAREX has accomplished a number of firsts in human space flight. SAREX was the first to demonstrate crew-tended 2 meter voice, packet radio from space, crew tended amateur television uplinks and Slow Scan TV uplinks and downlinks.

In 1988 a permanent amateur radio facility was placed on board the Russian space station Mir. Technical capabilities have steadily increased on Mir over time. Currently Mir provides capabilities for 2m voice, a packet bulletin board system, slow scan television, a 70cm repeater, and a digi-talker. This station, developed primarily by our German (SAFEX) and Russian colleagues, provides an important spontaneous link for the astronauts and cosmonauts. While it isn't officially a backup communications source for Mir, ham radio has served as a secondary psychological ice-breaker; for the Mir crew, particularly after events such as the political and economic reorganizations in Russia and the 1997 Mir/Progress accident.

The Mir space station amateur radio facilities have provided a critical capability for the crew. As stays in space get longer and longer the psychological impacts of isolation become more severe. Amateur radio allows the crew to interact with friends and loved ones as well as serving educational needs with school contacts. The ability to perform random QSOs provides a

vital psychological break for a crewmember that may have been stuck "in a tin can" with their crewmates for months at a time.
The world's space flight community is now concentrating a significant amount of their resources on the development and implementation of an International Space Station (ISS.) The ISS has gone through a number of name and configuration changes since its first inception in 1985. The current design calls for modular components from a number of countries to be lofted on board Russian expendable rockets and the United States Space Shuttle. Construction began in 1998 with permanent human residence to start in 2000.

With ISS hardware design and development underway, preliminary planning for ISS on-orbit operations took place through joint experiments and U.S. astronaut visits on board the Russian space station Mir. This joint U.S.-Russian activity was called ISS "Phase 1." U.S. astronauts learned valuable lessons on Mir during their 4-6 month stays. Astronauts were primarily transported up to Mir using NASA's Space Shuttle. Supporting experiments, hardware and materials were carried on the shuttle or on the Russian Progress resupply ships. This effort had refocused nearly all the Space Shuttle missions to become Mir/Shuttle docking flights. Since these missions were typically fairly short and exceedingly busy, the SAREX team had curtailed its activity on those Shuttle missions. During the construction of ISS, the U.S. space shuttle has become a primary carrier of ISS hardware, materials, and crew. Thus, these flights will also be too busy for SAREX activities. During this time of transition, the SAREX team reduced its activity on the shuttle and concentrated on astronaut amateur radio operations on Mir. In parallel, the SAREX team in the USA worked with its international partners to make the ISS a permanent base for amateur radio operations. The amateur radio facility on ISS is expected to be used by the visiting shuttle crews, if they have time, and will serve as an educational outreach and recreation tool for the crews stationed on the ISS.

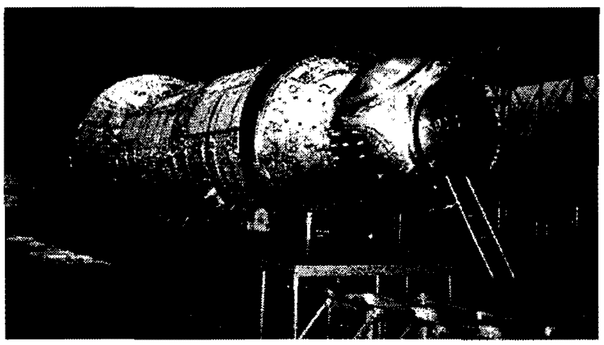
In November of 1996 a meeting was held at Johnson Space Center in Houston, Texas with representatives from national amateur radio organizations of eight countries. This meeting served to initiate the dialog on the development of a permanent amateur radio station on ISS. The outcome of the meeting was a Memorandum Of Understanding (MOU) that states that the groups would work together to coordinate the development of one amateur radio plan for the ISS. This coordinated international station would be called ARISS for Amateur Radio on the International Space Station.

In July of 1998 a follow up meeting was held in Surrey, England to better define the hardware complement to be flown for ARISS. An international "hardware committee" has been established which will define the permanent ham station for ISS, given the space and power resources obtained from the ISS project. An administrative committee was also established to work on matters such as the station call sign, third party traffic and general operations scheduling. On-board space for the permanent ISS facility is expected to become available late in the ISS construction project (around 2004). In the interim, the international hardware committee has been charged with implementing a series of "transportable stations" which can be launched as early as December 1999.

A joint meeting between NASA and Energia was held in Houston on January 22-27, 1999. This meeting finalized the design of the initial set of amateur radio hardware for the ISS and was to "develop a more effective understanding and advocacy of the ARISS program within NASA and Energia." The hardware proposed includes equipment housed in the pressurized "Zvezda" service module as well as antenna systems located around the periphery of Zvezda. A total of four amateur radio antenna systems were baselined and hardware delivery schedules were established. A detailed set of minutes from this meeting, including details of the hardware concept, have been published in the AMSAT Journal (reference #3.)

ISS Development Status

Deployment of the ISS is progressing fairly well. The first component of the ISS is the Russian Functional Cargo Block (FGB) named "Zarya." See figure 1. This first ISS element was launched November 20th, 1998 on board a Russian Proton rocket. The Russian built Functional Cargo Block provides initial propulsive capability through the early life of ISS. The first USA built "node," named

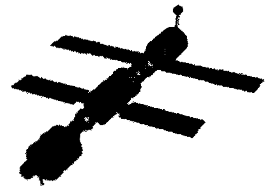


Functional Cargo Block (Zarya)
Readied for Flight
Figure 1

"Unity," was launched on space shuttle flight STS-88 a month later on December 4th. The nodes provide six connection ports that will allow different modules to be docked, providing a way to build the ISS out of separate modules. The Russian built "Zvezda" Service Module is currently scheduled for launch in November of 1999. It will provide propulsive, attitude control, and life support systems for the ISS.

In December of 1999 the STS-101 Space Shuttle flight to ISS, called the "2A.2 Logistics flight," will carry supplies to ISS. The ARISS team in the US has arranged for the launch of an initial ham station, with

Functional Cargo Block "Zarya" November 1998



2A.2 Logistics Flight December 1999

voice and packet capabilities on 2 meters and 70 cm, on this flight. This initial station, called "ISS Ham," will provide a temporary ham radio capability on board the ISS.

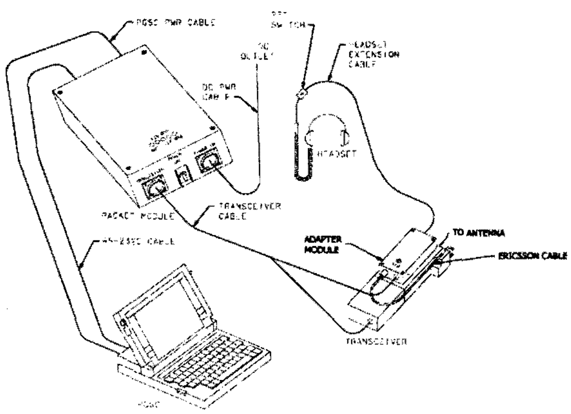
UF-3 February 2003
Figure 2

Several years later on flight UF-3, (figure 2) currently scheduled for February 2003, the ARISS US team has arranged for space on board an "EXPRESS Pallet." EXPRESS Pallets are mounted external to the station, and it is expected that there will be room for a fairly sophisticated "OSCAR like" payload.

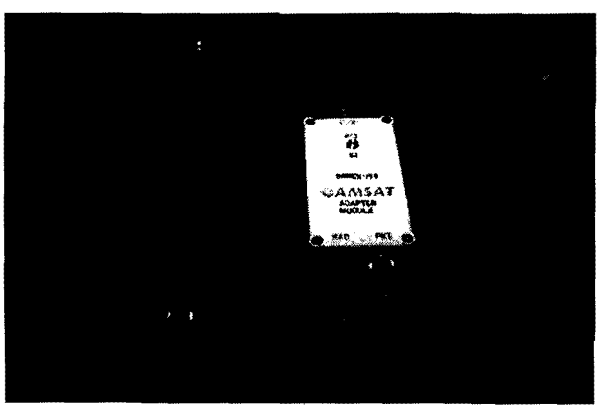
A request is in progress for permanent rack space in the "habitation module" which is to be launched on flight 16A no later than November of 2004. The request includes access to external antennas and access to the ISS computer systems for status information.

Initial Station Development Status

A block diagram representation of the initial ISS Ham radio station is shown in figure 3. The initial ham radio station on ISS will use intrinsically safe commercial 2m and 70cm hand held radios from Ericsson. See figure 4. These radios are extremely rugged and will not pose a hazard on the Space Shuttle or ISS. The radios are very simple to operate, with text displays for frequency configurations. If needed, they can be easily reprogrammed to support future configurations.



Initial ISS Ham Configuration
Figure 3



Ericsson Radio, Power Converter, Adapter Module, & Headset
Figure 4

The packet bulletin board system on Mir has proven to be incredibly valuable for educational and recreational activities. The primary problems observed with the Mir packet system is the limited memory space for messages and the fact that only a single connection can be made at a time. Hams unfamiliar with Mir packet operating practices have been known to lock up the system over an entire pass because the single connection does not time out for approximately 5 minutes. The Terminal Node Controller (TNC) that is being qualified for the ISS transportable station is the PicoPacket TNC from PacComm corporation. PacComm TNCs are also used on board Mir so the user interface for the Mir and ISS systems will be close if not identical. The PicoPacket will also support multiple connections so this should ease some of the problems that have been seen when connecting to Mir.

The ISS Ham initial station will be installed in the Russian Service Module. The service module has no rack space for an amateur radio station, so the station will be attached to the wall using Velcro. A power receptacle has been reserved for the radio station and a Russian power cable has been produced to attach to the service module power receptacle. Our Russian colleagues have installed a total of 4 antenna feedthroughs on the Service Module to support ISS Ham operations. Four antenna systems will be mounted around the periphery of one end of the service module. See Figure 5. These externally mounted antennas (see Figure 6) are being supplied by our Italian colleagues to provide a 4-6 watt voice and packet communication capability.

Approximate Antenna Locations
Figure 5

All these components are to be delivered to the ISS on the 2A.2 logistics flight (STS-101) that is tentatively scheduled for launch in December of 1999. The ISS Ham hardware that will be installed inside the Service Module (radios, packet TNC, etc.) has completed qualification and flight verification testing and has been delivered to the Spacehab team at the Kennedy Space Center. The Spacehab team has loaded the "pressurized module" hardware into the Spacehab module that serves as the hardware stowage facility for the 2A.2 STS-101 mission. The antenna systems and their special adapters and cables are currently under final integration and testing. They too will be transported in Spacehab and then mounted on handrails outside of the Service Module during a spacewalk on STS-101.

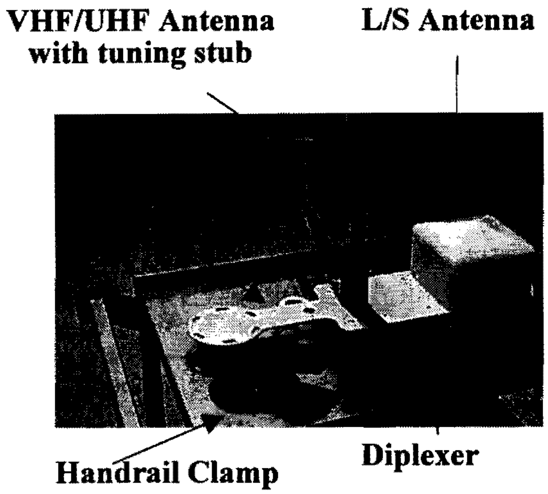
The antenna systems being developed for ISS include a dual band VHF/UHF antenna, a multi-band microwave antenna and a diplexer mounted on a plate that attaches to an Extra Vehicular Activity (EVA) handrail-clamping device. See figures 6-10. A total of four flight antenna systems are being developed. These four antenna systems will attach to the four bulkhead feedthroughs on the Service Module that were made available to the ARISS international team through substantial efforts by Sergej Samburov, RV3DR in Russia.

A high fidelity EVA mockup was developed by the AMSAT-NA/Goddard Amateur Radio Club team in Washington DC. This mockup (see figure 6) and four additional mockups were delivered to Matt Bordelon, KC5BTL, in Houston for EVA training. On one of the four antenna systems, the VHF/UHF dual band antenna will be swapped out with a 2.5 meter HF antenna. In all, the four antenna systems will support amateur radio operations on 20 meters, 15 meters, 10 meters, 2 meters, 70 cm, L-band and S-band.

The VHF/UHF and HF antennas were developed by the ARISS team members in the U.S. They use a flexible measuring tape covered with yellow Kapton as the driven element. A large circular piece of Delrin provides a solid mounting interface and houses the connector and attachment hardware. A tuning stub is mounted below the VHF/UHF antenna to provide maximum efficiency of the antenna system. The design is very robust and has no sharp edges.

Antenna System Mockup
Figure 6

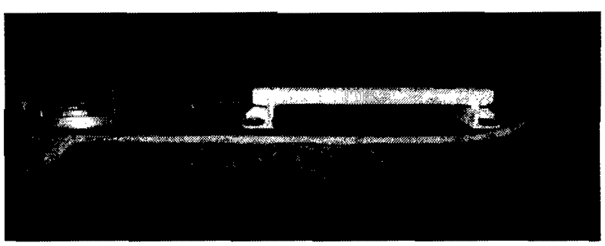
The microwave antenna system, developed by the ARISS members in Italy, will support L-band and S-band operation. Alberto Zagni, I2KBD, and Paolo Pitacco, IW3QBN, are leading the antenna system development in Italy with past coordination by Fabrizio Bernadini. The microwave antenna design chosen by the ARISS team consists of a flat spiral antenna mounted on a printed circuit board that is mounted on an aluminum box that serves as the antenna cavity. A white Delrin radome covers the antenna to protect the antenna from damage and the crewmembers from sharp edges during EVAs. See figures 7 and 11. This antenna is dual use in that it is intended for ham operations and NASA/Energia use. It has been specially designed to serve as the antenna system, which enables the ISS crew to transmit and receive local video during their EVAs using a Glisser television system.



Antenna System Components
Figure 7

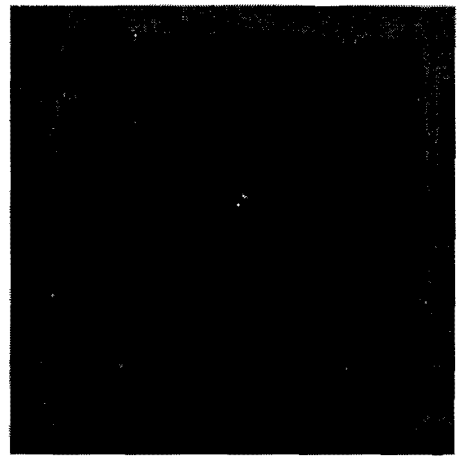
Top view of the EVA handrail clamp adapter
Figure 8

Side view of the EVA handrail adapter
Figure 9



Side view of EVA handrail
Figure 10

The diplexer, designed and developed by the Italians, provides an efficient split in radio signals between the lower frequency (HF/VHF/UHF) antenna and the microwave antenna. The antennas, diplexer, EVA "Clothespin-type" handrail clamp, and the various coax connections will be integrated in the U.S. on an antenna system plate developed by the U.S. team as shown in figure 7.



Microwave (L/S) Antenna
Figure 11

The flight antenna systems are currently being integrated and run through a battery of antenna measurements at the NASA Goddard Space Flight Center, in Greenbelt, Maryland. AMSAT-NA member Ron Parise, WA4SIR is leading a team of hams from Goddard's Microwave Branch in the test activity. Once antenna testing is completed, the four antenna systems will be shipped to the Kennedy Space Center for launch on STS-101.

Initial Station Upgrades

Several upgrades to the ham radio station on ISS are planned. These include upgrades to the initial station, development of a larger, transportable station, installation of the Express Pallet system and the development and installation of the Permanent, Rack mounted system.

Upgrades of the initial station will include a SAFEX supplied digitalker module, a cable for dual band (2-meter/70 cm) operations, a SSTV capability and an RF filter to prevent interference with the Russian communications system using 143.625 MHz. The digitalker speaker-microphone functions as a digital voice memory beacon and was developed by the German SAFEX team members. With this device, the crewmembers can record short messages in the digitalker's memory, and the unit then sends the message as a beacon at specific intervals. The ARISS team expects to launch this hardware on a Shuttle/ISS flight in the year 2000.

In late 2000 to early 2001 there exists an opportunity to place an upgraded transportable station on ISS. This will likely consist of a SAFEX supplied dual band transceiver, digitalker, and packet unit which will provide a more robust dual band capability to support operations until the permanent station can be implemented.

A Permanent Amateur Radio Station on the ISS

Plans for the development of a permanent amateur radio station located in the habitation module have also begun. A set of derived requirements were generated for the permanent station. These are shown below.

Permanent station derived requirements:

- Eight minute contact with well equipped ground station
- Computer to computer radio links
- Thirty second contact with a minimal ground station
- Autonomous beaconing of status in digital form
- Still picture transmit & receive
- Video transmit & receive
- Support continuous contacts (for at least thirty minutes)
- Support multiple concurrent operations
- Space-to-space as well as space-to-ground operations

Based on these requirements, the NASA ISS management were briefed on specific interfaces for the ham station. The briefing suggested 30 kg of hardware in a standard 19-inch wide rack. The rack-mounted system would be 24 inches high and would draw 200 Watts of power. The station includes external antennas, and connections to the ISS audio, video, and computer networks. ISS management thought these requests were quite reasonable. A summary of the hardware described included:

- Multi-band radio support: 10m, 2m, 70cm, & up
- External Omni antennas for voice and low rate data: nadir and zenith
- 5-25 Watts transmit power; 100 Watt for ATV
- Flexible TNCs (probably DSP based)
- Multiple transceiver systems to support concurrent operations
- PC interface to the ISS flight computer systems
- Video processing capability (to support SSTV and ATV)
- Gained antennas for high data rates
- Active station control through the ground
- Pass planning and scheduling software
- Expandability for experimentation

The briefing also suggested external allocations for four "microsat class" payloads that could be changed out. This would allow schools and universities to develop stand alone payloads and not have to worry about attitude control, or power concerns. This allocation has been made on an EXPRESS Pallet scheduled for a flight in 2003. It will be incumbent upon the hardware committee to rapidly formulate plans to effectively utilize this space before it gets reallocated to another project.

Plans for utilizing the externally mounted payload opportunities of the EXPRESS Pallet still need to be generated. The initial EXPRESS Pallet is on the bottom of the ISS so it provides an ideal Earth view for amateur radio operations. Each Pallet can hold six experiment adapters, and ARISS has been allocated half of one of those, to be shared with a Jet Propulsion Laboratory optical communications experiment. Each adapter has a cubic meter of usable volume and a kilowatt of power is available on each EXPRESS Pallet.

Plans for utilizing these resources will come in the form of proposals to the international hardware committee. It will be the responsibility of the international hardware committee to evaluate the technical merit and feasibility of the proposals and generate a final integrated plan for the ISS. Those wishing to review the status of the various ISS hardware proposals are welcome to peruse the world-wide-web site: http://garc.gsfc.nasa.gov/~ariss/ariss.html

Launch windows and configurations of the final permanent station are still being evaluated. Designs will be modular to allow easy replacement of failed components and to allow for upgrades and experimentation. Command station operations will be supported from the ground so that crews will not have to spend valuable time reconfiguring the station.

Conclusions

The historic use of amateur radio on the Space Shuttle and Mir to support educational outreach, crew personal contacts and interaction with terrestrial-based hams will become even more important when the international aerospace community migrates to the International Space Station. The ARISS international partners are working hard to transform the dream of a permanent amateur radio station on the international space station into a reality. The first ARISS hardware, the "Initial Station" has been developed by an international team and is expected to be on-board ISS late this year or very early next year.

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AMSAT Software Should be Free Software

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Abstract:

Unfortunately, much software written by AMSAT members, and virtually all software distributed through AMSAT offices, is either made available in binary-only form, or is encumbered by source licensing terms that dramatically limits the value of the software to the community. In this paper, the author discusses several specific frustrations with the current situation, then presents a case for licensing future AMSAT software as Free software.

Background:

In recent years, the software development community has seen the rise of a significant new development model, popularly referred to as Open Source. This approach to software development is perhaps most visible as the driving force behind the Linux operating system. However, it has much wider implications.

The key concept behind the Open Source movement is Free Software. Just what, exactly, do we mean by "Free Software"? Fundamentally, this means software where the source code is available, not just binary executables. For a more thorough explanation, permit me to quote from a document published by the Free Software Foundation:

> "Free software" is a matter of liberty, not price. To understand the concept, you should think of "free speech", not "free beer."
>
> "Free software" refers to the users' freedom to run, copy, distribute, study, change and improve the software. More precisely, it refers to three levels of freedom:
>
> 1. The freedom to study how the program works and adapt it to your needs.
> 2. The freedom to redistribute copies so you can share with your neighbor.
> 3. The freedom to improve the program, and release your improvements to the public, so that the whole community benefits.

For the purpose of this discussion, there is another point to be made that became particularly apparent during recent Y2K bug remediation efforts. It is vitally important for the longevity of software that the source code not be held in secret. When it is not released to the community, the community cannot recover from the death or loss of interest by the author or company that originated or controls the source code.

The AMSAT Connection:

AMSAT is involved in the creation and distribution of computer software in a number of ways. Many members use computers for predicting orbits, pointing antennas, tuning out Doppler shift, communicating with digital-only satellites, and many other ham and non-ham applications. Satellite developers purchase and develop software that runs on the satellites themselves, and in ground stations used to test and manage spacecraft operations.

Various AMSAT offices are very involved in distributing software. A reportedly significant revenue stream has derived from the practice of accepting modest donations for satellite-related software from members and non-members alike. This software distribution activity is both a valuable service to the community, and a useful way to raise money for building more satellites.

As an organization shepherding software development activities on several levels, and as a software distributor with an opportunity to influence source availability of various programs, I believe AMSAT should take a definite stance on the desirability of AMSAT software development and distribution using the Open Source model.

Some Experiences:

At the meeting in Vicksburg last year, we were treated to a very thorough presentation on the state of various tracking programs relative to the Year 2000 bug. This is the situation where programs were originally written to only use 2-digit years, such that they will be confused about what year it is after 1 January 2000. Some programs were reported to be in good shape, and some were reported to have new versions out or on the way that fixed the problem, but a few very popular programs were reported to not be compliant now... or ever! In the case of an AMSAT tracking program, this may not be an earth-shattering issue, but in the general case, I consider this situation utterly intolerable. If the source code to these programs were available, it would be an easy matter for someone to update them to handle Y2K.

This issue of long-term supportability arises with more issues than just Y2K. One of my neighbors passed away a while back. He authored a small but useful program that is available through AMSAT offices. At his memorial service, I couldn't help but wonder what the state of his source code might be. An old cartoon, I think from the New Yorker, came to mind. In this cartoon a manager was consoling the widow at graveside, with a caption something like "I know this isn't a good time to ask, but did he ever mention source code?" Again, this particular program may not be all that important in the global scheme of things, but the principle bothers me.

Starting with the AMSAT Microsat series, and continuing through Phase-3D RUDAK, the operating system that has flown on virtually every amateur or amateur-like small satellite I am aware of has been SCOS. This kernel and related toolset has been extremely reliable and effective, and NK6K's continuing support of the community is admirable. However, there are some frustrations with the current situation. Due to the history of the kernel, it is available to AMSAT in binary-only form, and ties us to processors in the Intel 80x86 family or compatible processors from NEC, etc. Working with SCOS requires the use of fairly old, and no longer supported, versions of the Microsoft C compiler and tools. We are also very dependent on Harold's interest and availability for any new projects that come along that need a port of SCOS. It is my understanding that some special arrangements have been put in place to insulate AMSAT from the worst possible scenarios should NK6K no longer be available to support SCOS. Despite this, the various issues surrounding SCOS combined with interesting developments in diverse CPU's of possible interest for future satellites motivates us to look for alternatives for the future. I can think of no good reason to ever accept another kernel that fails to comply with the Open Source Definition for an AMSAT project.

As a developer of the Debian GNU/Linux distribution (my other big hobby activity besides amateur radio), I have been frustrated by the baroque licenses that accompany many amateur radio programs that actually do ship with source. These range from a flavor that was once popular permitting use by hams only, through "ok for non-commercial use", to some truly weird restrictions on distribution of modified versions of programs. These weird licenses have made it impossible to include many of these programs in the Debian distribution, despite our strong desire to actively support use of Debian in the ham radio community!

Finally, I've had the experience a number of times in recent times with project articles in QST, and even in the ARRL Handbook, where full design information for the project was freely distributed... except the software source! In some particularly nasty cases, the only way to get the software at all was to buy a "pre-programmed micro-controller" from the author. While I admire the willingness of authors to help out those who can't program a chip by themselves by providing this service, it doesn't do anything for me at all. In virtually every case, I've dreamed up at least one component substitution or minor design change that I want to make before I even finish reading the article! The best examples are projects that use LCD displays. I have a number of displays of various geometries bought surplus that would work fine, except that they don't have the same geometry as the ones the author used. This is almost always completely trivial to handle with source in hand, and virtually impossible otherwise! Another good example is code for the PIC series of micro-controllers. I have various versions in my parts supply, and could almost always make a project work with what I had... if only I could reassemble the sources that were written for a slightly different PIC version! There are signs that the ARRL takes this concern seriously, and I hope AMSAT will do the same.

Observations:

This leads to my first observation. The "Spirit of Experimentation" in ham radio is not just a hardware thing! In fact, with more and more kids growing up with computers, and with the performance of analog to digital conversion systems and CPUs rapidly approaching the point where many radios will become entirely software-defined systems, I anticipate the number of hams wanting to focus their experimentation in the software realm will continue to grow. Why would we publish detailed schematics, mechanical drawings, and theory of operation explanations... but not make the source code for the micro-controller available? A quick look at the proceedings from the last two AMSAT-NA annual meetings makes it clear that software experimentation is a growing part of the contemporary AMSAT experience.

Another observation is that "People Buy Free Software". That isn't really true, because what they're really buying is the distribution and support of free software. This means we don't need to assume that providing source code is going to immediately kill all revenue derived from distributing software through AMSAT offices. Frankly, I think that over time *not* providing source is the real revenue killer! There are many examples of individuals and companies making a steady income by packaging, distributing, and supporting Open Source applications. The example that comes immediately to mind as I am writing this is RedHat, a significant distributor of the Linux operating system and related applications. Their stock just went public, and after one day of trading, the company is valued at over $8 billion... and all they do is develop, distribute, and support software for which the source code is freely distributed! I firmly believe there is still an opportunity for AMSAT to generate revenue for distributing software if we choose to do so, even if and perhaps especially if we provide the source code to everything we sell!

There are an incredibly large number of real-time kernels available today, with all manner of licenses. Two significant Open Source kernels we might consider for future satellite on-board computers are eCos from Cygnus Solutions, and RTEMS from OAR. Both are solid, cross-platform kernels that need only satellite-specific protocol stack and boot-loading functionality to be suitable for our use. And it would be easier to help university teams and others we work with to replicate our work if we were using an Open Source kernel on an equally open development platform!

This is a hobby. Hobbies are supposed to be fun. Most of us have known since we were kids that it's more fun to share. The phenomenal growth in the last year or two of Linux demonstrates just how true this is with software. Even if we only considered the good will generated by including source code with the software we distribute, it would be enough to motivate me personally.

Finally, "we need more participants, not all of whom can afford us". Much is made of the need to grow the worldwide AMSAT membership, often implied through pleas for more "Easy Sats" that can be worked with minimal ground station resources. I submit that there are equally valid cases to be made for making sure that core software for tracking and communicating with digital satellites is available for popular free software operating systems that run on lesser performing computers that might be more easily obtained by these potential members.

Specific Proposals:

I would like AMSAT members to factor into their software procurement decisions the question of whether source code is available or not, and if so, under what terms.

I would like anyone related to AMSAT who is writing software as part of their hobby to distribute their software under license terms compatible with the Open Source Definition, preferably using the GNU General Public License.

While AMSAT has always and should always respect the intellectual property rights of individual software contributors, I would like the AMSAT-NA board to adopt a resolution officially stating that software developed by and for AMSAT in the future should be licensed under terms compatible with the Open Source Definition.

I propose that AMSAT-NA develop and distribute a "Linux for Hams" distribution derived from a subset of the Debian GNU/Linux distribution. The Debian model explicitly supports our doing this. It would capitalize on the growing interest in Linux, could substantially lower the overall system cost of entry for a newcomer to satellite-related computing, and would provide additional software distribution revenue for AMSAT-NA. The distribution would be offered for a nominal fee on CD through the office, and would be 100% compliant with the Open Source Definition. I am willing to lead this effort, and I believe I already have enough expressions of interest from my immediate circle of friends to make it happen.

Conclusions:

The power of the growing Open Source movement is such that the future of proprietary software systems for all except truly niche applications is in grave doubt. Even if you find this hard to believe, the other problems posed by programs that are released without source code in the AMSAT community compel us to consider alternatives for the future.

I believe that AMSAT must choose to embrace the Open Source phenomena. Any other course is counter to our desire to retain a position of relevance in the future of the amateur satellite hobby.

References:

The author wrote a paper on how the Internet and Free Software have influenced AMSAT, presented at the 1997 annual meeting in Toronto, proceedings of which are available through the AMSAT-NA office.

www.opensource.org	The Open Source Definition is found here.
www.spi-inc.org	Software in the Public Interest
www.debian.org	Debian GNU/Linux, the premier Open Source operating system.
www.cygnus.com	The eCos real-time kernel.
www.oarcorp.com	The RTEMS real-time kernel.
www.gnu.org	The Free Software Foundation.

Anatomy of a SETI Hoax

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"We're getting a carrier, all right" confirmed Trevor, barely able to conceal his excitement.

Ken's fingers flew over the keyboard, his eyes never leaving the monitor. "Frequency?" he asked.

"Fourteen seventy one point five," answered Trevor, tweaking the tuning dial on the Icom 7000 receiver. "It's steady at S2. I've marked the local sidereal time. Shall I ring up the BBC?"

"Are you daft, man? Let's not forget the verification protocols! Check for modulation, and be quick about it."

"It's CW -- no, there's sidebands. Looks kind of like modem tones. Low baud."

The two English radio amateurs were manning their radio telescope, much as they had during every spare waking hour for the past three weeks, in search of an intelligent signal from the stars. As UK Co-Coordinators for *Project Argus*, the all-sky survey launched by The SETI League on Earth Day, April 21, 1996, their job was to assist other British hams in building sensitive microwave listening posts. Their 3.5 meter diameter dish and associated electronics were put together as a demonstration station, and now they were demonstrating the patience and deliberation for which their one hundred combined years had uniquely prepared them. They were systematically analyzing an anomaly.

"Doppler's kind of high. Tens of Hertz per minute. I'm betting it's an LEO."

Ken's colleague knew that Low Earth Orbit satellites were the bane of SETI, the scientific Search for Extra-Terrestrial Intelligence. Fortunately, their Doppler shift, a change in radio frequency caused by their motion relative to the Earth, made such man-made sources readily distinguishable from signals of interstellar origin. Still, there was something odd about this particular signal.

The *Argus* concept had been born in the States a year and a half earlier, in response to Congress canceling all of NASA's SETI funding. For just a couple of years, NASA had conducted a modestly funded SETI effort from headquarters at the Ames Research Center in Mountain View, CA. Consuming just one tenth of one percent of NASA's science budget, or about five cents per American per year, NASA SETI promised to be one of the best scientific bargains of all time. Then the budget-balancers axed it, reducing the US national debt in the process -- by point zero zero zero six percent.

A group of American microwave experimenters was not about to let the Search die for lack of intelligence in Washington. Ken and Trevor had heard about their amateur effort at the World Science Fiction Convention in Glasgow the previous summer, and were the first Europeans to sign on. Now their many months of effort and training were being put to the test.

"Save to disk," commanded Trevor unnecessarily, for Ken was already doing so. "Let's get a GIF, and also maybe a WAV file. We're going to have to Internet this one."

The signal amplitude rose smoothly, then fell. "Wow!" exclaimed Ken.

"Let's not be hasty," cautioned Trevor. "I think it's time to *Ask Dr. SETI.*"

It was a moment of great excitement, for this "Wow!" event exhibited many of the characteristics we would expect of an intelligently generated microwave signal from space. Still, restraint was the order of the day. The experimenters sent their signal file to Dr. SETI (that's me.)

The signal looked for all the world to have originated from space, but its Doppler shift (that artifact of relative motion which makes railroad whistles and radio signals alike change in frequency over time) was suggestive of near space. This appeared to be a low Earth orbit satellite which Ken and Trevor had snared. Still, it was a worthy detection, for three reasons:

(1) This was an extremely weak signal, which spoke well for the sensitivity of our participants' homebuilt receiving equipment.
(2) The Doppler shift was instantly evident in the computer printout, which gave us confidence in the capabilities of our signal analysis software.
(3) Most important, our amateur SETIzens did not ring up the Times of London, the BBC, or (heaven forbid!) The Sun (that bastion of journalistic excellence), and proclaim "ET is calling me." Rather, they opted to abide by The SETI League's Signal Verification Protocols, and to *Ask Dr. SETI.* So we had our first solid evidence that nonprofessionals were indeed capable of shunning sensationalism, and conducting credible science.

Presently, I showed an image of the candidate signal to a room full of radio astronomers at the National Radio Astronomy Observatory in Green Bank, WV, home to the world's first SETI search in 1960. One professional observer exclaimed, "You landed that one on 1470.5 MHz, didn't you?"

"How did you know that?" I asked, stunned.

"Oh, we've seen this baby before. She's a classified US Navy satellite."

"Can you tell me more about it?"

"Well, yes, I could," my colleague grinned, "but then I'd have to kill you."

Project Argus continues to detect likely candidate signals, and on analysis, all (so far) have had similarly prosaic explanations. But that doesn't lessen our members' excitement at participating in their peculiar brand of electronic archaeology. So far, all of our Argonauts have exhibited the restraint and professionalism which Ken and Trevor modeled for them early on. Still, there have been claims in the media, about once a year, that SETI has indeed detected the evidence we seek. Four times now The SETI League has had to go public with what most would view as disappointing news.

The first false claim we found it necessary to dispel was a simple matter of mistaken identity. The second involved a statement made at a scientific meeting and taken out of context. The third was a matter of a private email cross-posted to the wrong Internet list. These things happen, and are easily rectified. But when the EQ Pegasi Hoax reared its ugly head, even Dr. SETI began to have doubts.

Two and a half years into our search, an anonymous hacker broke into a private signal verification email list, and made claims of an extraordinary nature. He had, he alleged, detected clear, unambiguous evidence of extra-terrestrial intelligence, while using his employer's ten meter satellite dish after hours. He could not identify himself, he claimed, because that would put his job in jeopardy. But here were email attachments, images showing precisely the kinds of signals we were looking for! For three weeks, SETI League members around the world scrambled to test the claim.

Only, it was a total fabrication. The images posted were testimony to the power of our computer technology. However, it was not the capabilities of any signal analysis software which they demonstrated, but rather those of a graphics program called Paint Shop Pro. The images in question were a cut-and-paste masterpiece, all part of an elaborate hoax to discredit SETI.

And it almost worked. When the press ran stories of the powerful signals from the EQ Pegasi binary star system, detected by an amateur radio astronomer, the public ate it up. The SETI community was thrown into damage-control mode. We pointed out that science cannot be done anonymously, that a credible researcher owns his successes as well as his failures. We mentioned that an admitted hacker (he signed his emails 'anon1420') was more likely to plant a virus than to discover aliens. And we emphasized that these powerful, repeating signals from a nearby star system were seen by but one person, day after day, yet somehow eluded detection by dozens of dedicated radio astronomers around the world.

For that claim, we in SETI were labeled part of the Grand Cover-Up. It was suggested in the tabloids that some nefarious Government conspiracy was at work.

So yes; I admit it: I'm part of the Government conspiracy. I pay taxes.

Meanwhile, we continue to search for proof. Which begs the question, what exactly would constitute incontrovertible proof of extra-terrestrial intelligence? That question is complicated by the fact that the general public (from whom the *Project Argus* constituency is largely drawn) may make only a vague distinction between proof and faith. The spectrum of human skepticism vs. gullibility encompasses a wide range of extremes, characterized by diverse viewpoints ranging from "of course they exist -- we couldn't possibly be alone!" to "I'll believe in the existence of intelligent extra-terrestrials only when one walks up and shakes my hand." We must take pains to prevent such declarations of faith from clouding the judgment of our SETIzens.

We start by acknowledging that one can never conclusively prove the negative, but that it takes only one counter-example to disprove it. Conservative experimental design demands that we frame our research hypothesis in what's called the *null* form: "resolved that there are no civilizations in the cosmos which could be recognized by their radio emissions." Now a single, unambiguous signal is all it takes to disprove the null hypothesis, and negate the notion of humankind's uniqueness.

But what exactly constitutes an unambiguous signal? A popular definition holds it to be one which could not have been produced by any naturally occurring mechanism which we know and understand. But this is an insufficient condition. The first pulsars, after all, fitted that definition. They were first labeled "LGM" for Little Green Man, and their intelligent extra-terrestrial origin seriously considered for several months, until our knowledge of the mechanics of rapidly rotating, dense neutron stars became more complete. There is the risk that any signal which cannot be produced by any known natural mechanism could well have been generated by an astrophysical phenomenon which we have yet to discover. So we need an additional yardstick.

We know *a priori* several of the hallmarks of artificiality which we can expect to be exhibited an electromagnetic emission of intelligent origin. The common denominator of all these characteristics, in fact of all human (and we anticipate, alien) existence, is that they are anti-entropic. Any emission which appears (at least at the outset) to defy entropy is a likely candidate for an intelligently generated artifact. In that regard, periodicity is a necessary, though not a sufficient, condition for artificiality (remembering once again the pulsar).

Ideally, we would hope to receive communication rich in information content, signals which convey otherwise unknown information about the culture which generated them. Unless we are blessed with such a message, we are unlikely to ever achieve absolute certainty that what we have received is indeed the existence proof we seek. Multiple independent observations, however, can do much to dispel the obvious alternative hypotheses of equipment malfunction, statistical anomaly, human made interference, and deliberate hoax. In that respect the development of well coordinated signal verification protocols can do much to narrow our search space. Once again, in signal verification activities, it is the null hypothesis we should be attempting to verify. We thus expect that we will ultimately rule out most candidate signals. There may eventually come a signal, however, which simply cannot be explained away.

"When you have ruled out the impossible," Arthur Conan Doyle wrote in the voice of Sherlock Holmes, "whatever remains, no matter how unlikely, must be the truth." Above all else, this truth must pass the inter-ocular trauma test: when the proof we seek is so powerful as to hit us between the eyes, we can no longer deny it. No Government pronouncement is likely to pass this demanding test, as far as a skeptical public is concerned. But if a diverse, international group of laymen, working independently, can produce multiple, internally consistent observations backed by the corroboration of their professional counterparts, then the world is most likely to accept that group's interpretation as reasonable. SETI continues to seek clear, unambiguous evidence, without even knowing for certain what form that evidence will take. We hope to stumble across the inescapable.

Until we do, we continue to test the null hypothesis.

About The Author

An Extra-class radio amateur first licensed in 1961, N6TX has been operational in all 20 ham bands between 1.8 MHz and 24 GHz. Paul has chaired the VHF/UHF Advisory Committee of the American Radio Relay League, been a Director of the Central States VHF Society and served as Technical Director and Board Chairman of Project OSCAR, Inc. A retired engineering professor, Paul now serves as Executive Director of the nonprofit SETI League, Inc.

Paul's honors include the National Space Club's Robert H. Goddard Scholarship, the American Radio Relay League Technical Achievement Award, a Hertz Foundation Fellowship in the Applied Physical Sciences, the Hertz Doctoral Thesis Prize, and the Central States VHF Society's John T. Chambers Memorial Award. He is a Fellow of the British Interplanetary Society, an FAA Aviation Safety Advisor, serves as a fellowship interviewer for the Hertz Foundation, a manuscript reviewer for several peer reviewed journals, has been an advisor to the National Science Foundation, and is a military program evaluator for the American Council on Education. Paul was Banquet Speaker for several past AMSAT meetings, as well as the 1996 Dayton Hamvention.

Using Point-to-Point Protocol for Satellite Communications

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Section 1 - Introduction

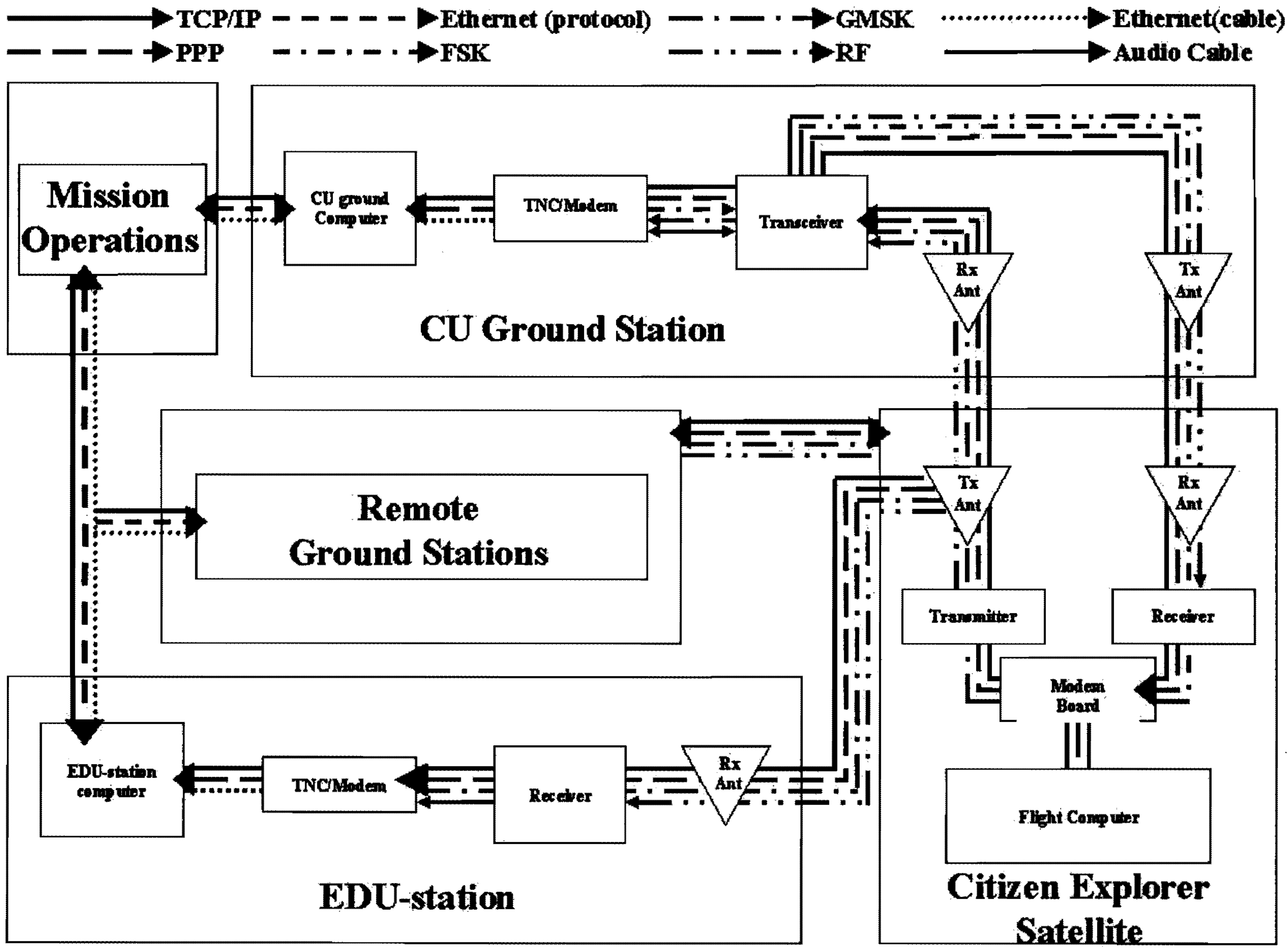
The Citizen Explorer satellite is an educational project that will provide satellite measurements of local ozone and ultraviolet (UV) radiation for students all over the world. The communication system, which provides the link between the spacecraft and Earth, is used for the uplink of commands, downlink of scientific data, and the downlink of engineering data used for monitoring the satellite's health and status. The communication system is composed of three segments: 1) Commanding/data reception ground stations, 2) the flight communications system, and 3) the educational ground stations (EDU-stations) located at participating K-12 schools. Development, integration, and testing of these components are currently under way.

The reported research includes an investigation of using the Point-to-Point Protocol (PPP) in the satellite to ground station link. Terrestrially, PPP is used for the data link protocol layer in serial computer communications. Traditionally, robust protocols have been used for extraterrestrial communications. These robust protocols require a considerable amount of overhead reducing communication efficiency. However, using PPP in extraterrestrial connections will result in an increase in the effective data rate, lower cost for the flight software, and allow a practical communications design, hence the satellite functions simply as a node on a wireless Internet connection. Using a TCP/IP network along with PPP will allow the Citizen Explorer Mission Operations Center (shown top left on the block diagram) easy access to the Citizen Explorer Satellite through remotely located ground stations located in Colorado, Mew Mexico, and Alaska. These remote ground stations will act as gateways between the Mission Operations Center and the satellite. Human intervention at the remote ground stations will not be required during operation. The Citizen Explorer project will offer an excellent operational analysis of protocols used for data communications.

Section 2 - Communication System Components

The Citizen Explorer's primary ground station, located at the University of Colorado at Boulder, is nearing completion. A simplified block diagram of the station is shown top right on the block diagram. This and the other remote stations will be used to transmit commands to the satellite and receive science, health and status information. The station consists of two Cushcraft OSCAR Cross Yagi antennas providing an uplink at 145.860 MHz and a downlink at 436.750 MHz. The satellite's position is predicted by

Communications Block Diagram & Low Protocol Layers



a TAPR "TrackBox" that generates azimuth and elevation positions to a Yaesu G-5400B rotator controller. The rotator controller maintains correct antenna positioning throughout each pass. Radio frequency (RF) transmission and reception is done with a Yaesu FT-736R satellite transceiver, which has been modified to provide data rates up to 9600 bits per second (bps). The realtime orbit simulation program "SatTrack" will be used to adjust the transceivers operating frequencies during each pass for Doppler shift compensation. The ground station computer uses Linux, which includes the necessary software to run PPP as well as a standard set of tools used with TCP/IP networks. Data packets are created by PPP and modulated through a PacComm G3RUH modem/TNC using the Frequency Shift Keying (FSK) modulation scheme. FSK and the RF carrier are the lowest level protocols in the uplink.

The on-board satellite communication system has been financed by the International Foundation for Telemetering through a grant to the New Mexico Space Grant Consortium. The system has been constructed by SpaceQuest, Ltd. The flight system is shown in the bottom right block on the diagram. The modem, connected to the fight computer uses the Gaussian Minimum Shift Keying (GMSK) modulation scheme. The modem has the capability of producing 4 data rates below 19.2Kbps. GMSK is represented in the downlinks of the block diagram. The modem receives packets from a very high frequency (VHF) commercial telemetry/data receiver, modified by SpaceQuest for use in space applications. The receiver interfaces with a 19-inch deployable antenna. A frequency modulated (FM) ultra high frequency (UHF) transmitter, capable of delivering 2 to 5 watts RF output, is connected to an antenna-phasing network providing right-hand polarized transmissions through a canted turnstile antenna array consisting of four 7.5inch elements.

The Citizen Explorer Mission also includes an educational ground station (bottom left on the block diagram) called the EDU-Station. The EDU-Station is a low-cost satellite data receiver designed for K-12 students to easily receive science, health and status data from the Citizen Explorer Satellite. The current EDU-station design is undergoing testing and tradeoff evaluation to optimize the design for a dependable, easy to use, low-cost satellite tracking station. Currently the design consists of a M2 Omni-directional antenna allowing satellite tracking to be accomplished without pointing. The receiver, an Icom PCR1000, is run by computer and provides an easy to use graphical user interface. A SPIRIT-2 demodulates the Satellite data packets and passes the information to an EDU-Station computer. When the EDU-station is actively tracking the Citizen Explorer, an Internet connection to CU will be opened and the new science and health data will be sent directly to CU and archived.

Section 3 - The Protocols

A group of layered protocols are used for computer-to-computer communication. These various protocol layers are classified by their particular purpose. A simplified diagram of the protocol structure for the Citizen Explorer Mission is shown below[i].

Simplified Protocol Structure

	Ground-Ground Communication	Ground-Satellite Communication
Application Layer	Flight Software	Flight Software
Transport Layer	TCP	TCP
Network Layer	IP	IP
Data Link Layer	Ethernet	PPP
Physical Layer	Ethernet/802.3	GMSK/FSK RF carrier

The network and transport protocol layers are identical for ground-ground and extraterrestrial communications. These protocols create a TCP/IP based network interconnecting Citizen Explorer Mission Operations to the satellite through various ground routes. These routes are dependent on the location of the satellite and which ground station is in the satellite's footprint. This network relies on the integrity of the data link protocol, which must endure bit errors produced by the RF link.

The lowest level protocol is the physical layer. As the diagram indicates, Citizen Explorer's network will use Ethernet between terrestrial computers. The extraterrestrial connections will be achieved using GMSK/FSK modulation on a RF carrier. On top of the physical layer is the data link layer. The data link layer must endure data flaws introduced by the physical layer such as packet corruption or network congestion. Ethernet, commonly used for terrestrial communications, is a proven data link protocol and not of concern to the mission. However, many factors of satellite communication may affect the performance of PPP as well as the higher level protocols. Some of these factors include[ii]:

- Noise - A low signal-to-noise ratio may result from a weak RF signal. The outcome is a high bit error rate (BER) in the data stream. The number of correctly received packets reduces as the BER increases. The corrupted packets must be re-transmitted slowing the effective data rate of the link.
- Variable feedback loop - The propagation delay of the satellite channel varies from approximately 2.4 - 10.4 milliseconds over a single pass.
- Intermittent connection - Packet loss may result as the satellite connection is transferred from one ground station to another.
- Delay-bandwidth product (DBP) - The amount of data a protocol should have transmitted but has not yet been acknowledged is critical to maximize the channel capacity and will vary over the course of a pass.

Traditionally, robust protocols such as AX.25 have been used for the Data Link Layer in amateur satellites. By providing a data field limited in size (illustrated in the diagram below[iii,iv]), the chance that each packet will have to be re-sent is reduced. However, the number of packets sent is large and a considerable amount of communication time is lost due to excessive error checking and addressing.

AX.25 Frame Format

	flag	Address	Control	Protocol ID	Data	Frame Check Sequence	flag	Total Bytes (using shortest address)
Bytes:	1	14-70	1	1	0-256	2	1	276

Data Overhead (assuming shortest address): 20 bytes

PPP Frame Format

	flag	Address	Control	Protocol ID	Data	Frame Check Sequence	Total Bytes
Bytes:	1	1	1	2	0-1,500 (default)	2	1,507

Data Overhead: 7 bytes

Accumulated contact time between acquisition of signal (AOS) and loss of signal (LOS) with The Citizen Explorer will net approximately 10 minutes per day. Recognizing that communication time will be lost due to RF and ground delays, an assumption can be made that at least 5 minutes of communication will take place. With a data rate of 9600bps approximately 2.88 million bits are transferred over a five-minute period. In this time AX.25 would transfer approximately 1,304 packets including 208,700 bits of overhead data and 2.671 million bits of data. PPP would transfer approximately 238 packets with 13,378 bits of overhead data and 2.866 million bits of data. A summary of these figures is displayed below. The additional 195,000 million bits of data obtained by using PPP is over a 7% increase. This additional data is greatly desired for communicating as much science data and as many software commands as possible in the limited communication windows.

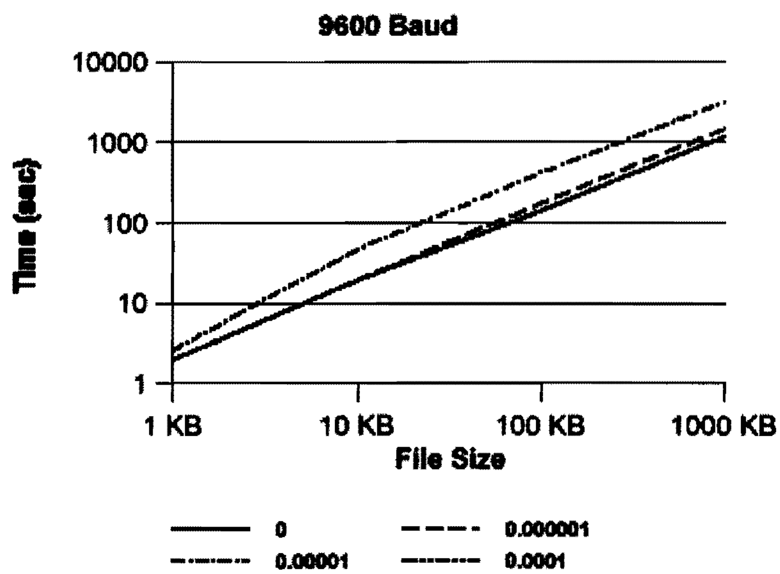
Data Transfer of AX.25 and PPP over a Five Minute Period

Protocol	Total Bits Sent	# Packets Sent	Overhead Bits	Data Bits
AX.25	2.88M	1,304	208,700	2.671M
PPP	2.88M	238	13,378	2.866M

The effect of the satellite link's BER on PPP will result in corrupt packets. In order to have an effective communications system, a reliable stream of non-corrupt packets must be received. Corrupt packets are thrown away by PPP and a packet re-transmission is requested. The effective data rate decreases as the number of corrupt packets increase. If the BER is high enough essentially all packets will contain corrupted data and communication with the satellite will not be possible.

Dr. Stephen Horan and Ru-hai Wang of New Mexico State University have constructed a channel error simulator for testing communication parameters of space protocol links. Currently testing allows simultaneous bi-directional data flow, user-selectable error rates, and unbalanced forward and return transmission rates. Further goals of the project include providing time-variable error rates over several minutes and adding a .25 second channel delay. The results of the BER test is promising for PPP as a space protocol. Using a data rate of 9600bps and the TCP/IP based file transfer protocol (ftp), files containing random text of size 1KB, 10KB, 100KB and 1000KB were transferred between computers with user defined BERs of 0, 10^{-6}, 10^{-5}, and 10^{-4}. Each case was run ten times and the average run time of each transmission was recorded. A graph of the results is displayed below[v].

File Transfer Time vs. File Size for Indicated BER



BER Legend

In general it was not possible to transfer files using a BER of 10^{-4} consequently the file transfer times are not displayed on the graph. However, a BER of 10^{-6} produced results nearly as good as the file transfer run with a BER of 0. As the BER was increased to 10^{-5} the transmission times also increased.

Eric Darnel, of the University of Alaska, has completed a link budget analysis for the Citizen Explorer's command link. The link budget, a theoretical evaluation of the satellite links, includes the expected BER for the Citizen Explorer's communication link. The budget implies that a BER of 10^{-6} is highly realistic.

More robust satellite protocols may not be commonly used. Consequently available software support is limited. Special software may have to be developed which is time consuming and expensive. The Citizen Explorer flight operating system (VxWorks) and the ground station operating systems (Linux) include PPP packages as well as a set of standardized tools such as ftp and telnet. Having these readily available greatly reduces the amount of software written in-house.

Section 4 - Conclusions

"Better, faster, and cheaper," the motto used in today's space industry depicts the potential impact of PPP on space missions. Increased data rates, costs reduction and easy operation of satellites over the Internet can all be accomplished by using the common terrestrial protocol PPP for space applications. This analysis of PPP as a space protocol has demonstrated its ability to transfer considerably larger amounts of data than the amateur satellite space protocol AX.25. Using virtual instrument techniques it has been shown PPP maintains its integrity for BER rates above those generally seen in satellite communications. The Citizen Explorer Communication team will continue testing PPP's capacity as a space protocol throughout the summer and plans on being one of the first space missions to take full advantage of the benefits PPP has to offer.

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[i] Mark A. Miller, P.E. *Troubleshooting TCP/IP,* M & T Books, 1996

[ii] M. Allman, D. Glover, and L. Sanchez. *Enhancing TCP Over Satellite Channels using Standard Mechanisms.* The Internet Society, 1999.

[iii] Omid Mohammadi, Warren Toomey, and Lawnie Brown. *DUAL – A Packet Format for a New Amateur Radio Link Layer.* Department of Computer Science, The University of New South Wales, Australian Defence Force Academy, 1995

[iv] W. Simpson, RFC 1661, *The Point-to-Point Protocol (PPP).* Network Working Group, 1994.

[v] Dr. Stephen Horan and Ru-hai Wang. *Design of a Channel Error Simulator Using Virtual Instrument Techniques.* New Mexico State University Technical Report NMSU-ECE-99-002, 1999.

*Instant*Tune and the FT-847

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Introduction

A major difficulty in operating through satellites, especially *Low Earth Orbit* (LEO) satellites, is in tuning the earth-station receiver and transmitter. Because of the constantly, and often rapidly, changing *Doppler-shift*, determining and maintaining the proper frequency relationships in real-time can be quite challenging.

By automating the radio-tuning task with a computer, operating through satellites can be made dramatically easier. With automatic tuning, a computer can predict the Doppler-shift, calculate the proper up link and down link frequencies, and set the radios to these frequencies.

*Instant*Tune is an automatic radio tuning software package designed to work with AMSAT's *Instant*Track software. When used with the Yaesu FT-847, it allows the operator to use the radio's main tuning knob to tune the receiver while the software automatically sets the transmit frequency and provides Doppler shift compensation on both the receiver and transmitter links.

*Instant*Tune does not require or use any special hardware. It uses standard serial COM ports making it ideal for use with laptop and notebook computers.

Radio Tuning for Satellites

If satellites were not moving, tuning would be straightforward and would be essentially the same as operating through a traditional repeater. Since the satellites *are* moving, the tuning situation is much more complicated. Due to the relative motion of the satellite, a receiver sees a radio signal at a different frequency than that sent by the transmitter on both the up and down radio links. This difference in frequency is called the *Doppler shift.* Since the relative velocity of the satellite is generally different at each earth station, the Doppler-shift is also generally different at each station.

Depending on the transponder frequencies, the Doppler shift can be quite severe. For mode J, LEO satellites, it can be as much as 9 to 10 kHz on the downlink. The rate of change of the Doppler shift can also be quite high. For a mode J, LEO satellite, it can be in the 100 Hertz per second range. Similarly, on mode S or other microwave bands, the Doppler shift may be quite a challenge even for satellites in an elliptical orbit.

Manual Tuning

Ideally, satellite operation should be similar to terrestrial operation in that the stations involved in a contact would pick a transponder down link frequency to use and would stay on that frequency for the duration of the contact. However, this requires maintaining a constant up link frequency *at the satellite.* At the earth station, we do not know the frequencies at the satellite. What's more, it is not easy for a person to calculate the satellite's velocity or Doppler-shift in real-time. But, without some guidance the operators could easily "walk" the frequency all the way up or down the satellite pass-band causing all sorts of interference as they go.

To reduce this frequency drift, a variety of simple tuning rules have been suggested and most stations follow the guideline of *tuning only the highest frequency link* as this results in the smallest frequency drift. On mode A satellites, this means only tuning the *transmitter* whereas on mode J satellites, this means only tuning the *receiver*. Following this guideline helps to *reduce* the frequency drift with a method that is possible for a human operator to manage. It does not eliminate the problem. This leads us to...

The One True Rule for Doppler Tuning

In an article published in the OSCAR Satellite Report, "The One True Rule for Doppler Tuning," Paul, KB5MU, discussed Doppler shift tuning in detail and clarified the issue by describing the only rule that actually properly corrects for Doppler-shift:

> *"Tune both the transmitter and the receiver to achieve a constant frequency at the satellite"*[1]

While it is virtually impossible for a human operator to do this correctly in real-time, it is quite easy to do on a computer. In his article, Paul also introduces the terminology of "transparent" Doppler tuning. The concept was to make tuning satellite contacts much like an ordinary HF contact. That is, the operator tunes the receiver using the receiver's tuning knob and a computer takes care of all of the Doppler shift tuning issues "transparently."

A Brief History of *Instant*Tune

*Instant*Tune was initially inspired by the difficulty of operating the RS-12/13 satellite with a single HF transceiver. When using a HF transceiver, you cannot hear your own down link so setting the transmitter frequency correctly is a big problem. This seemed like the perfect job for a computer. The goal of *Instant*Tune was to make satellite operation easy by implementing "transparent" Doppler tuning. That is, the operator would tune using the radio's front panel knob, and the software does the rest.

The first experimental version of *Instant*Tune for *Instant*Track was completed in September of 1994. In order to prove the concept without having to write a lot of software; the only radios supported in this first release were the Kenwood HF transceivers. These radios have an excellent serial port control interface and to this day are the only ones that can do mode K with a single transceiver (half-duplex of course).. This release had a very limited distribution, only on the AMSAT email reflector (AMSAT-BB,) but the results were very encouraging and proved the idea of "transparent" Doppler tuning.

From 1994 to 1997 a variety of new radio drivers and features were experimented with and sent to AMSAT-BB volunteers to test. Based on these experiments, a version was created that provided support for the most popular radios including the FT-736, Kenwood HF radios, mic-button radios, frequency converters, and a variety of bells and whistles[2]. The author presented the high-level design concepts behind this version of *Instant*Tune at the 1997 AMSAT space symposium[3].

What's Wrong With this Picture?

Because Yaesu was the first company to really address the needs of the serious satellite operator, the FT-736 became, by far, the most popular radio among the satellite *cognoscenti*. However, the FT-736 disables the front panel controls when the Computer-Aided Transceiver (CAT) interface is activated, and this interface does not provide a command for reading the VFO. These problems eliminate the possibility of "transparent" Doppler tuning, as it is impossible to tune the FT-736 with its tuning knob and be under computer control at the same time. The work-around for this is to use the PC keyboard to tune the radio. This works but it is a cumbersome way to tune a radio and clearly fails to achieve the goal of making satellite operation as easy as HF.

On the mode B satellites (AO-10 and AO-13 R.I.P.) with their highly elliptical orbits, the Doppler-shift is not that large and does not change that rapidly for most of a pass. On these satellites, the built-in,

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[1] *The One True Rule for Doppler Tuning*, OSCAR Satellite Report #284, January 1, 1994 by Paul Williamson, KB5MU.

[2] ICOM and TS-790 radio drivers had also been written but were dropped when no AMSAT-BB volunteers could be found to operationally test them.

[3] *An Object-Oriented approach to Automatic Radio Tuning*, Proceedings of the AMSAT-NA 15^{th} Space Symposium, 1997.

VFO tracking function of the FT-736 is much better than using a PC keyboard in spite of not providing automatic Doppler-shift correction. A blow for "transparent" Doppler tuning...

Mic-button radios are even worse. Besides the need to use the PC keyboard to tune, the tuning is painfully slow. In addition, the mic-buttons can only tune one VFO so you can only use it for transmitting or receiving not both.

Overall, to implement automatic tuning, you end up with a complex set of possible radio configurations some of which work well and some of which do not. For example, mode K with a Kenwood radio works nicely and mode A using the Kenwood receiver with the FT-736 as a transmitter works well since you tune using the Kenwood knob. Using VHF/UHF down converters with a Kenwood receiver is another option when combined with the FT-736 as a transmitter. The FT-736 by itself for AO-27 mode J also works well since the downlink is a single channel. On the other hand, using the FT-736 receiver for modes J, B, and T does not work very well, since you have to tune from the PC keyboard.

In addition, to do all these configurations requires several PC COM ports but most PC's come with only one or two so typically one or more switchboxes are also needed to manually set up the radio configuration for each satellite. In addition, it is cumbersome to have to configure *Instant*Tune to specify all of these radio configurations for each satellite transponder. While it works well for some modes and some radios, a lot of effort is needed to get everything set up.

It's too complicated!

Enter the Yaesu FT-847

In 1998, Yaesu released their newest satellite radio, the FT-847, to take over the flagship position from the aging FT-736. The FT-847 has many new features and improvements. It was the first radio to provide a complete HF/VHF/UHF satellite ground station in one box.

Alas, the first release of this radio had the same type of problems with the CAT interface as the FT-736. The CAT protocol provided no way to read the VFO frequency or mode. This time, however, Yaesu listened to the strong negative response from the ham radio community. They upgraded the software in the radio to remedy the major shortcomings in the CAT interface and to their credit, provided free upgrades to buyers of the earlier radios. While there are is still a few minor "gotcha's[4]" in the CAT interface, the FT-847 provides enough capabilities to allow true "transparent" Doppler tuning on all satellite transponder modes in the HF/VHF/UHF bands except mode K.

In May of 1999, a new version of *Instant*Tune was made available for beta test on the AMSAT-BB that added support for the FT-847. It also incorporated several other changes to make getting started much easier. This included pre-configuring the software for the FT-847 on COM 1 for all satellite transponders. If the user wants to use an FT-847 on COM 1, there is no additional configuration. If they want to use COM 2, they need only change the "1" in the configuration file to a "2." The configuration file includes transponder info for all current satellites and uses an easy to read ASCII text format for adding new transponders.

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[4] A few remaining CAT problems:

- The read VFO command reports the front panel frequency after the *clarifier* is applied rather than the true VFO so the *clarifier* function does not work under computer control
- No way to control split mode
- No way to select 1200 versus 9600 BPS packet mode
- No way to control memories
- No error control on serial link

Operating with *Instant*Tune and the FT-847

Operating with *Instant*Tune and the FT-847 is simple! From an *Instant*Track tracking screen, just hit the "r" key on the PC keyboard to start tracking and tuning. *Instant*Tune will set the FT-847 receiver to the proper frequency and mode to monitor the satellite beacon. When you can hear the beacon, just tune the main tuning knob to listen to a station or to find a clear spot in the transponder pass-band. *Instant*Tune will automatically set the transmitter to the proper frequency. You can fine tune the transmit frequency with the sub-band tuning knob to correct for minor errors in the Keplerian elements or your PC's clock. If you select a new receive emission mode, *Instant*Tune will set the transmitter to the appropriate mode depending on the type of satellite transponder.

*Instant*Tune is a DOS TSR and runs in the background. That means that you can start tracking and tuning on a satellite, then exit InstantTrack, and run other DOS programs. This might be useful for running a telemetry decoder like AMSAT's TLMDC software.

When you are done with a pass, hit the "r" key again to stop tracking and tuning. You can then select a new satellite and start again.

Bells and Whistles

*Instant*Tune has many other features and can support sophisticated radio configurations such as dual receivers. The details of configuring and using these features are provided in the *User Guide*, which has been included with this article as an appendix.

Summary

The vision of making satellite operation as easy as HF can finally be realized with *Instant*Tune and the FT-847. Testing of this software has been completed. It has been tested on machines ranging from a 20 MHz 386SX laptop to a 600MHz Pentium III and has been run under both DOS and Windows.

*Instant*Tune is available on the AMSAT web site, www.amsat.org, for download. The software is free for any non-commercial use. Source code is also available for any adventurous souls who would like to add their own radios, port it to other operating systems, or are just curious as to how it works.

*Instant*Tune

Automatic Radio Tuning Software

User's Guide

Version 1.05

aa2tx@amsat.org

***Instant*Tune** works with AMSAT's *Instant*Track software to provide "transparent" Doppler Shift Tuning[5] for satellite operation. This means you just tune your receiver to the desired station or frequency and the ***Instant*Tune software** does the rest, no need to manually correct for Doppler shift or to tune your transmitter.

HOW IT WORKS

With ***Instant*Tune**, you use your receiver's VFO knob to tune in a desired station or frequency. ***Instant*Tune** detects when you are tuning and waits for you to finish. When you stop tuning, it remembers that frequency.

Based on your receiver's frequency, the current satellite velocity, and a satellite configuration file, ***Instant*Tune** calculates the proper up link frequency and tunes your transmitter to that frequency.

About once per second, ***Instant*Tune** re-calculates the up link and down link Doppler shifts and fine-tunes *both* your receiver and transmitter to compensate, maintaining a constant transponder frequency pair at the satellite. This method is superior to manual techniques that tune only the transmitter or receiver. With ***Instant*Tune** you can be sure you are on frequency and not drifting through the satellite pass band.

FEATURES

Sets Transmitter Frequency and Mode

***Instant*Tune** sets your transmitter frequency to track your receiver frequency and sets the proper transmitter modulation mode to track the mode you select on your receiver including opposite side-band selection on inverting transponders.

Doppler Shift Tuning

Once a second, ***Instant*Tune** fine-tunes both your receiver and transmitter to compensate for Doppler shift.

Sets Main Receiver to Satellite Beacon and Mode

When you select a new satellite to track, ***Instant*Tune** sets your receiver to the proper frequency and modulation mode to monitor the beacon while you wait for the satellite to come into range.

Auxiliary Receiver

***Instant*Tune** lets you use a second receiver with automatic tuning and Doppler correction to monitor a second down link from the satellite. This lets you easily monitor both down links on dual transponder satellite or monitor an engineering beacon while using your main receiver to make contacts.

[5] *The One True Rule for Doppler Tuning*, OSCAR Satellite Report #284, January 1, 1994 by Paul Williamson, KB5MU.

Frequency Converters and Transverters

Instant**Tune** supports transmit and receive frequency converters. Both up and down converters may be used.

*Easy to Use with Instant*Track

Instant**Tune** is a DOS TSR program and is a companion to AMSAT's popular *Instant*Track software. Radio tuning is automatically controlled from the *Instant*Track graphics or text satellite-tracking screen. When you select rotor tracking, ***Instant*****Tune** intercepts the messages so it knows which satellite to use with no special pop-up screens. You can use it with or without an antenna rotor. You can even check its status from the *Instant*Track TSR status screen.

Instant**Tune** supports background operation allowing you to exit from InstantTrack and run other DOS programs while continuing to track and tune the satellite.

Easy to Setup and Maintain

Instant**Tune** comes pre-configured for use with the Yaesu FT-847 and current amateur satellites. The configuration file is plain ASCII text making it easy to add satellites as they are launched or to change or add new radios. There is no limit to the number of satellites or transponders and you can configure multiple transponders for each satellite.

No Special PC Hardware

Instant**Tune** uses ordinary PC serial and parallel ports. No special cards or hardware is required making it ideal for use with laptop and notebook computers. ***Instant*****Tune** does not use a floating-point processor either so it will run on older PC's.

Works with Popular Radios Including the New FT-847!

Instant**Tune** supports the new Yaesu FT-847. It also includes support for the Yaesu FT-736, Kenwood HF radios, and mic-button radios[6].

Instant**Tune** allows you to mix and match radios at the same time. For example, you can use a Kenwood TS-450 as a receiver with a Yaesu FT-736 as a transmitter for mode-A satellites.

INSTALLATION

What You Need

- PC/AT class machine with **minimum** x286 CPU, 1 Meg RAM, DOS 5.0. ***Instant*****Tune** will also run in a FULL-SCREEN, DOS window under Windows 3.1, Windows95, or Windows98.
- AMSAT's InstantTrack software package.
- ***Instant*****Tune** installation file "install.exe". This is a self-extracting pkzip file.

Step 1

Copy the ***Instant*****Tune** "install.exe" file to your *Instant*Track directory. This will usually be c:\it. Run "install.exe" from the *Instant*Track directory. The "install.exe" file will unpack itself. Don't worry, "install.exe" will NOT modify your "autoexec.bat" or "config.sys" files or modify your environment. It will add the following files to your *Instant*Track directory:

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[6] Drivers were written for ICOM radios and the Kenwood TS-790. They were not tested and are not supported in this release. The author will entertain requests for these or other radio types.

```
itunetsr.exe    The RadioDRV TSR program
itune.exe       A command-line control program
itune.cfg       The satellite configuration file
itune.doc       This User's Guide
itstart.bat     A batch file to load all TSR's and start InstantTrack
it.pif          Program information file for use with Windows
it.ico          A satellite icon for use with windows
```

Step 2

***Instant*Tune** is pre-configured to use the Yaesu FT-847 on COM 1 for all satellites. If you want to use a different radio or different COM port, you will need to edit the itune.cfg file. This is an ASCII text file so you can use any text editor to change it.

For simple changes, such as a different COM port, follow the directions in the comments in the "itune.cfg" file. To set up more complex configurations, review the commands in the detailed technical reference part of this manual.

Step 3

The order of setting environment variables and loading the TSR programs is critical for proper operation. The environment variables must be set first, then the rotor driver must be loaded, then the OrbitDRV TSR, and finally the ***Instant*Tune** radio driver TSR. After these are loaded, you may start *Instant*Track. Note that the radio driver TSR will refuse to load if it can not find OrbitDRV.

The included batch file "itstart.bat" will do all of this for you, just type "itstart" at the dos prompt. The "itstart.bat" file is set up to run the co-processor version of the *Instant*Track program. If you need to run the no co-processor version, edit the "itstart.bat" file and read the comments in the file for directions.

Similarly, the "itstart.bat" file is set up to use the dummy rotor driver, "dummykct.com," included with *Instant*Track. If you use a real rotor driver, just replace "dummykct.com" with the name of the real driver in the "itstart.bat" file. Congratulations, You have completed installation of ***Instant*Tune**!

Running under Windows

*Instant*Track and ***Instant*Tune** can be run as a DOS session under Windows 3.1, Windows95, or Windows98. **It must be run in a FULL-SCREEN or it will not work correctly**. If you minimize the DOS session, ***Instant*Tune** operation will be suspended. When you switch back to a full screen, satellite tracking and tuning will resume.

To run under Windows, complete the installation for DOS as described above. To run, you can just open a full-screen DOS window and type "itstart."

If you want to be fancy, the included "it.pif" file can be added to your menu bar and you can change the icon using the included file "it.ico" which has an icon resembling a micro-sat. See your Windows manual if you need help doing this.

OPERATION

***Instant*Tune** was specifically designed to work with *Instant*Track. In most cases, you do not have to do anything special to activate radio tuning on a satellite.

To use ***Instant*Tune**, type "itstart" at the DOS command prompt or double-click on the satellite icon. This will load all the required drivers and start *Instant*Track.

Select a Satellite

Choose an *Instant*Track text or graphics real-time tracking screen and select a satellite to track.

Start and Stop Radio Tuning

Type the "r" command from a real-time tracking screen. *Instant*Track will start rotor tracking and ***Instant*Tune** will start radio tuning on the selected satellite. To stop rotor tracking and radio tuning, type the "r" command again.

*Operating with Instant*Tune

When you start tuning with the "r" command, you should see your receiver VFO change to the satellite beacon or digital down link frequency. Then, about a second later, it will retune to correct for the Doppler shift. The receiver should continue to track the beacon or down link frequency unless you manually tune it to another frequency. If you have a transmitter configured, the transmitter VFO will also change to the correct up link frequency.

***Instant*Tune** detects when you re-tune your receiver. Once you have stopped tuning, ***Instant*Tune** will maintain the proper frequency for you by fine tuning the receiver to compensate for Doppler shift.

For satellites with analog transponders, ***Instant*Tune** will tune your transmitter to track your receive frequency and will also adjust the transmit frequency to compensate for up link Doppler shift. ***Instant*Tune** will maintain a constant transponder input-output frequency pair at the satellite. If you change the modulation mode on your receiver, ***Instant*Tune** will automatically set the proper transmitter mode including selecting the opposite sideband on inverting transponders.

For fixed frequency transponders (i.e. AO-27) or digital satellites, ***InstantTune*** tunes your transmitter to the up link frequency and sets the proper modulation mode for the satellite. ***InstantTune*** will fine-tune the transmitter frequency to compensate for the Doppler shift. Although this is not always required, it can help improve the effectiveness of your up link signal. Tuning your receiver or changing the receive modulation mode will not change the transmitter frequency or mode on these satellites.

Due to errors in the published transponder parameters, satellite Keplerian elements, or the frequency accuracy of your radios, you may need to adjust the transmitter or receiver VFOs to bring your transmit and receive signals together. For the FT-847, you use the sub-band tuning knob to adjust the transmit frequency. You cannot use the "clarifier" function. For all other radios, you can use either the receiver independent tuning (RIT) or transmitter independent tuning (XIT) functions.

If you find the signals consistently off-frequency or beyond the range of your RIT/XIT controls for a given satellite, you will want to change the transponder translation constant in the "itune.cfg" file for that satellite. Specific instructions are in the technical reference section.

Checking Tuning Status

Selecting "TSR Status," item 9, on the *Instant*Track main menu shows the status of the RotorDRV and OrbitDRV TSR's. ***Instant*Tune** controls the tuning status of OrbitDRV so it will reflect the current state of radio tuning.

Selecting a Specific Transponder Mode

By default, ***Instant*Tune** selects the first transponder listed for a satellite in the "itune.cfg" file. Since most satellites only have one mode, this is usually sufficient. Some satellites like Phase 3D support many different transponder modes. You can tell ***Instant*Tune** to use a specific transponder mode instead of the default. When you select a specific transponder mode, ***Instant*Tune** saves your selection in a file named "itune.sel." Once you select a specific transponder, it remains selected until you change it, even after you power off your computer. You can reset all transponders of all satellites back to the default by deleting the "itune.sel" file.

Here are the instructions for selecting a specific transponder mode instead of the default:

Step 1

Quit from *Instant*Track putting you back to the DOS prompt.

Step 2

At the DOS prompt type:

```
itune mode SATELLITE MODE  <ENTER>
```

where *SATELLITE* is the name of the satellite and *MODE* is the desired transponder mode. For example, to set RS-12/13 to use mode A, type:

```
itune mode RS-12/13 A  <ENTER>
```

To specifically select the default mode, use the same command without specifying a transponder mode. For example to select the default mode for RS-12/13, type:

```
itune mode RS-12/13 <ENTER>
```

You can set the mode in this way at any time. You do not have to have *Instant*Track running or even have the radio driver TSR loaded.

Step 3

Type "it" at the DOS prompt to re-start InstantTrack. When you start rotor tracking again on the selected satellite, it will use the transponder mode you selected instead of the default. Note that this will not affect any radio tuning that may be already in progress.

Background Tracking and Tuning

Once you have started rotor tracking and radio tuning, they can be run in the background. You can quit from *Instant*Track with tracking and tuning running and run other DOS programs in the same DOS session such as terminal emulators, digital satellite software, or telemetry decoding programs. Note that you CANNOT run Windows programs and have tracking and tuning continue in the background. Tracking and tuning will cease if you change the DOS prompt Window from a full-screen.

OPERATIONAL NOTES FOR SPECIFIC RADIOS

YAESU FT-847

The FT-847 works great with automatic tuning. You just tune using the transceiver's tuning knob and select whatever receiver modulation type you want. ***Instant*Tune** does the rest. You may want to fine tune your transmit frequency initially to compensate for errors in the Keplerian elements. To do this, use the "sub-band" tuning function not the "clarifier" function.

Before starting up ***Instant*Tune**, make sure that the built-in tracking function in the satellite mode is turned off and the receiver VFO is set to the main tuning knob.

The FT-847 does not support mode K satellite transponders.

YAESU FT-736

The CAT interface on the FT-736 is limited; you cannot use computer control and the front panel at the same time. Therefore, ***Instant*Tune** supports the FT-736 by using your PC keyboard to control the receiver VFO. Keyboard control becomes active after you start tracking/tuning from *Instant*Track. This works as follows:

- To enable the keyboard for tuning, turn on <CAPSLOCK>.
- To disable keyboard tuning, turn off <CAPSLOCK>.

Once you have turned on <CAPSLOCK>, the following keys are used to control the radio's RECEIVE frequency:

<RIGHT ARROW>	UP VFO
<LEFT ARROW>	DOWN VFO
<UP ARROW>	UP RIT
<DOWN ARROW>	DOWN RIT

The frequency step size depends on the modulation mode and can be increased by holding down a modifier key. The tuning steps are as follows:

	Main Tuning		RIT	
modifier key	**CW/SSB**	**FM**	**CW/SSB**	**FM**
none	50 Hz	500 Hz	10 Hz	100 Hz
<CTRL>	500 Hz	5 kHz	100 Hz	1 kHz
<SHIFT>	5 kHz	50 kHz	1 kHz	10 kHz
<SHIFT> + <CTRL>	50 kHz	500 kHz	10 kHz	100 kHz

You can set the receive modulation mode by using the following keys:

<F>	FM
<C>	CW
<L>	LSB
<U>	USB

You may need to set the satellite mode VFOs to the proper bands before starting radio tuning or the FT-736 may refuse the CAT commands.

The FT-736 always uses the COM port at 4800 BPS regardless of COM port speed settings in the "itune.cfg" file.

KENWOOD HF Radios

Kenwood HF radios work nicely with ***Instant*Tune**. You just tune the receive VFO using the transceiver tuning knob and select whatever receive modulation type you want. ***Instant*Tune** does the rest. You may want to fine tune your transmit or receive frequency to compensate for errors in the Keplerian elements. To do this, you just use the RIT or XIT controls as you normally would.

***Instant*Tune** has a special tuning algorithm for Kenwood radios that dramatically reduces audio blanking. This allows you to use an unmodified radio to receive digital satellites. Of course, for HF radios you generally would also need to use a down converter.

On the HF radios, this algorithm is disabled if you try to use both the transmitter and receiver at the same time. However, you CAN use a single HF transceiver to operate mode K in split mode (i.e. half-duplex.)

On HF radios, FINE-TUNE is turned ON by ***Instant*Tune** in FM or AM modes and turned OFF in SSB/CW/FSK modes. This is to maintain a 10 Hz tuning step. For proper operation, do not change this setting.

Kenwood radios always use the COM port at 4800 BPS, regardless of COM port speed settings in the "itune.cfg" file.

Mic-Button Radios

Mic-Button radios do not have a CAT interface. However, ***Instant*Tune** can work with these radios by activating the up/down mic-buttons using the PC parallel port. This interface is limited in functionality and user convenience. Mic-button radios can only be used as either a receiver or a transmitter; they cannot be used as both at the same time. When used as a transmitter, Mic-Button radios are a bit slow in tuning but otherwise work fine. For receiving, Mic-button radios can be tuned from the PC keyboard much like the FT-736. This works but is cumbersome!

Keyboard tuning control becomes active if you have configured the radio as a receiver and you start tracking/tuning from *Instant*Track. This works as follows:

- To enable the keyboard for tuning, turn on `<CAPSLOCK>`.
- To disable keyboard tuning, turn off `<CAPSLOCK>`.

Once you have turned on <CAPSLOCK>, the following keys are used to control the radio's RECEIVE VFO:

<RIGHT ARROW>	UP VFO
<LEFT ARROW>	DOWN VFO
<UP ARROW>	UP RIT
<DOWN ARROW>	DOWN RIT

The frequency step default is 100Hz. You can change the default step to anything your radio will support by setting the proper parameter in the "itune.cfg" file. You can tune faster by holding down the shift keys while tuning with the arrow keys. The tuning steps are then multiplied as follows:

key	**STEP**
none	x 1
<CTRL>	x 10
<SHIFT>	x 100
<SHIFT> + <CTRL>	x 1000

You can set the RECEIVE VFO modulation by using the following keys:

<A>	AM
<F>	FM
<C>	CW
<L>	LSB
<U>	USB

This will NOT change the receiver modulation mode of course, as the UP/DOWN buttons cannot do this. This function is used to tell ***Instant*Tune** that you have changed it manually so that the software can properly set the transmitter mode.

To use a mic-button radio, you need to provide an electrical interface from the PC parallel port to your radio. The following leads are used on the parallel port:

FUNCTION	**SIGNAL NAME**	**PIN on DB-25 LPT port**
UP step	DATA 0	2
DOWN step	DATA 1	3
Tuning Complete	DATA 2	4
Signal Ground	GND	18 - 25

All signals are normally LOW (0 Volts) and pulse High (+5 Volts) when active. The PC parallel port signals will directly drive a 6N139 optical coupler when used with a 4.7K Ohm series resistor. The 6N139 outputs will drive most modern radios when tied in parallel with the mic-buttons. Observe the proper polarity. No external power supply is needed.

The "Tuning Complete" signal can be used to drive an LED for a positive visual indication that tuning is complete. When large frequency changes are made, tuning can take several seconds depending on the step size. You can watch your radio's frequency display to see when it stops changing, but the indication is a nice convenience. This signal is set HIGH to directly drive a low power LED when the radio tuning is finished; no external power supply is needed.

No IRQs are used with the parallel port. You may re-use the LPT IRQ for your serial ports if you need them. ***Instant*Tune** supports LPT1, LPT2, and LPT3.

To operate with a Mic-button radio, set the radio to the initial frequency before starting Tracking/Tuning. The initial frequency is the one you configured in the "itune.cfg" file for this radio. Also, be sure to set the step size on the radio to match the step size you selected, 100Hz is the default size. When you start Tracking/Tuning, the radio will start step tuning to set the proper up link or down link frequency. You can "fine-tune" using the radio's tuning dial if needed.

CONFIGURATION

***Instant*Tune** is very flexible and allows you to specify as many different radio setups and as many satellites and transponders as you want. It uses the file "itune.cfg" to tell it about the satellite transponders and about your radio setup. This file is a human-readable, plain old, ASCII text file. You can use whatever text editor you prefer to view or modify it including the one that comes with DOS and Windows called "edit."

As supplied, this file includes information about all satellite transponders that were available when the software was released. As new satellites are launched, you will want to add the transponder information so that you can operate with these new satellites.

Similarly, the supplied "itune.cfg" file specifies a Yaesu FT-847 on COM 1 at 4800 BPS for all satellites. If you just want to change the COM port, you do not need to read this section of the manual. Instead, look at the comments in the "itune.cfg" file. The instructions for changing the COM port are in there. Comments are indicated by a semicolon. Everything on a line after a semicolon is ignored.

It may be helpful to review the supplied "itune.cfg" file before reading the rest of this section. The basic structure of this file consists of an optional COM port configuration section followed by a default radio configuration section followed by the satellite transponder section. You may over-ride the default radio configuration for each transponder.

After you have finished editing the "itune.cfg" file, you can check your work by typing:

```
itune verify
```

at the DOS command prompt. This checks the "itune.cfg" file for proper command syntax.

COM Port Configuration

If you use your radio at its factory default bit rate and on COM ports 1 or 2, you do not need to specify a COM port configuration.

To use COM ports 5 through 12, or if you have changed the default IRQs or I/O Addresses for COM ports 1 to 4, you must specify the COM port configuration so that ***Instant*Tune** can use them.

Due to the nature of the PC architecture, there are some constraints when using COM ports 3 or 4. By default, IRQ 4 is used for COM ports 1 and 3 and IRQ 3 is used for COM ports 2 and 4. However, the PC architecture does not allow IRQ sharing. This means that you cannot use COM 1 and 3 or COM 2 and 4 at the same time. If you can change the COM 3 or 4 port configuration in your PC to use unique IRQs, you can avoid problems with using these COM ports. The LPT2 IRQ is often available for such re-assignment. Otherwise, you will need to select your radio configuration carefully so that you do not use COM 1 and 3 or COM 2 and 4, at the same time. This includes using them for a mouse, TNC, or modem.

For example, if you have HF, VHF, and UHF radios that each need a COM port, you could use COM 1 for HF, COM 2 for VHF, and COM 3 for UHF. That way you can use satellite transponder modes A, B, and J without IRQ conflicts. In this case, you do not need to specify the COM port configuration.

You can put several radios on the same COM port with an A/B switch as long as they are not all active at the same time. To specify a COM port configuration, use the following command:

```
comport PORT RATE IRQ ADDRESS
```

Where:

```
PORT = serial port number 1 to 12
RATE = bit rate; 300 to 19200 BPS is supported
IRQ  = IRQ line 1 to 15
ADDRESS = base address of serial port in hexadecimal
```

To use the default value, set the parameter to 0 (zero.) When you select the default ADDRESS or IRQ, ***Instant*Tune** reads your PC's BIOS to find the values. This will generally work for COM ports 1 to 4 but it will not work on COM ports 5 to 12. The default bit rate is the factory default for the currently active radio. This 4800 BPS for Kenwood and Yaesu radios.

EXAMPLES:

1. Change COM 3 to use IRQ 7, no other changes

```
comport 3 0 7 0
```

2. Add COM 12 using IRQ 15, at address 7fe, default bit rate

```
comport 12 0 15 7fe
```

3. Change COM 1 to use 9600 BPS instead of radio default rate

```
comport 1 9600 0 0
```

Configuring Radios

***Instant*Tune** is very flexible and allows you to specify everything from a single radio for all satellites, to unique radios for each transponder of each satellite.

The command syntax to specify a radio is as follows:

```
COMMAND RADIO PORT {SPECIAL PARAMETERS}
```

The COMMAND values are:

COMMAND	Radio use
rx	receive main transponder
rx2	receive auxiliary transponder
tx	transmit to main transponder
xcvr	receive and transmit to main transponder

The RADIO types and SPECIAL PARAMETERS are:

Manufacturer	Model	RADIO	SPECIAL PARAMETERS
any	mic-button	micbutton	INITIALFREQ STEPSIZE
Kenwood	all HF	kenwood	
Yaesu	FT-736	ft736	
Yaesu	FT-847	ft847	

Notes:

- For mic-button radios, the INITIALFREQ parameter is the frequency that you will set the radio to before starting radio tuning in MHz. For analog transponders, a frequency that is just below the pass-band is a good choice. For digital satellites, the nominal uplink/downlink frequency is a good choice.

- For mic-button radios, the STEPSIZE is the frequency step of the UP/DOWN buttons in Hz. The minimum step size is 1 Hz. The tuning rate is 9 steps per second. A good compromise between speed and precision is 100 Hz step size. If you do not specify this parameter, the default is 100 Hz.

- The PORT parameter is the COM or LPT port number. ***Instant*Tune** accepts COM ports 1 to 12 and LPT ports 1 to 3.

EXAMPLE 1:
Kenwood TS-450 on COM 1 used a receiver

```
rx kenwood 1
```

EXAMPLE 2:
Yaesu FT-847 on COM 2 used as a transceiver

```
xcvr ft847 2
```

EXAMPLE 3:
Mic-button radio on LPT 2 used as a transmitter, initial frequency 145.825 MHz, 100 Hz step size

```
tx micbutton 2 145.825 100
```

Configuring Frequency Converters

You can add frequency converters by using the following commands:

```
rxconverter  TRANSLATION ; receive converter
rxconverter2 TRANSLATION ; receive converter for auxiliary rx
txconverter  TRANSLATION ; transmit converter
```

The frequency TRANSLATION parameter is calculated by **subtracting the antenna frequency from the radio frequency in MHz.** Note that receive up-converters and transmit down-converters will have negative TRANSLATION parameters.

EXAMPLES:
1. Add a 437 to 28 MHz receive down converter

```
rxconverter 409.0
```

2. Add a 144 MHz to 1296 MHz transmit up converter

```
txconverter 1152
```

Setting a Default Radio Configuration

To specify a default radio configuration for all satellite transponders, use the above commands before any satellite transponders in the "itune.cfg" file.

To over-ride the default for a specific transponder, use the above commands directly after the desired transponder configuration in the "itune.cfg" file.

Configuring a Satellite Transponder

To configure a satellite transponder, you need to provide the name of the satellite, the name of the transponder mode, and the specifications for the transponder.

The name of the satellite must match EXACTLY the name in the *Instant*Track satellite database. ***Instant*Tune** uses the *Instant*Track name to find the transponder specification. Thus if the InstantTrack database has a satellite named "RS-12/13" in it, you cannot use "RS-12," you must use "RS-12/13." However, ***Instant*Tune** will ignore the capitalization so the "rs-12/13" will match "RS-12/13." This allows you to use both NASA and AMSAT format Keplerian elements. As with *Instant*Track, satellite names may be up to 20 characters long.

The name of the transponder mode can be any character string up to five characters long. You can use the traditional mode names like "A, B, J, KA, or K/T" or the new mode names created for P3D, such as "V/U" and "L/S." ***Instant*Tune** uses the mode name to uniquely identify the transponder; it does not make any assumptions about the transponder frequencies based on the mode name.

***Instant*Tune** supports linear transponders such as that found on AO-10 as well as fixed frequency transponders such as those on AO-27 or KO-25.

Additionally, ***Instant*Tune** can support a second auxiliary down link. This down link can be used for a fixed frequency such as a beacon or it can be another tracking linear transponder. An example of a tracking linear transponder is RS-12/13 in mode KT. This mode has a 21 MHz up link with a 28 MHz down link and a simultaneous, tracking, 144 MHz down link.

To specify a new satellite transponder name and mode, the following command is used:

```
satellite NAME MODE
```

The keyword "satellite" must be lower-case. The satellite NAME can be up to 20 characters long and the MODE can be up to 5 characters long. If a satellite transponder has only 1 mode, you do not need to specify a MODE.

This is followed immediately in the file by the transponder parameters. To specify the transponder parameters, the following commands are used:

```
transponder TRANSLATION ; linear transponder
transponder2 TRANSLATION ; tracking auxiliary linear transponder
beacon FREQUENCY MODULATION ; beacon for linear transponder
downlink FREQUENCY MODULATION  ; fixed down link
downlink2 FREQUENCY MODULATION ; auxiliary fixed down link
uplink FREQUENCY MODULATION    ; fixed up link
```

Some examples will be helpful:

Linear Non-Inverting Transponder

To specify a linear transponder, use the *transponder* and *beacon* commands. For a non-inverting transponder, the transponder TRANSLATION parameter is the **DIFFERENCE** between the down link and the up link frequencies in megahertz. You can also specify the nominal beacon frequency and modulation mode (am, fm, usb, lsb, cw, fsk.)
The default mode is cw.

Example: RS-12/13 mode A

```
satellite  RS-12/13  A
transponder  116.502
beacon  29.4081  cw
```

Linear Inverting Transponder

To specify a linear transponder, use the *transponder* and *beacon* commands. For inverting transponders, the transponder TRANSLATION parameter is the **SUM** of the down link and the up link frequencies in megahertz followed by the key word "invert." You can also specify the nominal beacon frequency and modulation mode (am, fm, usb, lsb, cw, fsk.) The default mode is cw.

Example: AO-10 mode B

```
satellite  AO-10  B
transponder  581.004 invert
beacon  145.81  cw
```

Fixed frequency Transponder

Fixed frequency transponders have fixed up and down link frequencies. All digital satellites are of this type. To specify a fixed frequency transponder, use the *uplink* and *downlink* commands. After the command word, specify the frequency and modulation mode (am, fm, usb, lsb, cw, fsk) of each link.

Example: AO-27, FM repeater

```
satellite  AO-27
downlink 436.80 fm
uplink 145.85 fm
```

Example: PACSAT AO-16, fm uplink, usb downlink

```
satellite AO-16
downlink 437.0513 usb
uplink 145.9 fm
```

Auxiliary Tracking Linear Transponder

An auxiliary, tracking, linear transponder provides a second down link that tracks the primary down link. This type of auxiliary link can only be used if the primary transponder is a linear type. You use the tuning knob on the main receiver to control the primary down link. The frequency and mode of the second receiver will be set for you by ***Instant*Tune**. To specify an auxiliary tracking linear transponder, use the *transponder2* command. The TRANSLATION parameter is calculated in the same manner as for the *transponder* command.

Example: RS-12/13 mode K/T

```
satellite RS-12/13 KT
transponder -8.2008     ; main transponder, 10 meter down link
transponder2 -124.706   ; auxiliary transponder, 2 meter down link
beacon 29.4081 cw
```

Auxiliary Fixed Transponder

An auxiliary fixed transponder provides a second down link with a fixed frequency and mode. You can use an auxiliary fixed transponder with either a linear or fixed main transponder. This allows you to use a second receiver to monitor a satellite beacon while simultaneously using the main transponder. To specify an auxiliary fixed transponder, use the *downlink2* command followed by the nominal frequency and mode (am, fm, usb, lsb, cw, fsk.) The default mode is cw.

Example: RS-12/13 mode K plus cw robot downlink

```
satellite RS-12/13 K
transponder -8.2008
beacon 29.4081
downlink2 29.454 cw
```

COMMAND LINE CONTROL PROGRAM

The command line program "itune.exe" allows you to control certain aspects of the ***Instant*Tune** driver. The included "itstart.bat" batch file uses it to load the driver. You can use this program if you want to change the default satellite transponder or to verify your "itune.cfg" file after you have edited it. The other commands are provided for debugging and experimentation.

You execute commands one at a time by typing at the DOS prompt:

```
itune COMMAND PARAMETERS <ENTER>
```

The COMMANDs are as follows:

COMMAND	PARAMETERS	Action
		help - lists commands
check		Check radio driver TSR status
debug		prints version number
halt		Stop tuning
load		Load radio driver TSR
mode	SATELLITE MODE	select a specific transponder mode
select	SATELLITE	select a satellite
tune	VELOCITY	tune radios using new VELOCITY
verify		check "itune.cfg" for syntax errors

```
PARAMETER DEFINITIONS:

    MODE        = Satellite transponder mode in "itune.cfg"
    SATELLITE   = Satellite Name in "itune.cfg"
    VELOCITY    = Satellite velocity divided by the speed of light
```

You can get the list of all commands and parameters by typing "itune" with no parameters at the DOS prompt. You can abbreviate commands by typing only the first letter instead of the complete word.

TROUBLESHOOTING

*Instant*Tune *TSR Will Not Load*

***Instant*Tune** uses INT64 by default for its command interface. If another program or driver is using INT64, the "itune.exe" control program will print an error message and ***Instant*Tune** will refuse to load. If possible, change the other program or driver to use a different interrupt. Otherwise you will have to use a different interrupt for ***Instant*Tune**.

To change interrupts, set the environment variable "itcmd" to the desired interrupt in hexadecimal. For example, to set the command interrupt to INT62 use DOS command line:

```
set itcmd=62 <ENTER>
```

Do this before loading ***Instant*Tune**. You can edit the "itstart.bat" file to do this automatically. The instructions are in the "itstart.bat" file.

If you change the ***Instant*Tune** command interrupt, you must also change the OrbitDRV configuration to use this interrupt for radio tuning. See the OrbitDRV documentation for details.

***Instant*Tune** looks for OrbitDRV at INT63 and hooks this interrupt to automatically turn on radio tuning when tracking is enabled. If you use a different interrupt for OrbitDRV, you must set the environment variable "itorb" to the desired interrupt in hexadecimal. For example to set the OrbitDRV interrupt to INT61, use dos command line:

```
set itorb=61 <ENTER>
```

Do this before loading ***Instant*Tune**. You can edit the "itstart.bat" file to do this automatically. The instructions are in the "itstart.bat" file.

Note that *Instant*Track will not work with any OrbitDRV interrupt other than INT63. If you cannot use INT63, you will only be able to use the ITRACK command line program. See the documentation for OrbitDRV for details.

You can prevent ***Instant*Tune** from hooking the OrbitDRV interrupt and prevent automatic tuning control from *Instant*Track by setting the "itorb" environment variable to 0. This can be useful for experimenting.

No Radio Tuning

Check the TSR status, selection 9, from the *Instant*Track main menu. If it shows tuning disabled, it means that ***Instant*Tune** could not communicate with your radio.

- Verify your "itune.cfg" file.
- Check the RS232 cable and connection. This is by far the most common source of problems.
- Check to see that the COM port specified in the "itune.cfg" file matches your actual radio setup.
- Make sure you do not type "itstart" more than once per DOS session. If you type itstart more than once, you will end up with multiple copies of OrbitDRV and RotorDRV TSR's. This will not work and it uses up memory. To restart *Instant*Track from the same DOS session, just type "it."
- Check your "itune.cfg" file, you may have entered the wrong radio type or transponder information. Note that the "itune verify" command only checks for syntax errors, it will not detect an improper configuration.
- Check the operational notes for your radio to see if there is anything special that you need to consider.

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Brian Wruble, W3BW

AMSAT/ARES- A Premise Explored

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THE PREMISE:

Use Amateur Satellites as an adjunct to existing frequencies used by ARES and others interested in public service. There is no specious reasoning here; the facts are well documented.

In no way is this to be construed as an attempt to prescribe operating procedures, or to ordain specific relationships. The fact remains, however, that it is a symbiosis whose time has come. And there are many capable people in both organizations with the experience to accomplish just that.

THE PAST:

There are many documented cases where radio amateurs were the only methods of communication to aid in various emergencies. Radio clubs, ARES, RACES and individuals have all made significant contributions. Ten meters and 75 phone were used extensively for short range assistance, and the bands in between were used for longer ranges. The equipment available was bulky, heavy and power hungry. Dynamotors became available after WWII, and battery operation was possible, but difficult and expensive. They did a remarkable job with what they had available.

THE PRESENT:

FM, SSB, repeaters, solid state, improved batteries and other developments came along to enable portable extended operations. Some of the same frequencies used in the past are still being used for emergency operations and emergency drills. The majority of small area operations now have the advantage of 2 meters, 220, 440 and 1.2, both on simplex and on repeaters.

There are isolated examples of amateur satellites making emergency contacts, but it should cease to become an occasional event. Satellite operations should be woven into the fabric of our existing drills and actual emergencies.

EXISTING SATELLITES CAN BE USED TODAY TO ASSIST IN EMERGENCIES. Satellites are predictable. A two minute exercise on *Instant*Track and other programs gives contact predictions for months ahead, if desired (with the exception of Oscar 10).

Two moderately equipped satellite ground stations, properly spaced in most metropolitan areas, can guarantee delivery of messages outside of an impacted area. Local input to those stations can be by VHF/UHF repeater or simplex, whatever is available.

The fact that a satellite is not immediately available when an emergency occurs has no bearing on the fact that they could be used for emergencies at the present time. If a packet or analog satellite happens to be available, then obviously instant communications in the footprint is possible, by a relay from a site to any satellite station that may be operating in that area.

Instant communications in the impacted area would be best handled by existing facilities: simplex or repeater, depending on what is available.

The need for communications to an area not impacted by the emergency can easily be handled today with satellites that are now operational and with existing equipment that many operators are using today.

Satellite users can skip the following scenario. It is intended for public service interested amateurs that are not familiar with amateur satellite operations. Eighteen low orbit satellites, digital or analog, that make at least 4 usable passes every day with durations of 10 to 22 minutes are now operational. They cover almost every spot on earth, are 100% predictable, and if the two stations are in the footprint, communications is 99% assured. Compare those statistics with those of the frequencies now being used in public service.

A Scenario

The severity of a 7.4 earthquake in San Diego at 1933 on 19 January 2000 made Steve, WB6BDY, stop watering his prize tomatoes and he headed for his satellite station hamshack. An assigned emergency two meter simplex frequency was buzzing with the activity he expected. He dug out a satellite activity prediction previously printed by *Instant*Track

The next one over the horizon, Oscar 16, a digital bird would give him about 13 minutes access starting at 2012. He scribbled a note that the next one in line for San Diego would be FO29, analog mode (A Japanese satellite) and that AOS would be at 2040, about 15 minutes after he lost AO16.

Amazingly, he still had power, but he checked his emergency generator just to make sure...Back in the shack at about 2003 he got the expected request on two meter simplex. La Mesa Sports Center reported some severe casualties in an area with no medical help available, and local hospitals could give no assistance. Their telephone lines were jammed, and they could not reach a repeater.

Steve prepared a packet message requesting help from anyone that could contact an El Centro Hospital for any possible assistance. He promptly uploaded it to AO16 packet at 2014. His message also stated that he would be monitoring FO29's next pass on the assigned emergency downlink frequency of 435.860 SSB receive. After his upload to O16 he set up his equipment for 434.860 receive on FO29.

Randy, N7SFI, in Park City Utah had just finished his Sunday dinner. He heard the news about the quake, and he duplicated Steve's efforts on *Instant*Track. Oscar 16 indicated a mutual pass with San Diego, and he set up immediately to monitor the frequency. At 2018 he received Steve's message. His reply to Steve indicated that his wife was on the phone to El Centro Police, but she was having some problems getting an answer from their medical personnel. He answered Steve's packet message realizing that Steve would not get the message immediately, but this would be an indication to others that he would respond to Steve's request. He then set up for FO29 on 435.860. His AOS on FO29 would be 2028, and at 2030 his message to Steve on SSB indicated that an El Centro emergency team had left for La Mesa at 2022. Nineteen minutes after their initial call for help, La Mesa had assurances that help was on its way. Thank you amateur satellites!

With a minimum of planning that type of an operation is available NOW!

Damage to even the most sophisticated amateur satellite antenna systems can usually be easily repaired, and set up on a 10' pole in the backyard, if necessary.

Portable emergency satellite operations are available right now. Keying a 3 watt HT to a homebrew collinear J-pole on a 8' pole will provide a downlink to a 10 meter receiver connected to an inverted vee on a 15' pole on RS13. The coax and the connectors will cost three times more than the materials to build the antennas! A car battery would last for months. That is not a recommendation for planned emergency operating procedures, but it indicates what can be done. Increase the power to 20 watts, use 2 meter and 70cm radios with homebrewed, inexpensive quadrifilar antennas 8' off the ground and SSB communications can be guaranteed over a 2000 mile radius for a minimum of four 12 minute passes every day. The cost to build these antennas is about equal to the cost of the coax and connectors. All of the equipment will fit in a small car's trunk. With very little briefing, anyone can be taught to use similar equipment. Dozens of ARRL Field Day operators do it every year. These sample operations are but a fraction of those existing right today. Any one of our AMSAT conventions has a parking lot populated with Arrow antennas and potential ARES members on AO-27!

These facts are not new to amateur satellite operators. ARES members and other emergency groups should be made familiar with this potential. The process of informing them would undoubtedly increase their interest in HAMSATS and with a good potential of increasing AMSAT'S membership. Conversely AMSAT members, not presently involved, would take an interest in some phase of public service.

THE FUTURE:

Little imagination is required to appreciate the potential of these operations on Phase 3D. What better way to utilize (read KEEP) our UHF and above frequencies, than by scheduling emergency drills in addition to our casual operating procedures. This would provide usage in addition to justification. Increased satellite EIRP means even smaller antennas and lower power on the ground. Can handheld SSB satellite operations be far off?

Disagree; I learn.

NO-TUNE SSB TRANSCEIVERS FOR 1296, 2304 & 5760MHz

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1. Microwave SSB transceiver design

When discussing SSB transceivers, the first question to be answered is probably the following: does it make sense to develop and build new SSB radios? Today SSB transceivers are mass-produced items for frequencies below 30MHz. There is much less choice on the market for 144MHz or 432MHz SSB transceivers and there are just a few products available for 1296MHz or even higher frequencies.

Most radio-amateurs are therefore using a base SSB transceiver (usually a commercial product) operating on a lower frequency and suitable receive and transmit converters or transverters to operate on 1296MHz or higher frequencies. The most popular base transceiver is certainly the good old IC202. All narrow-band (SSB/CW) microwave activity is therefore concentrated in the first 200kHz of amateur microwave segments like 1296.000-1296.200, 2304.000-2304.200 etc due to the limited frequency coverage of the IC202.

Transverters should always be considered a poor technical solution for many reasons. Receive converters usually degrade the dynamic range of the receiver while transmit converters dissipate most of the RF power generated in the base SSB transceiver. Both receive and transmit converters generate a number of spurious mixing products that are very difficult to filter out due to the harmonic relationships among the amateur frequency bands 144/432/1296...

However, the worst problem of most transverters is the breakthrough of strong signals in or out of the base-transceiver intermediate-frequency band. This problem seems to be worst when using a 144MHz first IF. Strong 144MHz stations with big antenna arrays may break in the first IF even at distances of 50 or 100km. Since the problem is reciprocal, a careless microwave operator may even establish two-way contacts on 144MHz although using a transverter and antenna for 1296MHz or higher frequencies.

Some microwave operators solved the above problem by installing a different crystal in the transverter, so that for example 1296.000MHz is converted to a less used segment around 144.700MHz. Serious microwave contestmen use transverters with a first IF of 28MHz, 50MHz or even 70MHz to avoid the above mentioned problem. Neither solution is cheap. The biggest problem is to carry a large 144MHz or HF all-mode transceiver together with a suitable power supply on a mountaintop.

Even the good old IC202 has its own problems. This radio is no longer being manufactured for more than a decade. New radios can not be purchased while the maintenance of the old ones is becoming difficult. Second-hand radios are usually found in very poor conditions due to the many "modifications" and "improvements" made by their previous owners.

As a conclusion, today it still makes sense to develop and build SSB radios for 1296MHz and higher frequencies. Since the above mentioned problems of the transverters are well known and are not really new, many technical solutions were considered by different designers. Most solutions were discarded simply because too complex, too expensive and too difficult to build, even when compared to the already complex combination of a base RTX and transverter.

Most commercial SSB transceivers include a modulator and a demodulator operating on a high IF, as shown on Fig.1. The resulting SSB signal is converted to the RF operating frequency in the transmitter and back to the IF in the receiver. Both the transmitter and the receiver use expensive components like crystal filters. Besides crystal filters, additional filtering is required in the RF section to attenuate image responses and spurious products of both receiving and transmitting mixers.

The design of conventional (high-IF) SSB transceivers dates back to the vacuum-tube age, when active components (tubes) were expensive and unreliable. Passive components like filters were not so critical. Complicated tuning procedures only represented a small fraction of the overall cost of a vacuum-tube SSB transceiver.

SSB crystal filters usually operate in the frequency range around 10MHz. A double or even triple up conversion is required to reach microwave frequencies in the transmitter. On the other hand, a double or triple down conversion is required in the receiver to get back to the crystal-filter frequency. Commercial VHF/UHF SSB transceivers therefore save some expensive components by sharing some stages between the transmitter and the receiver.

A conventional microwave SSB transceiver is therefore complicated and expensive. Building such a transceiver in amateur conditions is difficult at best. Lots of work as well as some microwave test equipment is required. The final result is certainly not cheaper and may not perform better than the well-known transverter + base RTX combination.

Fortunately, expensive crystal filters and complicated conversions are not essential components of a SSB transceiver. There are other SSB transceiver designs that are both cheaper and easier to build in amateur conditions. The most popular seems to be the direct-conversion SSB transceiver design shown on Fig.2. A direct-conversion SSB receiver achieves most of its gain in a simple audio-frequency amplifier, while the selectivity is achieved by simple RC lowpass filters.

The most important feature of a direct-conversion SSB transceiver is that there are no complicated conversions nor image frequencies to be filtered out. The RF section of a direct-conversion SSB transceiver only requires simple LC filters to attenuate far-away spurious responses like harmonics and sub-harmonics. In a well-designed direct-conversion SSB transceiver, the RF section may not require any tuning at all.

The most important drawback of a direct-conversion SSB transceiver is a rather poor unwanted sideband rejection. The transmitter includes two identical mixers operating at 90 degrees phase shift (quadrature mixer) to obtain only one sideband. The receiver also includes two identical mixers operating at 90 degrees phase shift to receive just one sideband and suppress the other sideband. A direct-conversion SSB transceiver operates correctly only if the gain of both mixers is the same and the phase shift is exactly 90 degrees.

A direct-conversion SSB transceiver therefore includes some critical components like precision (1%) resistors, precision (2%) capacitors, selected or "paired" semiconductors in the mixers and complicated phase-shifting networks. The most complicated part is usually the audio-frequency 90-degree divider or combiner including several operational amplifiers, precision resistors and capacitors. Although using precision components, the unwanted sideband rejection will seldom be better than -40dB. This is certainly not enough for serious work on HF.

In spite of the above mentioned difficulties, direct-conversion designs are quite popular among the builders of QRP HF transceivers. At frequencies above 30MHz it is increasingly more difficult to obtain accurate phase shifts. Due to the low natural (antenna) noise above 30MHz, a low-noise RF amplifier is usually used to improve the mixer noise figure. A LNA may cause direct AM detection in the mixers. A LNA may also corrupt the amplitude balance and phase offset of the two mixers, if the local oscillator signal is picked up by the antenna. A VHF direct-conversion SSB transceiver is therefore not as simple as its HF counterpart.

On the other hand, a direct-conversion SSB design has important advantages over conventional SSB transceivers with crystal filters, since there are no image frequencies and less spurious responses. Professional (military) SSB transceivers therefore use direct conversion, but the AF phase shifts are obtained by digital signal processing. The DSP uses an adaptive algorithm to measure and compensate any errors like amplitude unbalance or phase offset of the two mixers, to obtain a perfect unwanted sideband rejection.

Additional AF signal processing also allows a different SSB transceiver design, for example a SSB transceiver with a zero IF as shown on Fig.3. The latter is very similar to a direct-conversion RTX except that the local oscillator is operating in the center of the SSB signal spectrum, in other words at an offset of about 1.4kHz with respect to the SSB suppressed carrier frequency.

In a zero-IF SSB transceiver, the audio frequency band from 200Hz to 2600Hz is converted in two bands from 0 to 1200Hz. Lowpass filters therefore have a cutoff frequency of 1200Hz, thus allowing a high rejection of the unwanted sideband. A zero-IF SSB transceiver therefore retains all of the advantages of a direct-conversion design and solves the problem of the unwanted-sideband rejection.

The quadrature IF amplifier of a zero-IF SSB transceiver includes two conventional AF amplifiers. Since the latter are usually AC coupled, the missing DC component will be converted in the demodulator in a hole in the AF response around 1.4kHz. Fortunately this hole is not harmful at all for voice communications, since it coincides with a hole in the spectrum of the human voice. In fact, some voice-communication equipment includes notch filters to create an artificial hole around 1.4kHz to improve the signal-to-noise ratio and/or to add a low-baud-rate-telemetry channel to the voice channel. Therefore a potential drawback of a zero-IF design is actually an advantage for voice communications.

Like a direct-conversion RTX, a zero-IF SSB transceiver also requires quadrature transmit and receive mixers. However, amplitude unbalance or phase errors are much less critical, since they only cause distortion of the recovered audio signal. Conventional components, like 5% resistors, 10% capacitors and unselected semiconductors may be used anywhere in a zero-IF SSB transceiver.

Finally, a zero-IF SSB transceiver does not require complicated phase-shifting networks. Both the quadrature modulator in the transmitter and the quadrature demodulator in the receiver (phasor rotation and counter-rotation with 1.4kHz) are made by simple rotating switches and fixed resistor/op-amp networks. CMOS analog switches like the 4051 are ideal for this purpose, rotated by digital signals coming from a 1.4kHz oscillator.

Although the block diagram of a zero-IF SSB transceiver looks complicated, such a transceiver is relatively easy to build. In particular, very little (if any) tuning is required, since there are no critical components used anywhere in the transceiver. In particular, the RF section only includes relatively wideband (10%) bandpass filters that require no tuning. The IF/AF section also accepts wide component tolerances and thus requires no tuning. The only remaining circuit is the RF local oscillator. The latter may need some tuning to bring the radio to the desired operating frequency...

2. Microwave SSB transceiver implementation

The described zero-IF concept should allow the design of simple and efficient SSB transceivers for an arbitrary frequency band. Three successful designs of zero-IF SSB transceivers covering the lower amateur microwave bands of 1296MHz, 2304MHz and 5760MHz will be described in this article. Similar technical solutions were first tested in PSK packet-radio transceivers operating at 1.2Mbit/s in the 23cm and 13cm amateur frequency bands.

Of course several requirements and technology issues need to be considered before a theoretical concept can materialize in a real-world transceiver. Fortunately the requirements are not severe for the lower amateur microwave bands. In this frequency range no very strong signals are expected, so there are no special requirements on the dynamic range of the receiver. Only a relatively limited frequency range needs to be covered (200 to 400kHz in each band) and this can be easily achieved using a VXO and multipliers as the local oscillator.

From the technology point of view it is certainly convenient to use up-to-date components. High-performance and inexpensive microwave semiconductors were developed first for satellite-TV receivers and then for mobile communications like GSM or DECT telephones. These new devices provide up to 25dB of gain per stage up to 2.3GHz and up to 14dB of gain per stage up to 10GHz. Many other functions, like schottky mixer diodes or antenna-switching PIN diodes are also available.

Using obsolete components makes designs complicated. For example, the well known transistors BFR34A and BFR91 were introduced almost 25 years ago. At that time they were great devices providing almost 5dB of gain at 2.3GHz. Today it makes more sense to use an INA-03184 MMIC to get 25dB of gain at 2.3GHz or in other words replace a chain of 5 (five) amplifier stages with the above mentioned obsolete transistors.

The availability of active components also influences the selection of passive components. Many years ago, all microwave circuits were built in waveguide technology. Waveguides allow very low circuit losses and high-Q resonators. Semiconductor microwave devices introduced microstrip circuits built on low-loss substrates like alumina (Al2O3) ceramic or glass fiber-teflon laminates. Conventional glass fiber-epoxy laminates like FR4 were not used above 2GHz due to the high losses and poor Q of microstrip resonators.

However, a zero-IF SSB transceiver design does not require a very high selectivity in the RF section. If the circuit losses can be compensated by high-gain semiconductor devices, cheaper substrates like the conventional glass fiber-epoxy FR4 can be used at frequencies up to at least 10GHz. The FR4 laminate has excellent mechanical properties. Unlike soft teflon laminates, cutting, drilling and hole plating in FR4 is well known. Even more important, most SMD component packages are designed for installation on a FR4 substrate and may break or develop intermittent contacts if installed on a soft teflon board.

Therefore, losses in FR4 microstrip transmission lines and filters were investigated. Surprisingly, the losses were found inversely proportional to board thickness and rather slowly increasing with frequency. This simply means that the FR4 RF losses are mainly copper losses, while dielectric losses are still rather low. FR4 RF copper losses are high since the copper surface is made very rough to ensure good mechanical bonding to the dielectric substrate.

In fact, if the copper foil is peeled off a piece of FR4 laminate, the lower foil surface is rather dark. On the other hand, if the copper foil is peeled off a piece of microwave teflon laminate, the colours of both foil surfaces are similar. Since different manufacturers use different methods for bonding the copper foil, RF losses are different in different FR4 laminates. On the other hand, the dielectric constant of FR4 was found quite stable. Finally, silver or gold plating of microstrip lines etched on FR4 laminate really makes no sense, since most of the RF losses are caused by the (inaccessible) rough foil surface bonded to the dielectric.

A practical FR4 laminate thickness for microwave circuits with SMD components is probably 0.8mm. A 50-ohm microstrip line has a width of about 1.5mm and about 0.2dB/cm of loss at 5.76GHz. Therefore microstrip lines have to be kept short if etched on FR4 laminate. For comparison, the FR4 microstrip losses are about three times larger than the microstrip losses of a glass fiber-teflon board and about ten times larger than the losses of teflon semi-rigid coax cables.

Although FR4 laminate losses are high, resonators and filters can still be implemented as microstrip circuits. Considering PCB etching tolerances and especially under-etching, both transmission lines and gaps in between them should not be made to narrow. A practical lower limit is 0.4mm width for the transmission lines and 0.3mm for the gaps.

A practical 5.76GHz two-resonator bandpass design is shown on Fig.4. The measured insertion loss of 3.5dB is referred to the worst-case, very lossy FR4. A better FR4 could get down to 3dB or even 2.5dB. Although an insertion loss of 3.5dB is rather high for a 10% bandwidth filter, it can easily be recovered with modern high-gain semiconductor devices. For comparison, the insertion loss of a SMD coupling capacitor may be as high as 0.5dB.

As already mentioned, modern semiconductor devices are really easy to use even at microwave frequencies. Silicon MMIC amplifiers provide 25dB of gain (limited by package parasitics) up to 2.3GHz. If less gain is required, conventional silicon bipolar transistors can be used, since their input and output impedances are also close to 50ohms.

GaAs semiconductors are more practical above about 5GHz. In particular, high performance devices like HEMTs became inexpensive since they are mass-produced for satellite-TV receivers. HEMTs operate at lower voltages and higher currents than conventional GaAsFETs, so their input and output impedance are very close to 50ohms at frequencies above 5GHz.

Serious microwave engineers are afraid of using HEMTs since these devices have enough gain to oscillate at frequencies above 50GHz or even 100GHz. In this case it is actually an advantage to build the circuit on a lossy laminate like FR4, since the latter will efficiently suppress any oscillations in the millimeter frequency range. Having the ability to control the loss in a circuit therefore may represent an advantage!

The availability of inexpensive power GaAsFETs greatly simplifies the construction of transmitter output stages. In particular, the high gain of power GaAsFETs in the 23cm and 13cm bands greatly reduces the number of stages when compared to silicon bipolar solutions.

Zero-IF and direct-conversion transceivers have some additional requirements for mixers. Mixer balancing is very important, both to suppress the unwanted residual carrier in the transmitter and to suppress the unwanted AM detection in the receiver. At microwave frequencies, the simplest way of achieving good mixer balancing is to use a sub-harmonic mixer with two anti-parallel diodes as shown on Fig.5.

Such a mixer requires a local oscillator at half frequency. Frequency doubling is achieved internally in the mixer circuit. A disadvantage of this mixer is a higher noise figure in the range 10 to 15dB and sensitivity to the LO signal level. Both a too-low LO drive or a too-high LO drive will further increase the mixer insertion loss and noise figure.

On the other hand, the above mentioned sub-harmonic mixer only requires two non-critical microstrip resonators that do not influence the balancing of the mixer. The best performances were obtained using schottky quads with the four diodes internally connected in a ring. The schottky quad BAT14-099R provides about -35dB of carrier suppression at 1296MHz and about -25dB of carrier suppression at 5760MHz with no tuning.

A very important advantage of the sub-harmonic mixer is that the local oscillator operates at half of the RF frequency. This reduces the RF-LO crosstalk and therefore the shielding requirements in zero-IF or direct-conversion transceivers. A side advantage is that the half-frequency LO chain requires less multiplier stages.

The three zero-IF SSB transceivers for 1296MHz, 2304MHz and 5760MHz have many parts in common. In particular, the AF and IF sections are identical in all three transceivers. The RF sections are similar, however the microstrip filters are necessarily different as well as the low-noise and power devices used in each frequency band. Finally, the same VCXO module is used, with small modifications, in all three transceivers.

Therefore the individual modules will be described first. Of course, similar modules for different frequency ranges will be described together. Finally, an overview of the construction techniques of the individual modules will be given, as well as shielding of the modules and integration of the complete transceivers.

3. VCXO and multipliers

Since a relatively narrow frequency range needs to be covered, a VXO followed by multiplier stages is an efficient solution for the local oscillator. The VXO is built as a varactor-tuned VCXO with a fundamental-resonance crystal, since the frequency-pulling range of overtone crystals is not sufficient for this application. A fundamental-resonance crystal has a lower Q and is less stable than overtone crystals, but for this application the performance is sufficient.

Fundamental resonance crystals can be manufactured for frequencies up to about 25MHz. Therefore the output of the VCXO needs to be multiplied to obtain microwave frequencies. Frequency multiplication can be obtained by a chain of conventional multipliers including class-C amplifiers and bandpass filters or by a phase-locked loop.

Although the PLL requires almost no tuning and is easily reproducible, the PLL solution was discarded for other reasons. A SSB transceiver requires a very clean LO signal, therefore the PLL requires buffer stages to avoid pulling the VCXO and/or the microwave VCO. Shielding and power-supply regulation are also critical, making the whole PLL multiplier more complicated than a conventional multiplier chain.

The circuit diagram of the VCXO and multiplier stages is shown on Fig.6. The VCXO is operating around 18MHz in the transceivers for 1296MHz and 2304MHz and around 20MHz in the transceiver for 5760MHz. All multiplier stages use silicon bipolar transistors BFX89 (BFY90) except the last stage with a BFR91. The module already supplies the required frequency of 648MHz for the 1296MHz version of the transceiver.

In the 2304MHz version, the module supplies 576MHz by using different multiplication factors. The latter frequency is doubled to 1152MHz inside the transmit and receive mixer modules. In the 5760MHz version, the module supplies 720MHz and this frequency is further multiplied to 2880MHz in an additional multiplier module. Of course, the values of a few components need to be adjusted according to the exact operating frequency, shown in () brackets for 2304MHz and in [] brackets for 5760MHz.

The VCXO and multiplier chain are built on a single-sided FR4 board with the dimensions of 40mmX120mm as shown on Fig.7. The corresponding component location (for the 648MHz version) is shown on Fig.8. The exact value of L1 depends on the crystal used. Some parallel-resonance crystals may even require replacing L1 with a capacitor. L2 and L3 have about 150nH each or 4 turns of 0.25mm copper-enamelled wire on a 10X10mm IF-transformer coil-former. L4 and L5 are self-supporting coils of 4 turns of 1mm copper-enamelled wire each, wound on an internal diameter of 4mm. L6, L7, L8 and L9 are etched on the PCB.

The VCXO module is the only part of the whole transceiver that requires tuning. L2, L3 and the capacitors in parallel with L4, L5, L6, L7, L8 and L9 should simply be tuned for the maximum output at the desired frequencies. In a multiplier chain, RF signal levels can easily be checked by measuring the DC voltages over the BE junctions of the multiplier transistors.

When the multiplier chain is providing the specified output power, L1 and the capacitor in parallel with the MV1404 varactor should be set for the desired frequency coverage of the VCXO. If standard "computer grade" 18.000MHz or 20.000MHz crystals are used, it is recommended to select the crystal with the smallest temperature coefficient.

Unfortunately not all amateurs are allowed to use the international segment around 2304MHz on 13cm. It is a little bit more difficult to find a crystal for 18.125MHz for the German segment around 2320MHz.

The 5760MHz transceiver requires an additional multiplier from 720MHz to 2880MHz as shown on Fig.9. The first HEMT ATF35376 operates as a quadrupler while the second HEMT ATF35376 operates as a selective amplifier for the output frequency of 2880MHz. The additional multiplier for 2880MHz is built on a double-sided microstrip FR4 board with the dimensions of 20mmX120mm as shown on Fig.10. The corresponding component location is shown on Fig.11.

The 2880MHz multiplier should provide the rated output power of +11dBm without any tuning. On the other hand, the tuning of L8 and L9 to 720MHz in the VCXO module can be optimized for the minimum DC drain current (max DC voltage) of the first HEMT. The two red LEDs are used as 2V zeners. LED's are in fact better than real zeners, since they have a sharper knee and do not produce any avalanche noise.

4. SSB/CW quadrature modulator

The main purpose of the SSB/CW quadrature modulator is to convert the input audio frequency band from 200Hz to 2600Hz into two bands 0 to 1200Hz to drive the quadrature transmit mixer. Additionally the module includes a microphone amplifier and a circuit to generate the CW signal. The circuit diagram of the modulator module is shown on Fig.12.

The microphone amplifier includes two stages with the transistors BC238. The input is matched to a low-impedance dynamic mike with the 33ohm resistor. The 1N4007 diode protects the input in the case the microphone input is simply connected in parallel to the loudspeaker output. Finally the output drives an emitter follower with another BC238.

The CW carrier is generated in the same way as the SSB transmission. The 683Hz square wave, coming from the demodulator module, is first cleaned in a low-pass audio filter and then processed in the same way as a SSB signal. Both AF modulation sources are simply switched by 1N4148 diodes.

The main component of the modulator is the 4051 CMOS analog switch. The switch is rotated with the 1365Hz, 2731Hz and 5461Hz clocks coming from the demodulator. The input audio signal is alternatively fed to the I and Q chains. The I and Q signals are obtained with a resistor network and the first four op-amps (first MC3403). Then both I and Q signals go through lowpass filters to remove unwanted mixing products. Finally there are two voltage followers to drive the quadrature transmit mixer.

The SSB/CW quadrature modulator is built on a single-sided FR4 board with the dimensions of 40mmX120mm as shown on Fig.13. The corresponding component location is shown on Fig.14. Most components are installed vertically to save board space. The SSB/CW quadrature modulator does not require any alignment. The 4.7kohm trimmer is provided to check the overall transmitter. Full power (in CW mode) should be obtained with the trimmer cursor in central position.

5. Quadrature transmit mixers

All three transmit mixer modules for 1296MHz, 2304MHz and 5760MHz include similar stages: a LO signal switching, an in-phase LO divider, two balanced sub-harmonic mixers, a quadrature combiner and a selective RF amplifier. LO signal switching between the transmit and receive mixers is performed in the following way: most of the LO signal is always fed to the receive mixer. A small fraction of the LO signal is obtained from a coupler and amplified to drive the transmit mixer. During reception the power supply of the LO amplifier stage is simply turned off. This solution may look complicated, but in practice it allows an excellent isolation between the transmit and receive mixers. The practical circuit is simple and the component count is low as well.

The circuit diagram of the quadrature transmit mixer for 1296MHz is shown on Fig.15. The 648MHz LO signal is taken from a -20dB coupler and the LO signal level is restored by the BFP183 amplifier stage, feeding two sub-harmonic mixers equipped with BAT14-099R schottky quads. The 648MHz lowpass attenuates the second harmonic at 1296MHz to avoid corrupting the symmetry of the mixers.

The two 1296MHz signals are combined in a quadrature hybrid, followed by a 1296MHz bandpass filter. The latter removes the 648MHz LO as well as other unwanted mixing products. After filtering the 1296MHz SSB signal level is rather low (around -10dBm), so an INA-10386 MMIC is used to boost the output signal level to about +15dBm.

The quadrature tansmit mixer for 1296MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX120mm as shown on Fig.16. The corresponding component location is shown on Fig.17. The circuit does not require any tuning for operation at 1296MHz or 1270MHz.

The circuit diagram of the quadrature transmit mixer for 2304MHz is shown on Fig.18. The 576MHz LO signal is taken from a -20dB coupler, amplified by the BFP183 transistor and then doubled to 1152MHz by the BFP196 transistor. The doubler output goes through a microstrip bandapss filter to feed the two sub-harmonic mixers with BAT14-099R schottky quads.

The two 2304MHz signals are combined in a quadrature hybrid, followed by a 2304MHz bandpass filter. The latter removes the 1152MHz LO as well as other unwanted mixing products. After filtering the 2304MHz SSB signal level is rather low (around -11dBm), so an INA-10386 MMIC is used to boost the output signal level to about +10dBm.

The quadrature transmit mixer for 2304MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX120mm as shown on Fig.19. The corresponding component location is shown on Fig.20. The circuit does not require any tuning for operation at 2304MHz or 2320MHz. For operation in the satellite band above 2400MHz, the LO bandpass should be readjusted to 1200MHz by shortening L7 and L8 at their hot ends.

The circuit diagram of the quadrature transmit mixer for 5760MHz is shown on Fig.21. The 2880MHz LO signal is taken from a -15dB coupler and the LO signal level is restored by the ATF35376 amplifier stage, feeding two sub-harmonic mixers equipped with BAT14-099R schottky quads. The 2880MHz lowpass attenuates the second harmonic at 5760MHz to avoid corrupting the symmetry of the mixers.

The two 5760MHz signals are combined in a quadrature hybrid, followed by a 5760MHz bandpass filter. The latter removes the 2880MHz LO as well as other unwanted mixing products. After filtering the 5760MHz SSB signal level is rather low (around -14dBm), so two amplifier stages with ATF35376 HEMTs are used to boost the output signal level to about +11dBm.

The quadrature transmit mixer for 5760MHz is built on a double-sided microstrip FR4 board with the dimensions of 30mmX120mm as shown on Fig.22. The corresponding component location is shown on Fig.23. The circuit does not require any tuning for operation at 5760MHz.

The quadrature transmit mixers do not supply any output signal when the modulation input is absent. For transmitter testing purposes it is possible to obtain an output signal by feeding a DC current of 2-10mA into one or both mixers.

6. RF front-ends

The RF front-ends include the transmitter power amplifiers, the receiver low-noise amplifiers and the antenna switching circuits. Of course there are major differences among different power amplifier designs, depending not just on the frequency, but also on the technology used and the output power desired. On the other hand, it no longer makes sense to use expensive coaxial relays, since PIN diodes can provide the same insertion loss and isolation at lower cost with better reliability and much shorter switching times.

The circuit diagram of the RF front-end for 1296MHz is shown on Fig.24. The transmitter power amplifier includes a single stage with a CLY5 power GaAsFET, providing a gain of 15dB and an output power of about 1W (+30dBm). The CLY5 is a low-voltage transistor operating at about 5V.

The negative gate bias is generated by rectification of the driving RF signal in the GS junction inside the CLY5 during modulation peaks. The gate is then held negative for a few seconds thanks to the 1uF storage capacitor. To prevent overheating and destruction of the CLY5, the +5VTX voltage is obtained through a current-limiting resistor. This arrangement may look strange, but it is very simple, requires no adjustments, allows a reasonably linear operation and most important of all, it proved very reliable in PSK packet-radio transceivers operating 24 hours per day in our packet-radio network.

The antenna switch includes a series diode BAR63-03W and a shunt diode BAR80. Both diodes are turned on while transmitting. L9 is a quarter-wavelength line that transforms the BAR80 short circuit into an open for the transmitter. The receiving preamplifier includes a single BFP181 transistor (15dB gain) followed by a 1296MHz bandpass filter (-3dB loss). In the 1296MHz RF front-end, the LNA gain should be limited to avoid interference from powerful non-amateur users of this band (radars and other radio-navigation aids).

The RF front-end for 1296MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX80mm as shown on Fig.25. The corresponding component location is shown on Fig.26. The RF front end for 1296MHz requires no tuning. However, since the output impedance of the INA-10386 inside the transmit mixer is not exactly 50ohms, the cable length between the transmit mixer and the RF front-end is critical. Therefore L1 may need adjustments if the teflon-dielectric cable length is different from 12.5cm.

The circuit diagram of the RF front-end for 2304MHz is shown on Fig.27. The transmitter power amplifier includes two stages: a BFP183 driver and a CLY2 final amplifier. The additional BFP183 driver is required since the gain and output power of the INA-10386 inside the transmit mixer are smaller at 2304MHz than at 1296MHz. Further the additional bandpass filter at the input of the power amplifier adds some insertion loss.

The BFP183 operates as a class-A amplifier while the CLY2 is used in a similar self-biasing arrangement like the CLY5 in the 1296MHz front-end. Of course the drain current of the CLY2 is smaller, the +5VTX current-limiting resistor must be higher and the RF output power on the antenna connector amounts to about 0.5W (+27dBm). The PIN-diode antenna switch is identical to that used in the 1296MHz RF front-end with a series diode BAR63-03W and a shunt diode BAR80.

Since there are no powerful users of the 2.3GHz band, the RF front-end for 2304MHz includes a two-stage LNA: a HEMT ATF35376 in the first stage and a BFP181 in the second stage. The overall gain of the LNA is around 23dB. Since the Idss of the ATF35376 is usually around 30mA, no negative voltage needs to be applied to the gate.

The RF front-end for 2304MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX80mm as shown on Fig.28. The corresponding component location is shown on Fig.29. The RF front-end for 2304MHz should require no tuning, since both the transmit and the receive chains have a few dB of gain margin. However, in order to squeeze the last milliwatt out of the CLY2 (is it really necessary?), some tuning may be attempted on the output.

The circuit diagram of the RF front-end for 5760MHz is shown on Fig.30. The transmit power amplifier uses two HEMTs ATF35376 in parallel to obtain about 100mW (+20dBm) on the antenna connector. The gain of the HEMTs is around 13dB, however circuit losses both in the input matching network and in the antenna switch on the output amount to about 3dB, so that about +10dBm of drive power is required.

The two PA HEMTs receive a positive bias on the gates both while transmitting and while receiving. In transmission the PA HEMTs generate a self-bias just like the CLY5 and CLY2 power GaAsFETs. Of course the +4VTX supply line requires a current-limiting resistor.

The antenna switch includes a single shunt diode BAR80 to protect the receiver input during transmission. During reception, the two PA HEMTs act as short circuits thanks to the positive gate bias. The short circuit is transformed through package parasitics, L5, L6 and interconnecting lines (total electrical length ¾ lambda) into an open circuit at the summing node.

Since the shunt diode BAR80 was not designed for operation above 3GHz, its capacitance introduces additional insertion loss in the receiving path at 5.76GHz. This additional loss can be substantially reduced if a reverse bias is applied to the BAR80 diode. Therefore a negative bias voltage is applied to the BAR80 during reception and a positive current is applied during transmission through the command line +-PIN.

Since there are no strong signals expected in the 5.7GHz band, the LNA for 5760MHz includes two stages with ATF35376 HEMTs. The total insertion gain including the losses in the antenna switching network and the two 5760MHz bandpass filters amounts to about 23dB.

The RF front-end for 5760MHz is built on a double-sided microstrip FR4 board with the dimensions of 30mmX80mm as shown on Fig.31. The corresponding component location is shown on Fig.32. The RF front-end for 5760MHz requires no tuning. It is however recommended to select the ATF35376 HEMTs according to the Idss. The highest Idss devices should be used in the transmitter PA while the lowest Idss devices should be used in the receiver LNA.

7. Quadrature receive mixers

All three receiving mixer modules for 1296MHz, 2304MHz and 5760MHz include similar stages: an additional RF signal amplifier, a quadrature-hybrid divider, two sub-harmonic mixers, an in-phase LO divider and two IF preamplifiers. The mixers, in-phase and quadrature dividers and RF bandpass filters are very similar to those used in the transmitting mixer modules.

The circuit diagram of the quadrature receiving mixer for 1296MHz is shown on Fig.33. The incoming RF signal is first fed through a microstrip bandpass filter, then amplified with an INA-03184 MMIC and further filtered by another, identical microstrip bandpass. The total gain of the chain of the two filters and the MMIC is about 20dB.

A high gain in the RF section is required to cover the relatively high noise figure of the two sub-harmonic mixers and the additional losses in the quadrature hybrid. The two receiving sub-harmonic mixers are also using BAT14-099R schottky quads. The mixer outputs are fed through lowpass filters to the IF preamplifiers.

The IF preamplifiers are using HF transistors BF199. These were found to perform better than their BC... counterparts in spite of the very low frequencies involved (less than 1200Hz). HF transistors have a smaller current gain, their input impedance is therefore smaller and better matches the output impedance of the mixers. Both IF preamplifiers receive their supply voltages from the IF amplifier module.

The quadrature receiving mixer for 1296MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX120mm as shown on Fig.34. The corresponding component location as shown on Fig.35. The receiving mixer for 1296MHz requires no tuning.

The circuit diagram of the quadrature receiving mixer for 2340MHz is shown on Fig.36. Since the same components, INA-03184 MMIC and BAT14-099R schottky quads, have similar performances in the 1296MHz and 2304MHz frequency bands, the circuit diagram of the 2304MHz mixer is almost identical to the 1296MHz mixer.

The only difference is the additional frequency doubler to 1152MHz with the transistor BFP196. The multiplier includes a lowpass on the input and a bandpass filter on the output. The input lowpass filter should prevent unwanted interactions with other circuits operating with the same 576MHz LO signal. The 1uH choke should have a ferrite core for the same reason.

The quadrature receiving mixer for 2304MHz is built on a double-sided microstrip FR4 board with the dimensions of 40mmX120mm as shown on Fig.37. The corresponding component location is shown on Fig.38. The receiving mixer does not require any tuning for operation on 2304MHz or 2320MHz. For operation in the satellite band above 2400MHz, the LO bandpass should be readjusted to 1200MHz by shortening L26 and L27 at their hot ends.

The circuit diagram of the quadrature receiving mixer for 5760MHz is shown on Fig.39. Since a component with the gain comparable to the INA-03184 is not available for 5.7GHz, two RF amplifier stages are required to obtain about 20dB of gain. ATF35376 HEMTs are used in both RF amplifier stages. Otherwise the circuit is almost identical to the quadrature receiving mixer for 1296MHz.

The quadrature receiving mixer for 5760MHz is built on a double-sided microstrip FR4 board with the dimensions of 30mmX120mm as shown on Fig.40. The corresponding component location is shown on Fig.41. The receiving mixer for 5760MHz requires no tuning.

8. SSB zero-IF amplifier with AGC

The basic feature of direct-conversion and zero-IF receivers is to achieve most of the signal gain with simple and inexpensive AF amplifiers. Further, the selectivity is achieved with simple RC lowpass filters that require no tuning. The circuit diagram of such an IF amplifier equipped with AGC is therefore necessarily different from conventional high-IF amplifiers.

A zero-IF receiver requires a two-channel IF amplifier, since both I and Q channels need to be amplified independently before demodulation. The two IF channels should be as much identical as possible to preserve the amplitude ratio and phase offset between the I and Q signals. Therefore both channels should have a common AGC so that the amplitude ratio remains unchanged.

The circuit diagram of the quadrature SSB IF amplifier with AGC is shown on Fig.42. The IF amplifier module includes two identical lowpass filters on the input, followed by a dual-amplifier stage with a common AGC. An amplitude/phase correction is performed after the first amplifier stage, followed by another pair of lowpass filters and another dual-amplifier stage with a common AGC.

The two input lowpass filters are active RC filters using BC238 emitter followers. Discrete bipolar transistors are used because much less noisy than operational amplifiers. The input circuit also provides the supply voltage to the IF preamplifiers inside the receiving mixer module through the 1.5kohm resistors.

The dual-amplifier stages are also built with discrete BC238 bipolar transistors. Each amplifier stage includes a voltage amplifier (first BC238) followed by an emitter-follower (second BC238) essentially to avoid mutual interactions when the amplifiers are chained with other circuits in the IF strip.

The AGC is using MOS transistors as variable resistors on the inputs of the dual-amplifier stages. To keep the gain of both I and Q channels identical, both MOS transistors are part of a single integrated circuit 4049UB. The digital CMOS integrated circuit 4049UB is being used in a rather uncommon way, however the remaining components inside the 4049UB act just as diodes and do not disturb the operation of the AGC.

The IF amplifier module includes two trimmers for small corrections of the amplitude balance (10kohm) and phase offset (250kohm) between the two channels. The correction stage is followed by two active RC lowpass filters using operational amplifiers (MC3403), since the signals are already large enough and the operational-amplifier noise is no longer a problem. Finally there is another, identical dual-amplifier stage with its own AGC.

The quadrature SSB IF amplifier is built on a single-sided FR4 board with the dimensions of 50mmX120mm as shown on Fig.43. The corresponding component location is shown on Fig.44. In order to keep the differences between the I and Q channels small, good quality components should be used in the

IF amplifier. Using 5% resistors, 10% foil-type capacitors and conventional BC238B transistors should keep the differences between the two channels small enough for normal operation. Most components are installed vertically to save board space.

The amplitude balance (10kohm) and phase offset (250kohm) trimmers are initially set to their neutral (central) position. These trimmers are only used while testing the complete receiver to obtain the minimum distortion of the reproduced audio signal.

9. Quadrature SSB demodulator and AF amplifier

The main function of the quadrature SSB demodulator is the conversion of both I and Q IF signals (frequency range 0 to 1200Hz) back to the original audio frequency range from 200Hz to 2600Hz. The same module includes a power AF amplifier and a clock generator for both the phasor rotation in the transmitter and the phasor counter-rotation in the receiver. The circuit diagram of the module is shown on Fig.45.

The quadrature SSB demodulator includes four operational amplifiers (MC3403) to produce an 8-phase system from the I and Q signals, using a resistor network similar to that used in the modulator. The signal demodulation or phasor counter-rotation is performed by the CMOS analog switch 4051, rotating with a frequency of 1365Hz. The I and Q signals are alternatively fed to the output or in other words the circuit performs exactly the opposite operation of the modulator.

Unwanted mixing products of the phasor counter-rotation are removed by an active RC lowpass (BC238). The demodulated audio signal is fed to the 100kohm volume control. A LM386 is used as the audio power amplifier due to its low current drain and small external component count.

The three clocks required to rotate both 4051 switches in the modulator and in the demodulator are supplied by a binary counter 4029. The 4029 includes an up/down input that allows the generation/demodulation of USB or LSB in this application. The up/down input has a 100kohm pull-up resistor for USB operation. LSB is obtained when the up/down input is grounded through a front-panel switch.

USB/LSB switching is usually not required for terrestrial microwave work. USB/LSB switching is only required when operating through satellites or terrestrial linear transponders or when using inverting converters or transverters for other frequency bands. Finally, USB/LSB switching may be useful to attenuate interference during CW reception. An alternative way of USB/LSB switching is interchanging the I and Q channels. When assembling together the modules of the described transceivers one should therefore check the wiring so that the transmitter and the receiver operate on the same sideband at the same time.

The 4029 counter requires an input clock around 11kHz. This clock does not need to be particularly stable and a RC oscillator could be sufficient. In the described transceivers a crystal source was preferred to avoid any tuning. In addition, if all transceivers use the same rotation or counter-rotation frequency, the mutual interferences are reduced.

The crystal oscillator is using a clock crystal operating on a relatively low frequency of 32768Hz. The dual D-flip-flop 4013 divides this frequency by 3 to obtain a 10923Hz clock for the 4029 binary counter. The resulting rotation frequency for the 4051 switches is 1365Hz. The latter figure almost perfectly matches the hole in the frequency spectrum of human voice. The same 4029 counter also supplies the CW tone 683Hz to reduce the unwanted mixing products in the transmitter.

The quadrature SSB demodulator and AF amplifier are built on a single-sided FR4 board with the dimensions of 40mmX120mm as shown on Fig.46. The corresponding component location is shown on Fig.47. Most of the components are installed vertically to save board space.

The 32768Hz crystal oscillator will only operate reliably with a 4011UB (or 4001UB) integrated circuit. The commonly available "B" series CMOS integrated circuits (4011B in this case) have a too-high gain for this application. In the latter case a 560pF capacitor may help to stabilize the oscillator. On the other hand, the oscillator circuit usually works reliably with old 4011 or 4001 circuits with an "A" suffix or no suffix letter at all.

10. SSB/CW switching RX/TX

A SSB/CW transceiver requires different switching functions. Fortunately both SSB and CW modes of operation require the same functions in the receiver. Of course two different operating modes are required for the transmitter:

SSB voice and CW keying.

The RX/TX changeover is controlled by the PTT switch on the microphone in the SSB mode of operation. In the CW mode of operation, most transceivers use an automatic delay circuit to keep the transmitter enabled during CW keying. This delay circuit was perhaps required in old radios using several mechanical relays. In modern transceivers with all electronic switching it makes no sense, since the RX/TX switching can be performed in less than one millisecond.

It therefore makes sense that SSB transmission is enabled by simply pressing the PTT switch while CW transmission is enabled by pressing the CW key so that no special (and useless) controls are required on the front panel of the transceiver. In the CW mode of operation, no delays are required and the receiver is enabled immediately after the CW key is released ("BK" mode of operation).

The circuit diagram of the SSB/CW switching RX/TX is shown on Fig.48. In the described SSB/CW transceivers, most modules are enabled at all times with a continuous +12V supply: VCXO and multipliers, receiving mixer, IF amplifier, demodulator and modulator. When enabling the transmitter either by pressing the PTT or CW keys, the RX LNA is turned off (+12VRX) and the TX PA is turned on (+12VTX and +5VTX or +4VTX).

During SSB transmission the RX AF amplifier is turned off (+12VAF), to avoid disturbing the microphone amplifier (+12VSSB). On the other hand, during CW transmission the AF amplifier remains on as well as most receiver stages, so that CW keying can be monitored in the loudspeaker or phones. The +12VCW supply connects the 683Hz signal to the modulator input.

The supply voltages +12VAF, +12VSSB, +12VCW and +12VRX are switched by BC327 PNP transistors. Due to the higher current drain, the +12VTX supply voltage requires a more powerful PNP transistor BD138. The TX PA receives its supply voltage through a current-limiting resistor from the +12VTX line. Since the latter dissipates a considerable amount of power, it is built from several smaller resistors and located in the switching unit to prevent heating the PA transistor(s).

The value of the current-limiting resistor depends on the version of the transceiver. The 1296MHz PA with a CLY5 requires 8 pieces of 33ohm 1/2W resistors for a total value of 16.5ohms. The 2304MHz PA with a CLY2 requires 4 pieces of 33ohm 1/2W resistors for a total value of 33ohms. Finally, the 5760MHz PA with two ATF35376s requires a single 82ohm 1W resistor.

The switching module also includes the circuits to drive the front-panel meter. The latter is a moving-coil type with a full-scale sensitivity of about 300uA. The meter has two functions. During reception it is used to check the battery voltage. The 8V2 zener extends the full scale of the meter to the interesting range from about 9V to about 15V.

During transmission the meter is used to check the supply voltage of the PA transistor(s). Due to the self-biasing operation, the PA voltage will be only 0.5-1V without modulation and will rise to its full value, limited by the zener diode inside the PA, only when full drive is applied. The operation of the PA and the output RF power level can therefore be simply estimated from the PA voltage.

An S-meter is probably totally useless in small portable transceivers as those described in this article. If desired, the AGC voltage can be amplified and brought to a front-panel meter. However, one should not forget that LED indicators are not visible in full sunshine on a mountaintop, so the choice is limited to moving-coil and LCD meters.

Most components of the SSB/CW switching RX/TX are installed on a single-sided FR4 board with the dimensions of 30mmX80mm as shown on Fig.49. Their location (1296MHz version) is shown on Fig.50. Only the reverse-polarity protection diode 1N5401 and the 470uF electrolytic capacitor are installed directly on the 12V supply connector. The 10kohm trimmer is used to adjust the meter sensitivity.

The 5760MHz version of the SSB/CW transceiver requires an additional PIN diode driver to provide a negative bias to the BAR80 PIN diode during reception. The corresponding circuit diagram is shown on Fig.51. The negative voltage is obtained from the 5461Hz clock, while the BC327 PNP transistor applies a positive voltage during transmission.

The PIN driver is built on a small FR4 board with the dimensions of 23mmX20mm as shown on Fig.52. The corresponding component location is shown on Fig.53. The whole PIN driver module is then installed piggy-back on the demodulator board, using as support the 5-pole connector carrying the clocks to the modulator.

11. Construction of zero-IF SSB transceivers

The described zero-IF SSB transceivers are using many SMD parts in the RF section. SMD resistors usually do not cause any problems, since they have low parasitics up to at least 10GHz. On the other hand, there are big differences among SMD capacitors. For this reason a single value (47pF) was used anywhere. The 47pF capacitors used in the prototypes are NPO type, rather large (size 1206), have a self-resonance around 10GHz and introduce an insertion loss of about 0.5dB at 5.76GHz. Finally, the 4.7uF SMD tantalum capacitors can be replaced by the more popular tantalum "drops".

Quarter-wavelength chokes are used elsewhere in the RF circuits. In the 5760MHz transceiver all quarter-wavelength chokes are made as high-impedance microstrips. On the other hand, to save board space in the 1296MHz and 2304MHz versions, the quarter-wavelength chokes are made as small coils of 0.25mm thick copper-enamelled wire of the correct length, chosen according to the frequency: 12cm for 648MHz, 9cm for 23cm mixers (648/1296MHz), 7cm for 1296MHz and for L3 on Fig.18, 5.5cm for 13cm mixers (1152/2304MHz) and 4cm for 2304MHz. The wire is tinned for about 5mm on each end and the remaining length is wound on an internal diameter of about 1mm.

The SMD semiconductor packages and pin-outs are shown on Fig.54. Please note that due to lack of space, the SMD semiconductor markings are different from their type names. Only the relatively large CLY5 transistor in a SOT-223 package has enough space to carry the full marking "CLY5". The remaining components only carry one-, two- or three-letter marking codes.

All of the microstrip circuits are built on double-sided 0.8mm thick FR4 glass fiber-epoxy laminate. Only the top side is shown in this article, since the bottom side is left un-etched to act as a ground-plane for the microstrips. The copper surface should not be tinned nor silver or gold plated. The copper-foil thickness should be preferably 35um.

Since the microstrip boards are not designed for plated-through holes, care should be taken to ground all components properly. Microstrip lines are grounded using 0.6mm thick silver plated wire (RG214 central conductors) inserted in 1mm diameter holes at the marked positions and soldered on both sides to the copper foil.

Resistors and semiconductors are grounded through 2mm, 3.2mm and 5mm diameter holes at the marked positions. These holes are first covered on the ground-plane side with pieces of thin copper foil (0.1mm). Then the holes are filled with solder and finally the SMD component is soldered in the circuit.

Feed-trough capacitors are also installed in 3.2mm diameter holes in the microstrip boards and soldered to the ground-plane. Feed-through capacitors are used for supply voltages and low-frequency signals. Some components like bias resistors, zeners and electrolytic capacitors are installed on the bottom side (as shown on the component-location drawings) and connected to the feed-through capacitors.

The VCXO/multiplier module and all of the microstrip circuits are installed in shielded enclosures as shown on Fig.55. Both the frame and the cover are made of 0.4mm thick brass sheet. The printed-circuit board is soldered in the frame at a height of about 10mm from the bottom. Additional feed-through capacitors are required in the brass walls. RF signal connections are made using thin teflon-dielectric coax like RG-188. The coax braid should be well soldered to the brass frame all around the entrance hole. Finally the frame is screwed on the chassis using sheet-metal screws.

The covers are kept in place thanks to the elastic brass sheet, so they need not be soldered. An inspection of the content is therefore possible at any time. The VCXO/multiplier module is built on a single-sided board and therefore requires both a top and a bottom cover. The remaining modules are all built as microstrip circuits, so the microstrip ground-plane acts as the bottom cover and only the top cover is required.

The sizes and shapes of the microstrip circuit boards are selected so that no resonances occur up to and including 2880MHz. Microwave absorber foam is therefore only required in the three modules operating at 5760MHz. To avoid disturbing the microstrip circuit, the microwave absorber foam is installed just below the top cover.

The modules of a zero-IF SSB transceiver are installed in a custom-made enclosure as shown on Fig.56. The most important component is the chassis. The latter must be made of a single piece of 1mm thick Al sheet to provide a common ground for all modules. If a common ground is not available, the receiver will probably self-oscillate in the form of "ringing" or "whistling" in the loudspeaker, especially at higher volume settings.

The chassis carries both the front and back panels as well as the top and bottom covers. All of the connectors and commands are available on the front panel. The later is screwed to the chassis using the components installed: CW pushbutton, SMA connector, meter and tuning helipot. The top and bottom cover are made of 0.5mm thick Al sheet to save weight and are screwed to the chassis using sheet-metal screws.

The shielded RF modules are installed on the top side of the chassis where a height up to 32mm is allowed. The audio-frequency bare printed-circuit boards are installed on the bottom side of the chassis. The interconnections between both sides of the chassis are made through five large-diameter holes.

The location of the modules of the 1296MHz or 2304MHz transceiver as well as the location of the connectors and commands on the front panel are shown on Fig.57 for both sides of the chassis. The 5760MHz transceiver has different RF modules, so the corresponding module location is shown on Fig.58. The location of the connectors and commands is the same for all three transceivers.

The loudspeaker should not be installed inside the transceiver, since the RF receiving modules are quite sensitive to vibrations. On the other hand, the same loudspeaker may also be used as a dynamic microphone for the transmitter. The circuit is designed so that it allows a simple parallel connection of the loudspeaker output and the microphone input. The PTT and CW keys are simple switches to ground.

12. Checkout of zero-IF SSB transceivers

The described SSB/CW transceivers for 1296MHz, 2304MHz and 5760MHz do not require much tuning. The only module that really requires tuning is the VCXO/multiplier. The latter is simply tuned for the maximum output on the desired frequency. Of course, the desired coverage of the VCXO has to be set with a frequency counter.

After the VCXO/multiplier module is adjusted, the remaining parts of the transceiver require a checkout to locate defective components, soldering errors or insufficient shielding. The receiver should already work and some noise should be heard in the loudspeaker. The noise intensity should drop when the power supply to the LNA is removed. The noise should completely disappear when the receiving mixer module is disconnected from the IF amplifier. A similar noise should be heard if only one (I or Q) IF channel is connected.

Next the receiver is connected to an outdoor antenna far away from the receiver and tuned to a weak unmodulated carrier (a beacon transmitter or another VCXO/multiplier module at a distance of a few ten meters). Tuning the receiver around the unmodulated signal one should hear both the desired tone and its much weaker mirror-image tone changing its frequency in the opposite direction. The two trimmers in the IF amplifier should be set so that the mirror tone disappears. The correct function of the USB/LSB switch can also be checked.

Finally, the shielding of the receiver should be checked. A small, handheld antenna (10-15dBi) is connected to the receiver and the main beam of the antenna is directed into the transceiver. If the noise coming from the loudspeaker changes, the shielding of the local oscillator multiplier chain is insufficient.

Next a mains-operated fluorescent tube (20W or 40W) is turned on in the same room. A weak mains hum should only be heard when the handheld antenna is pointed towards the tube at 2-3m distance. If a clean hum without noise is heard regardless of the antenna direction, the shielding of the local oscillator multiplier chain is insufficient.

The transmitter should be essentially checked for the output power. The full output power should be achieved with the trimmer in the modulator in a middle position in CW mode. The DC voltage across the PA transistor should rise to the full value allowed by the 5.6V or 4.7V zener diode. The output power should drop by an equal amount if only I or only Q modulation is connected to the transmit mixer.

Finally the SSB modulation has to be checked with another receiver for the same frequency band or best in a contact with another amateur station at a distance of a few km. This is the simplest way to find out the correct sideband, USB or LSB, of the transmitter, since the I and Q channels can be easily interchanged by mistake in the wiring.

The residual carrier level of the transmit mixer should also be checked. Due to the conversion principle this carrier results in a 1365Hz tone in a correctly-tuned SSB receiver. The carrier suppression may range from -35dB in the 1296MHz RTX down to only -20dB in the 5760MHz RTX. A poor carrier suppression may be caused by a too high LO signal level or by a careless installation of the BAT14-099R mixer diodes. Note that the residual carrier can not be monitored on another correctly-tuned zero-IF receiver, since it falls in the AF response hole of the zero-IF receiver.

The current drain of the described transceivers should be as follows. Receivers: 1296MHz:105mA, 2304MHz:175mA and 5760MHz:300mA. The current drain of the transmitters is inversely proportional to the output power due to the self-biasing of the PA. The minimum current drain corresponds to SSB modulation peaks or CW transmission. Transmitters:

1296MHz:650-870mA, 2304MHz:490-640mA and 5760MHz:410-440mA. All figures are given for a typical sample at a supply voltage of 12.6V.

At the end, one should understand that zero-IF transceivers also have some limitations. In particular, the dynamic range of the receiver is limited by the direct AM detection in the receiving mixer. If very strong signals are expected, the LNA gain has to be reduced to avoid the above problem. This is already done in the 1296MHz receiver, since strong radar signals are quite common in the 23cm band. The sensitivity to radar interference of the described zero-IF 1296MHz transceiver was found comparable to the conventional transverter + 2mRTX combination.

On the other hand, the 2304MHz and 5760MHz transceivers have a higher gain LNA. If the dynamic range needs to be improved, the second LNA stage can simply be replaced with a wire bridge in both transceivers. Of course, the internal LNA gain has to be reduced or the LNA has to be completely eliminated if an external LNA is used.

List of figures:

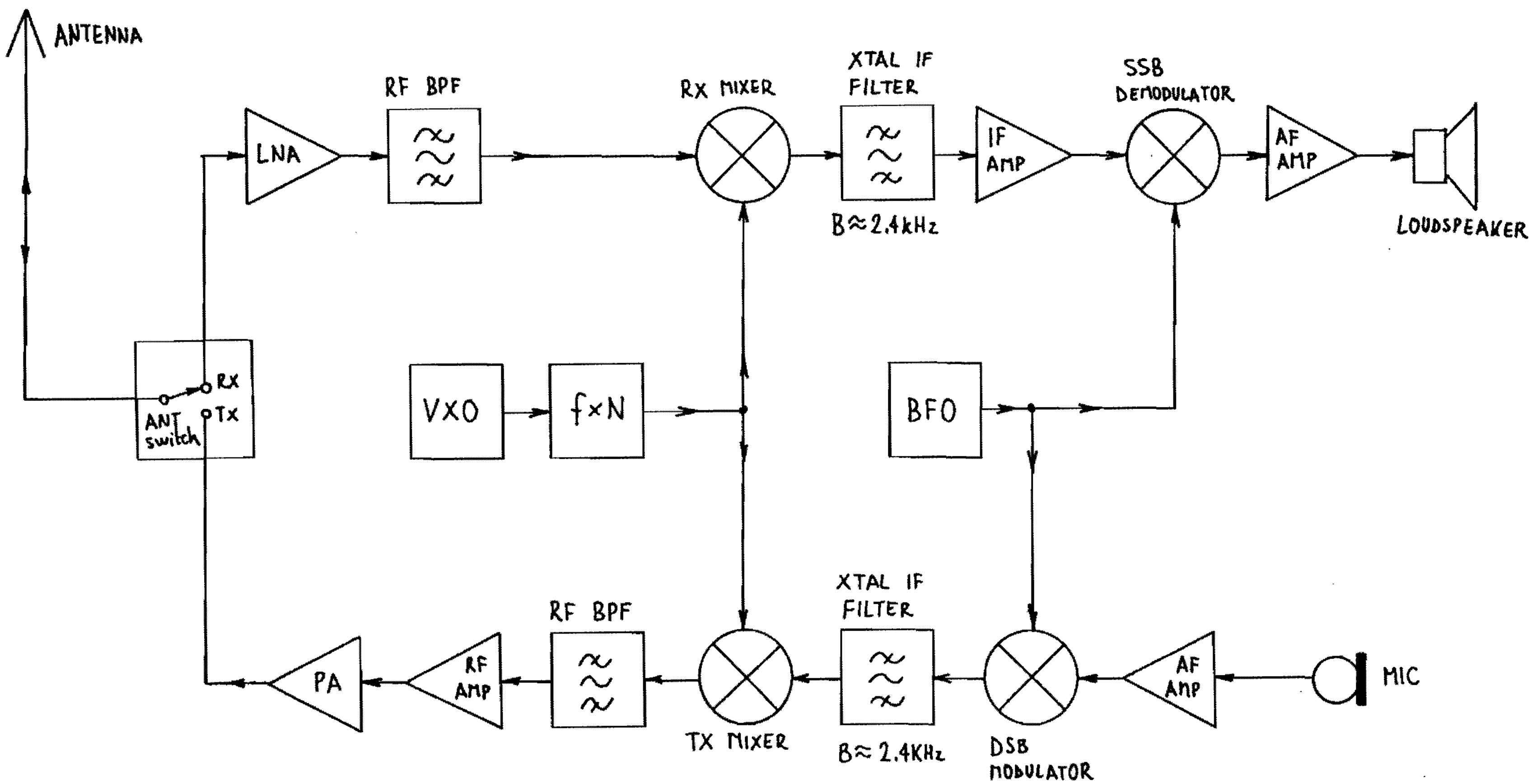


Fig. 1 - Conventional (high-IF) SSB transceiver design.

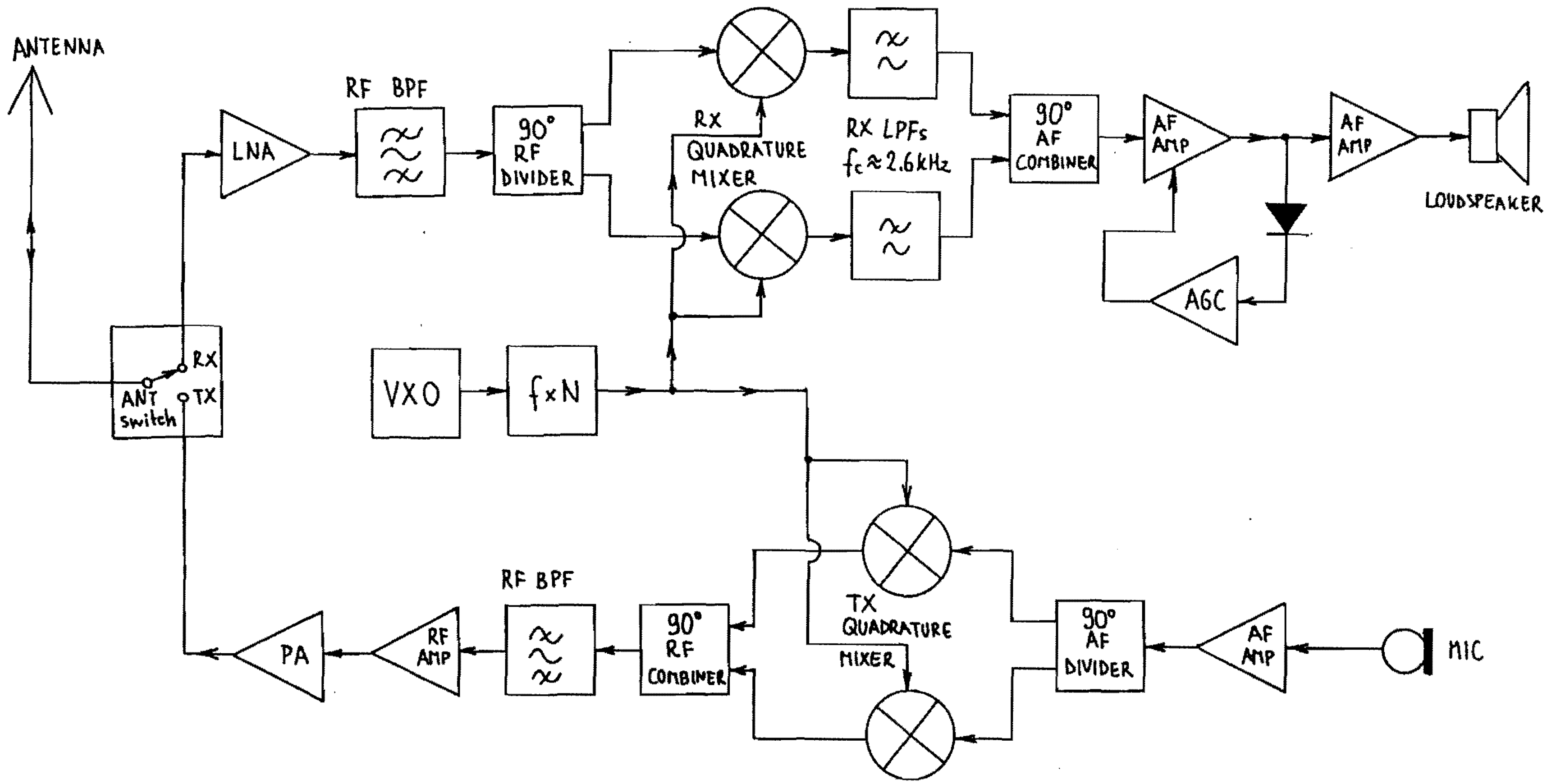


Fig. 2 - Direct-conversion SSB transceiver design.

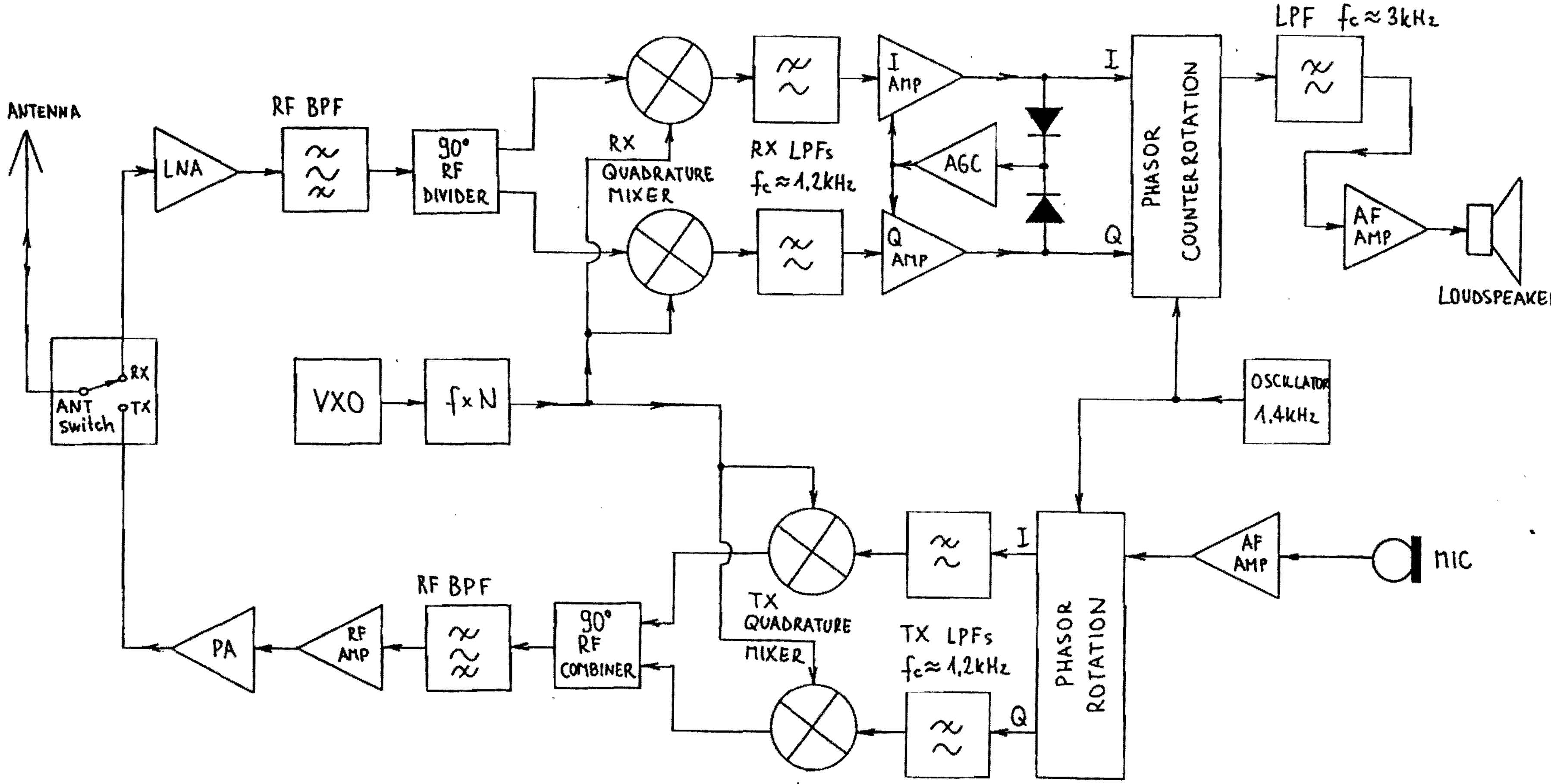
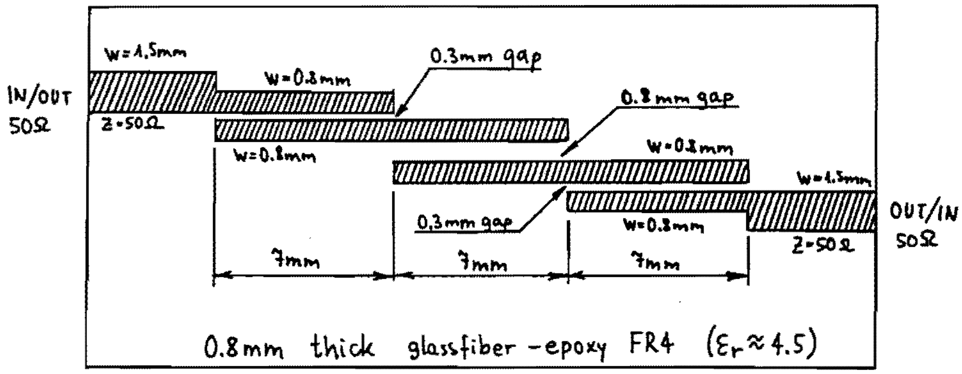


Fig. 3 – Zero-IF SSB transceiver design.



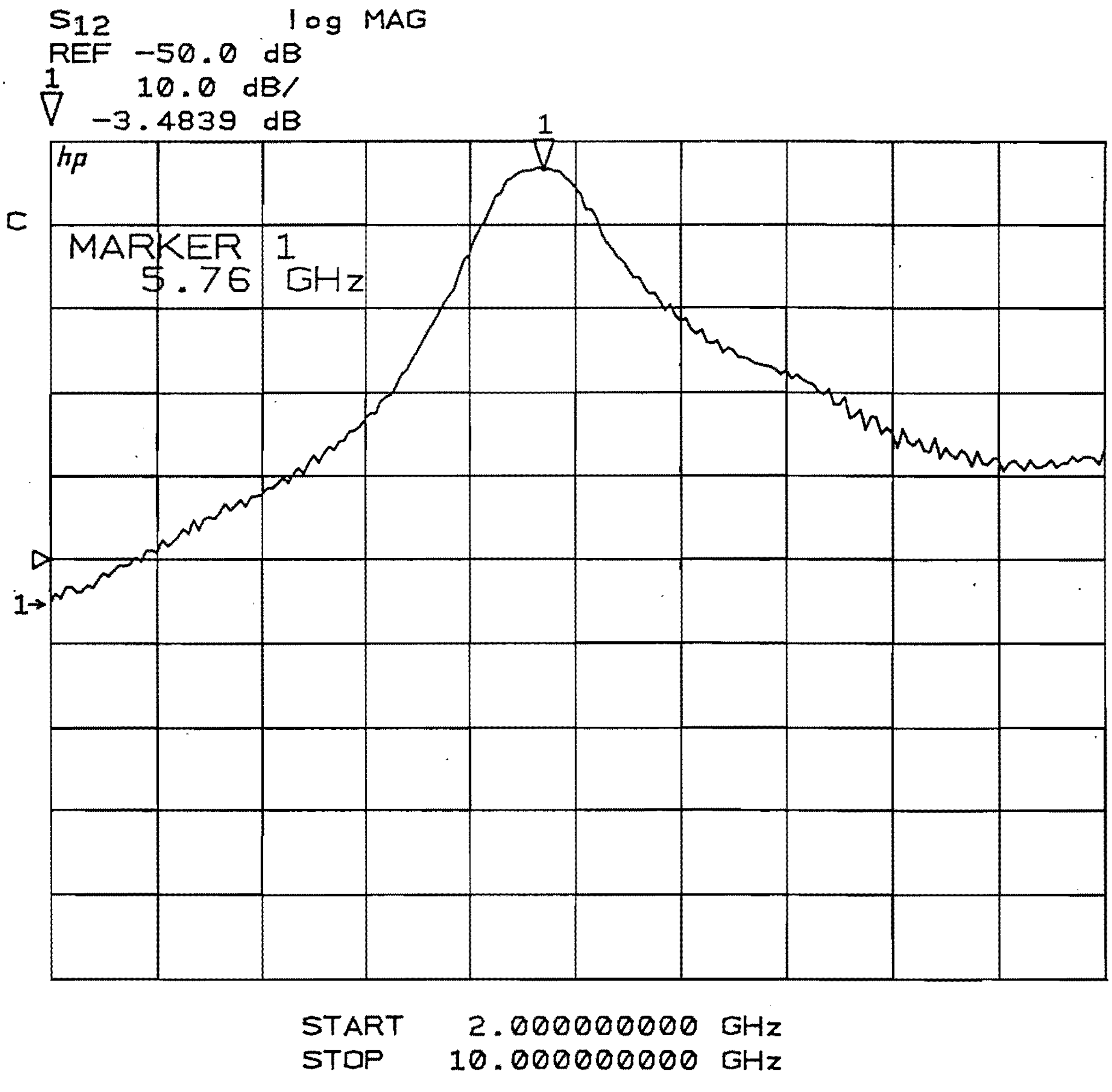


Fig. 4 – 5.76GHz bandpass filter response.

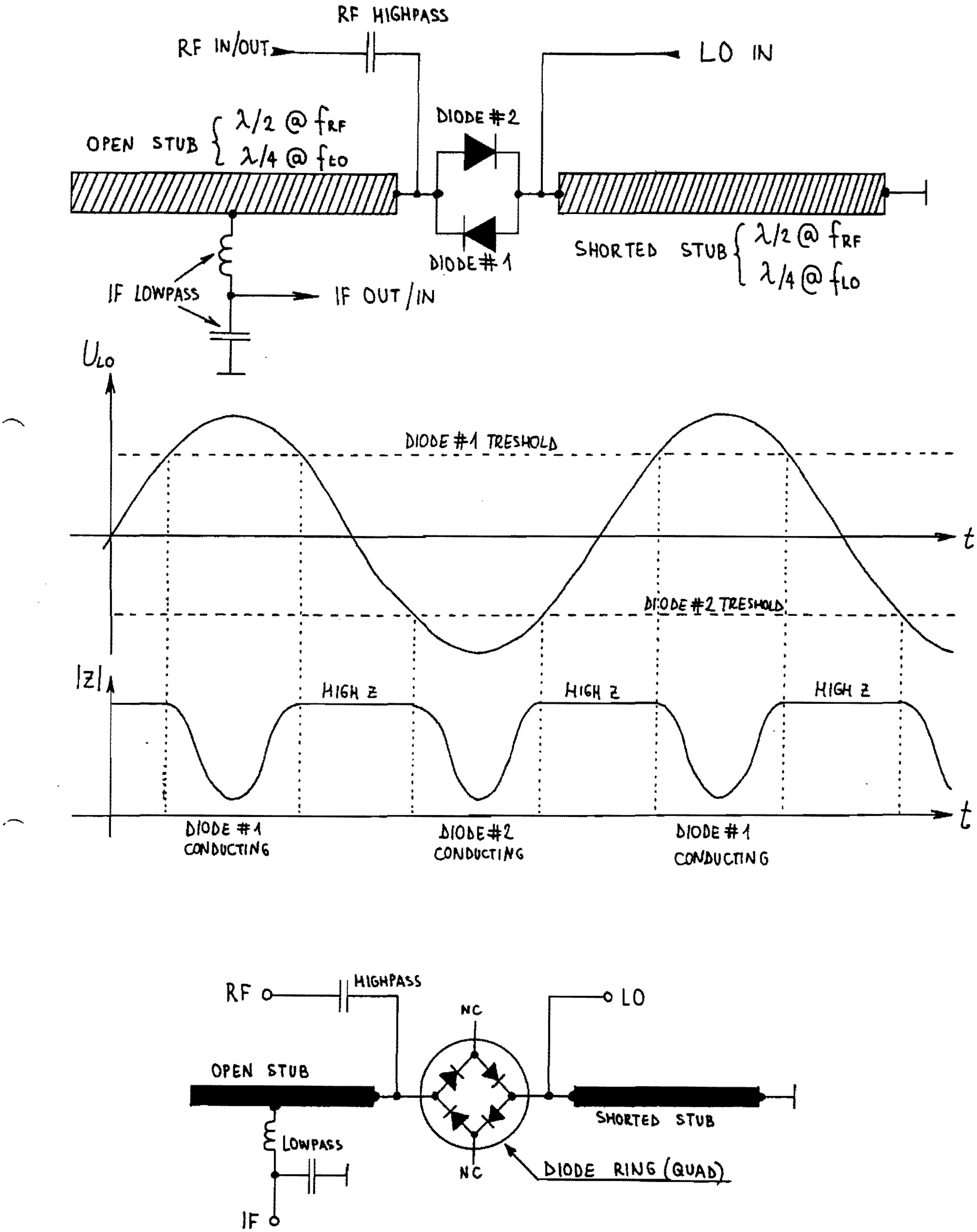


Fig. 5 - Subharmonic mixer design.

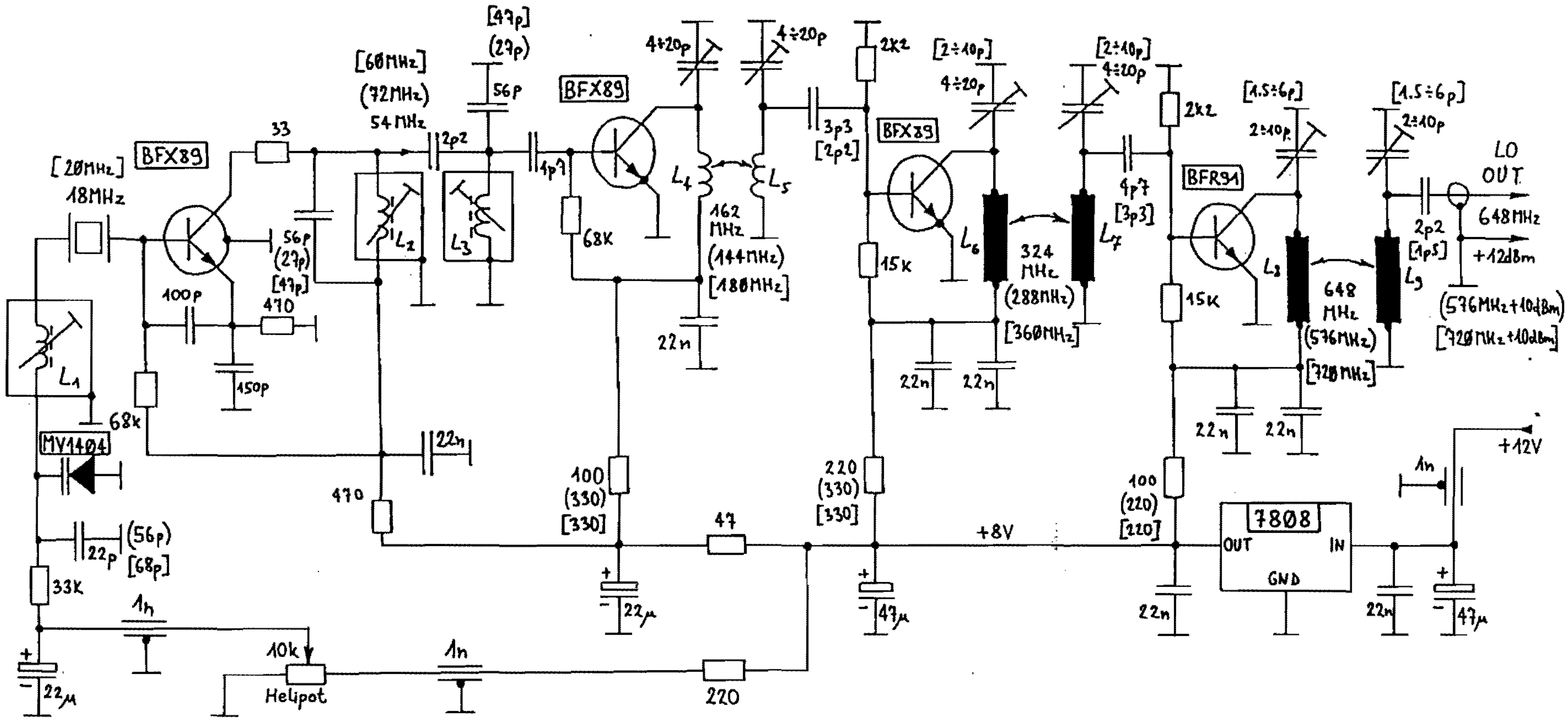


Fig. 6 - VCXO and multipliers for 648 MHz (576 MHz) [720 MHz].

Fig. 7 - VCXO PCB (0.8mm single-sided FR4).

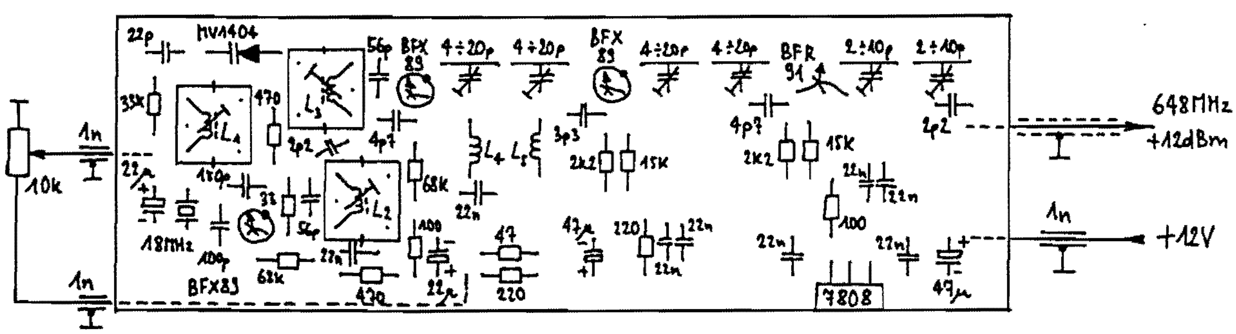


Fig. 8 - VCXO component location (648MHz version).

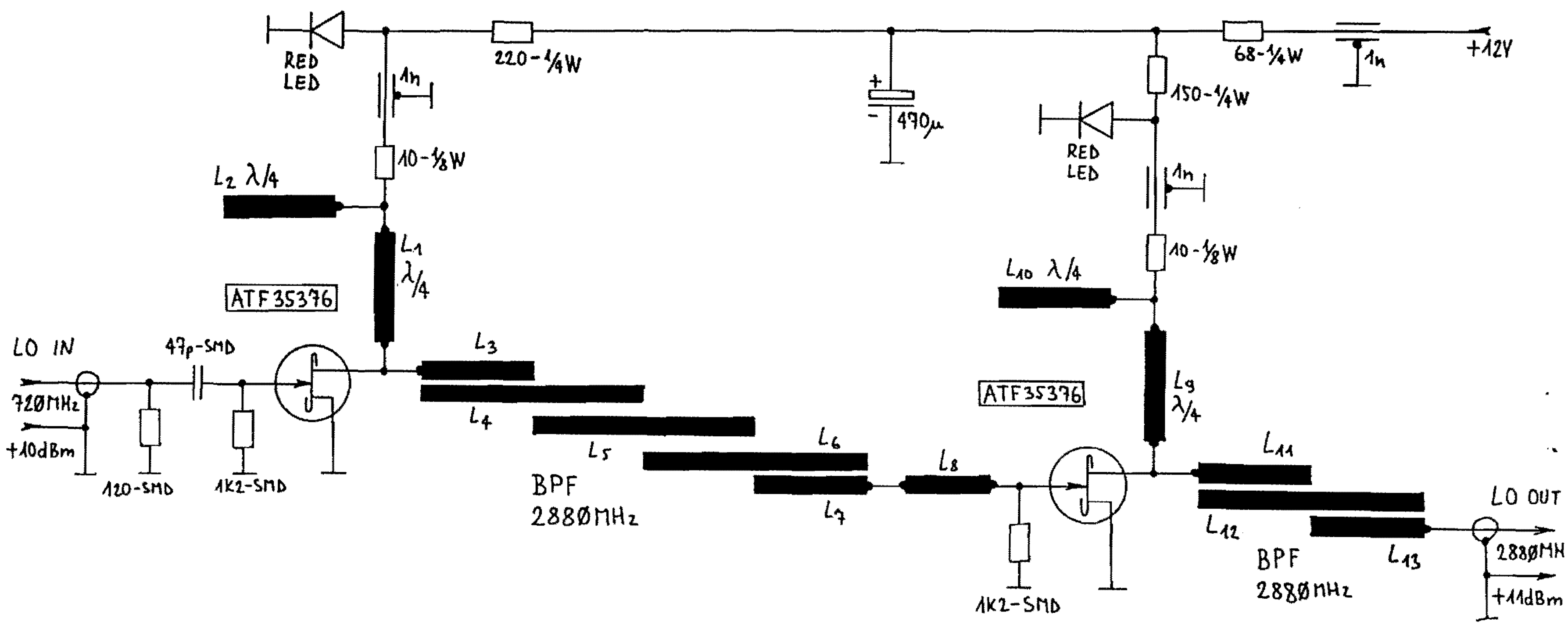


Fig. 9 - Additional multiplier for 2880 MHz.

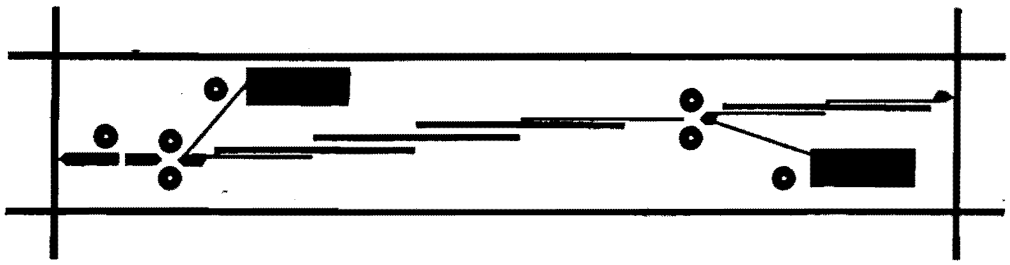


Fig. 10 - 2880MHz multiplier PCB (0.8mm double-sided FR4).

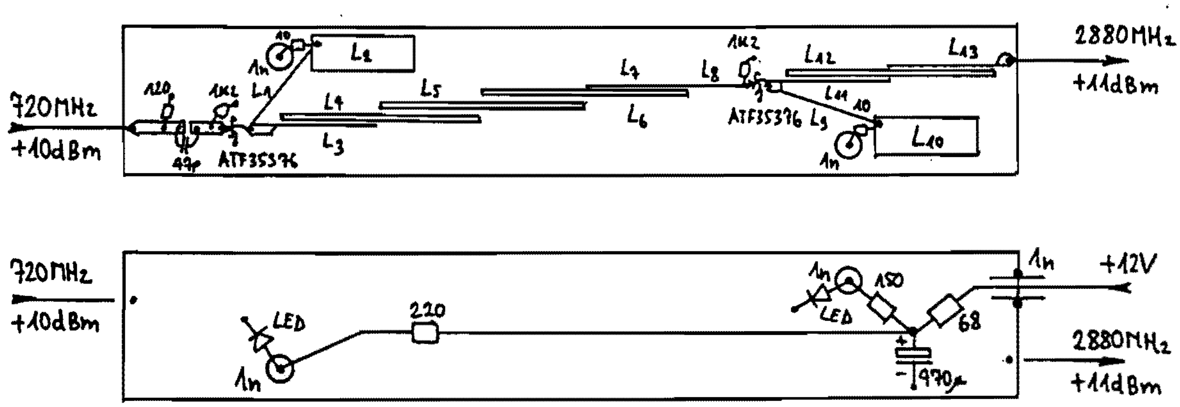


Fig. 11 - 2880 MHz multiplier component location.

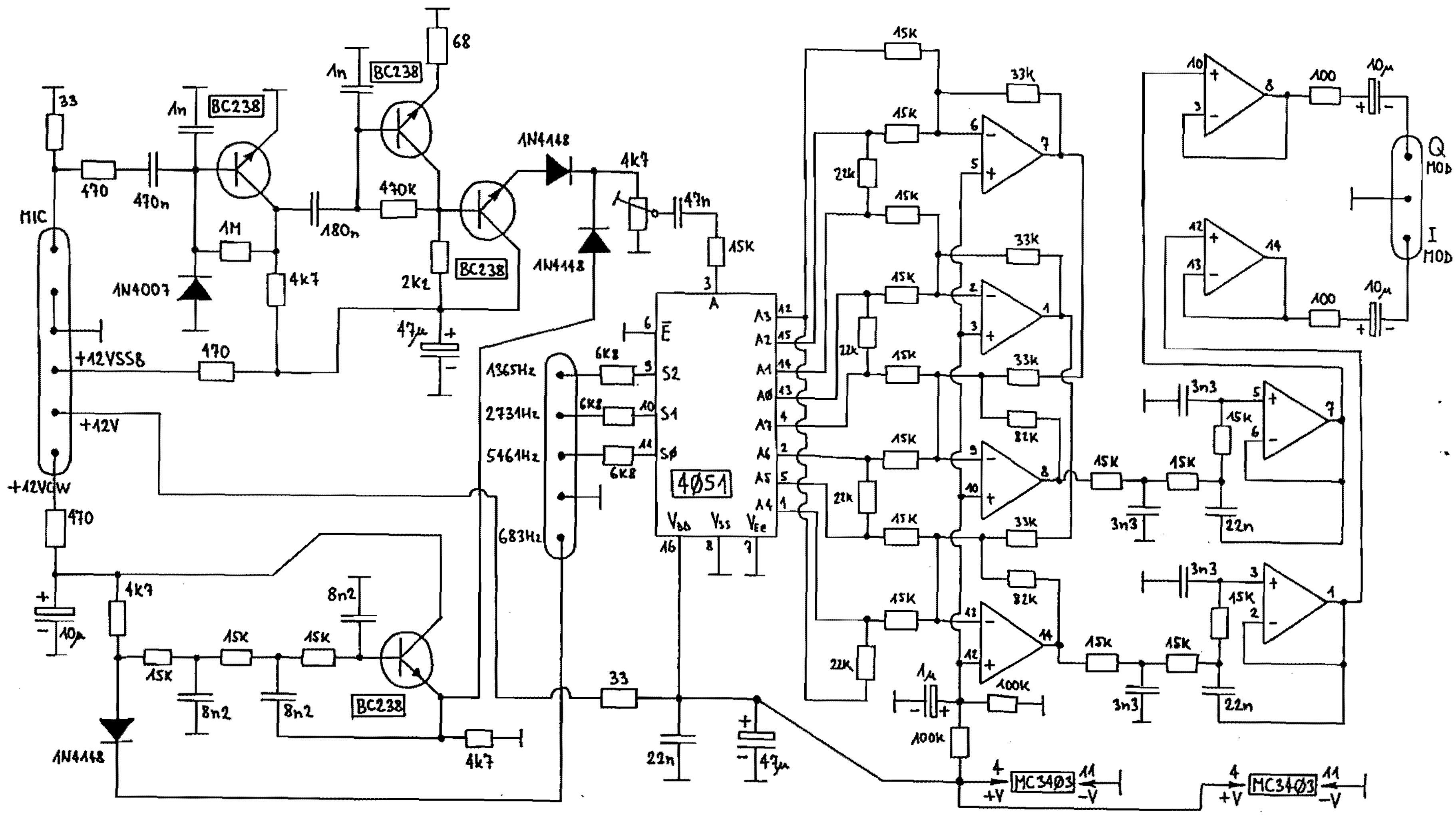


Fig. 12 – SSB/CW quadrature modulator.

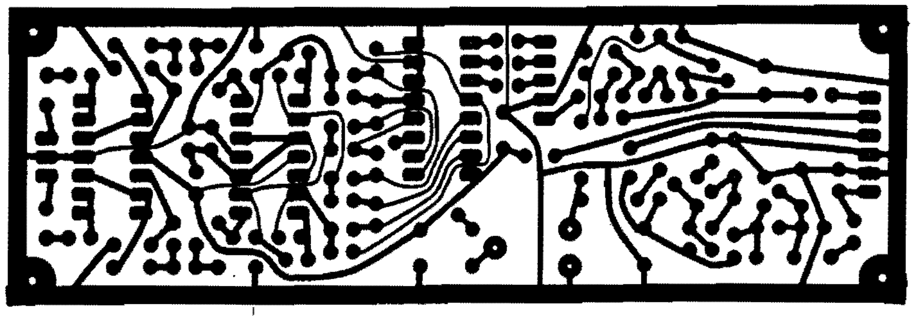


Fig. 13 - Modulator PCB (0.8mm single-sided FR4).

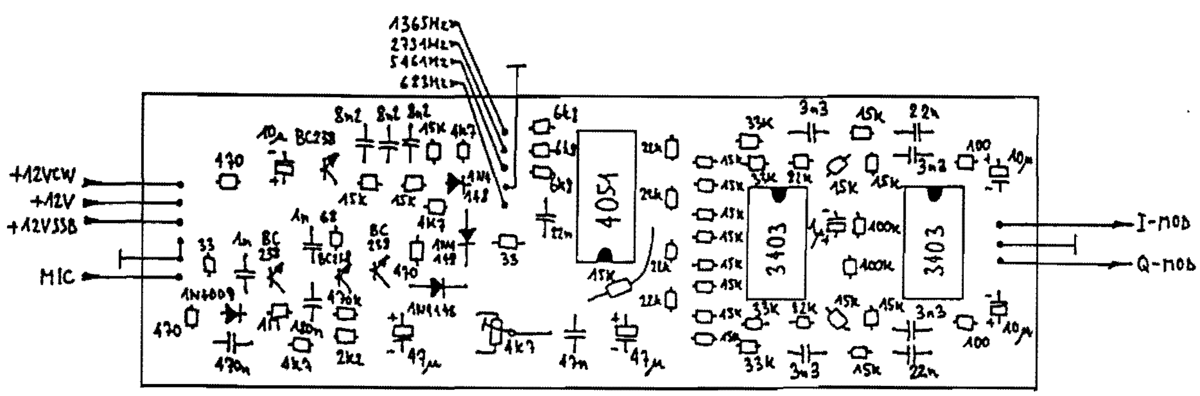


Fig. 14 - Modulator component location.

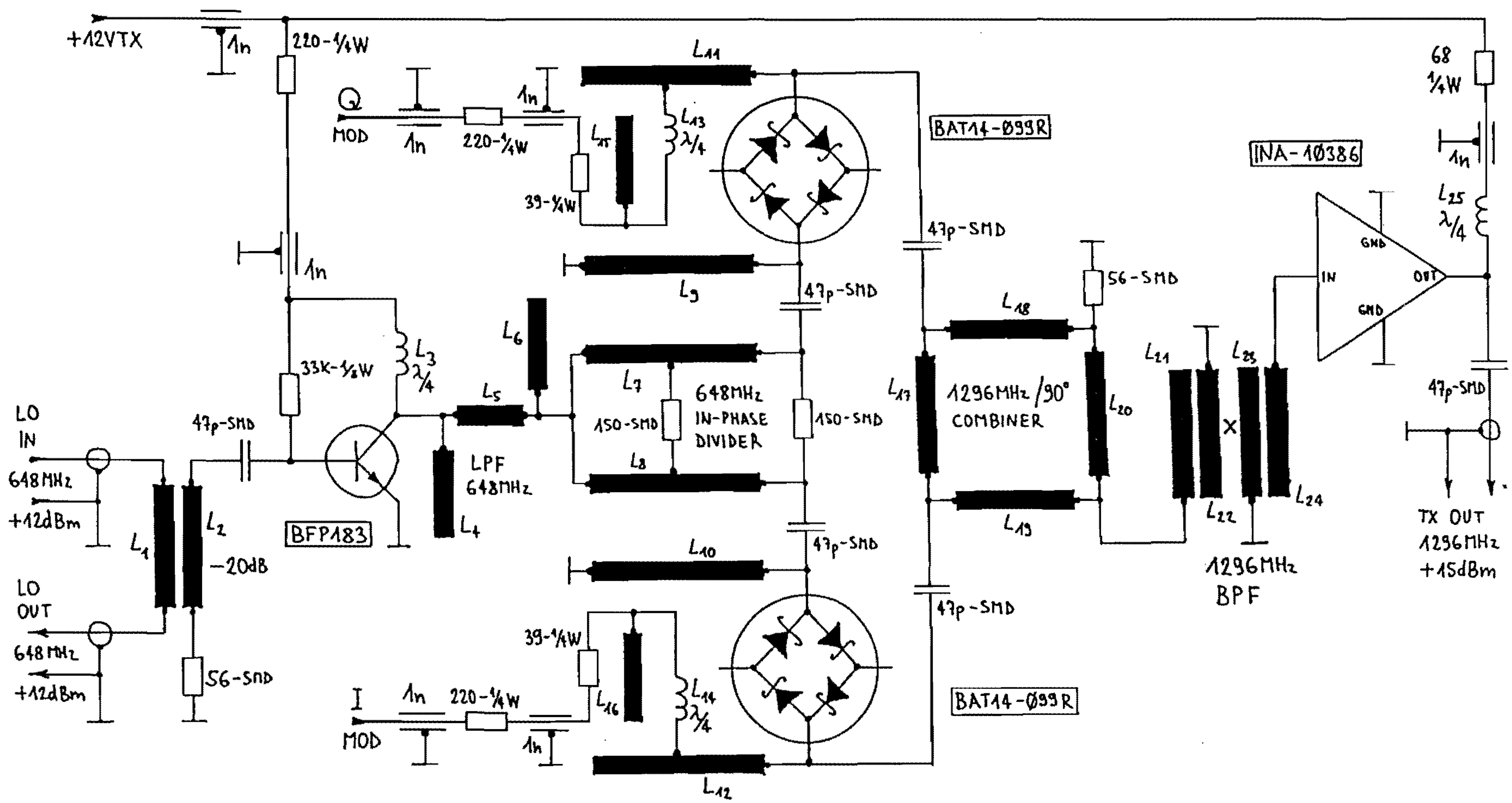


Fig. 15 - Quadrature transmit mixer for 1296 MHz.

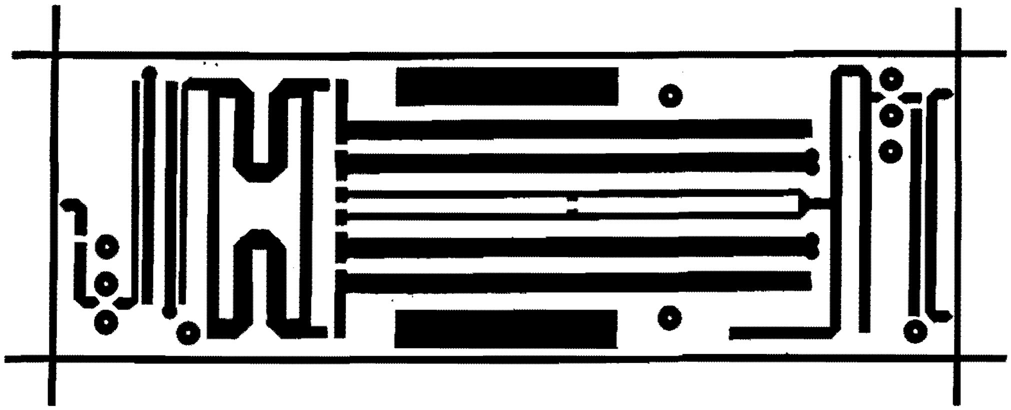


Fig. 16 - 1296 MHz TX mixer PCB (0.8mm double-sided FR4).

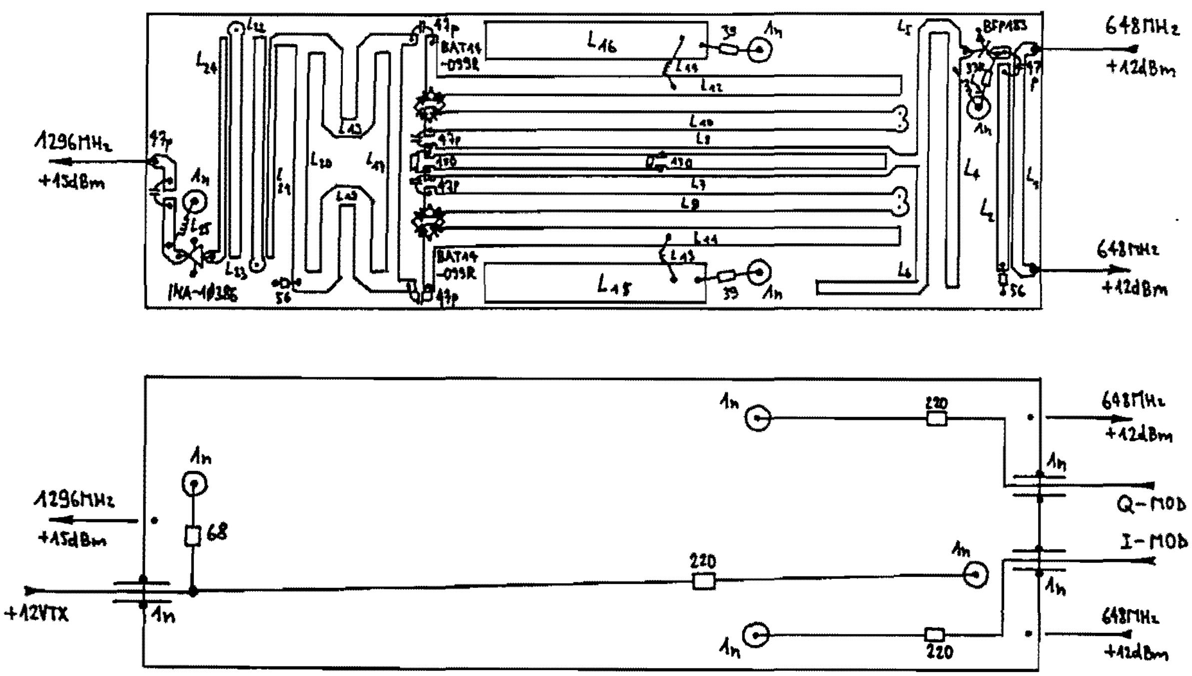


Fig. 17 - 1296 MHz TX mixer component location.

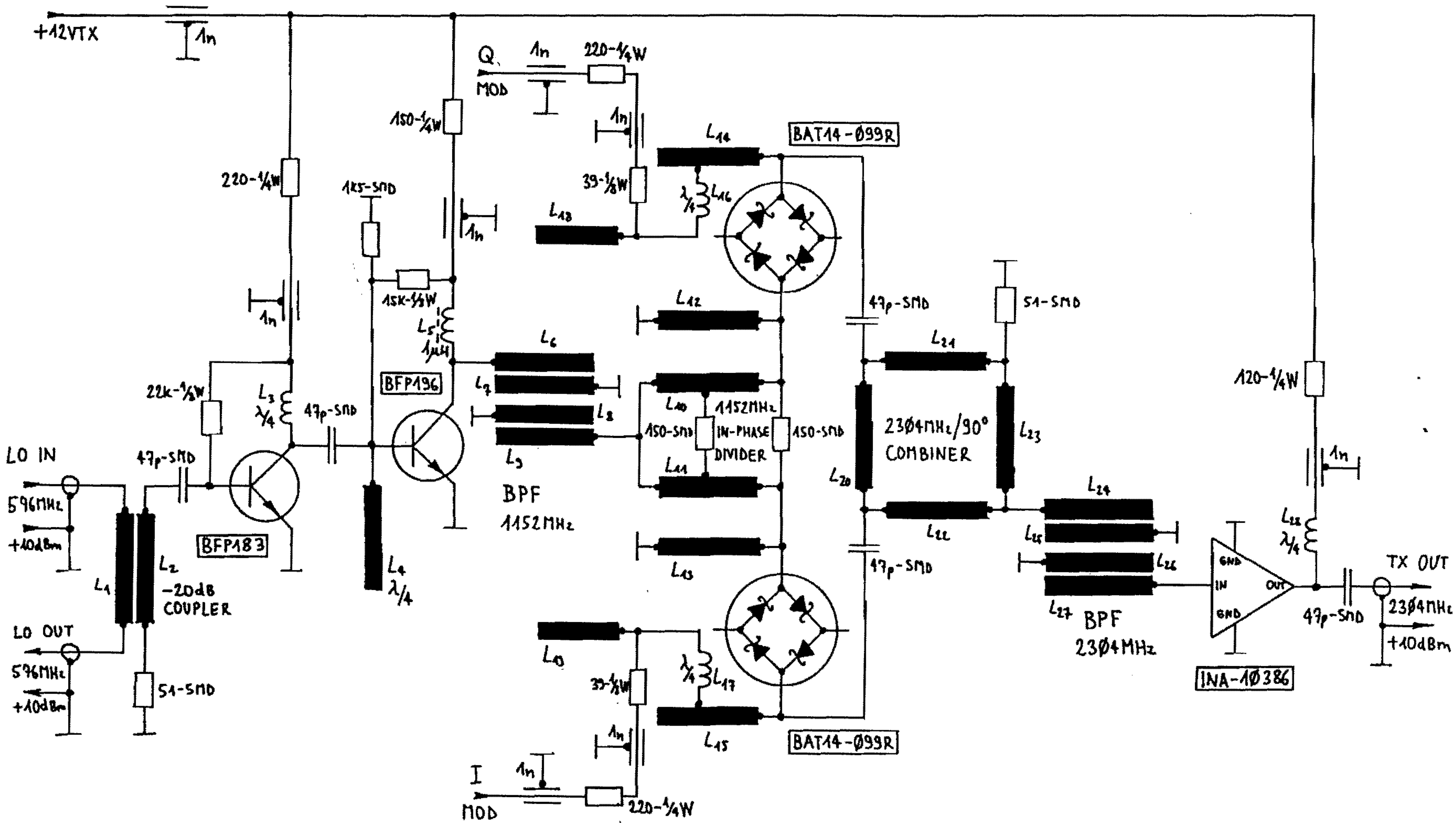


Fig. 18 - Quadrature transmit mixer for 2304MHz.

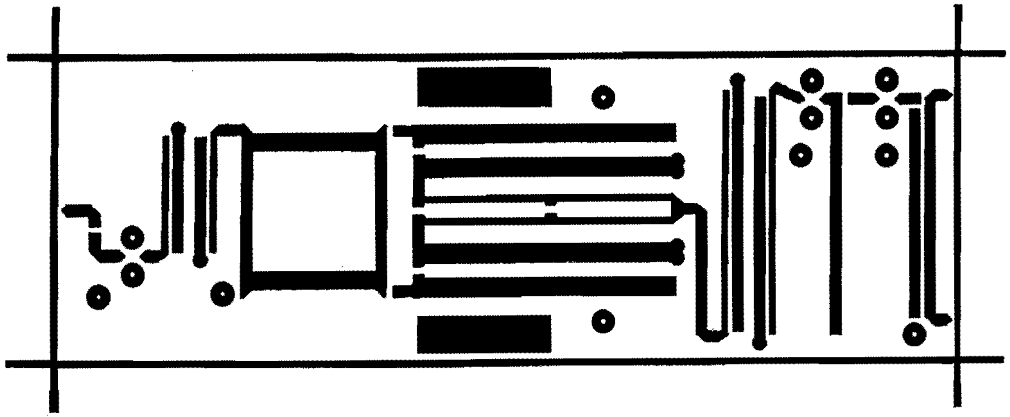


Fig. 19 - 2304 MHz TX mixer PCB (0.8 mm double-sided FR4).

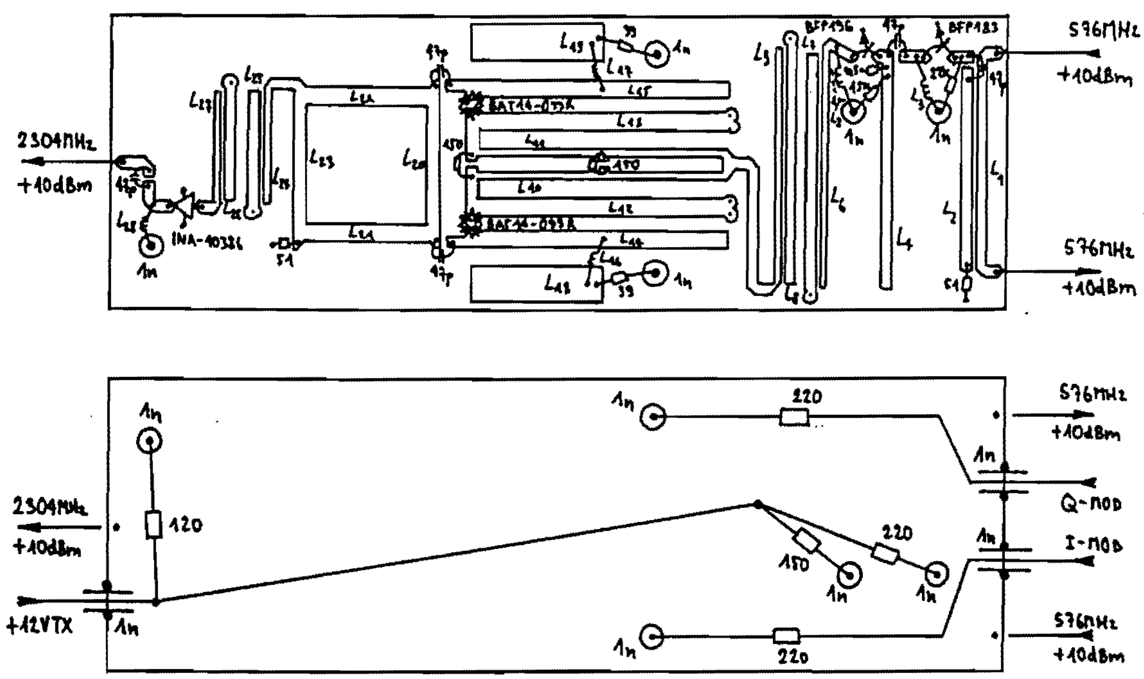


Fig. 20 - 2304 MHz TX mixer component location.

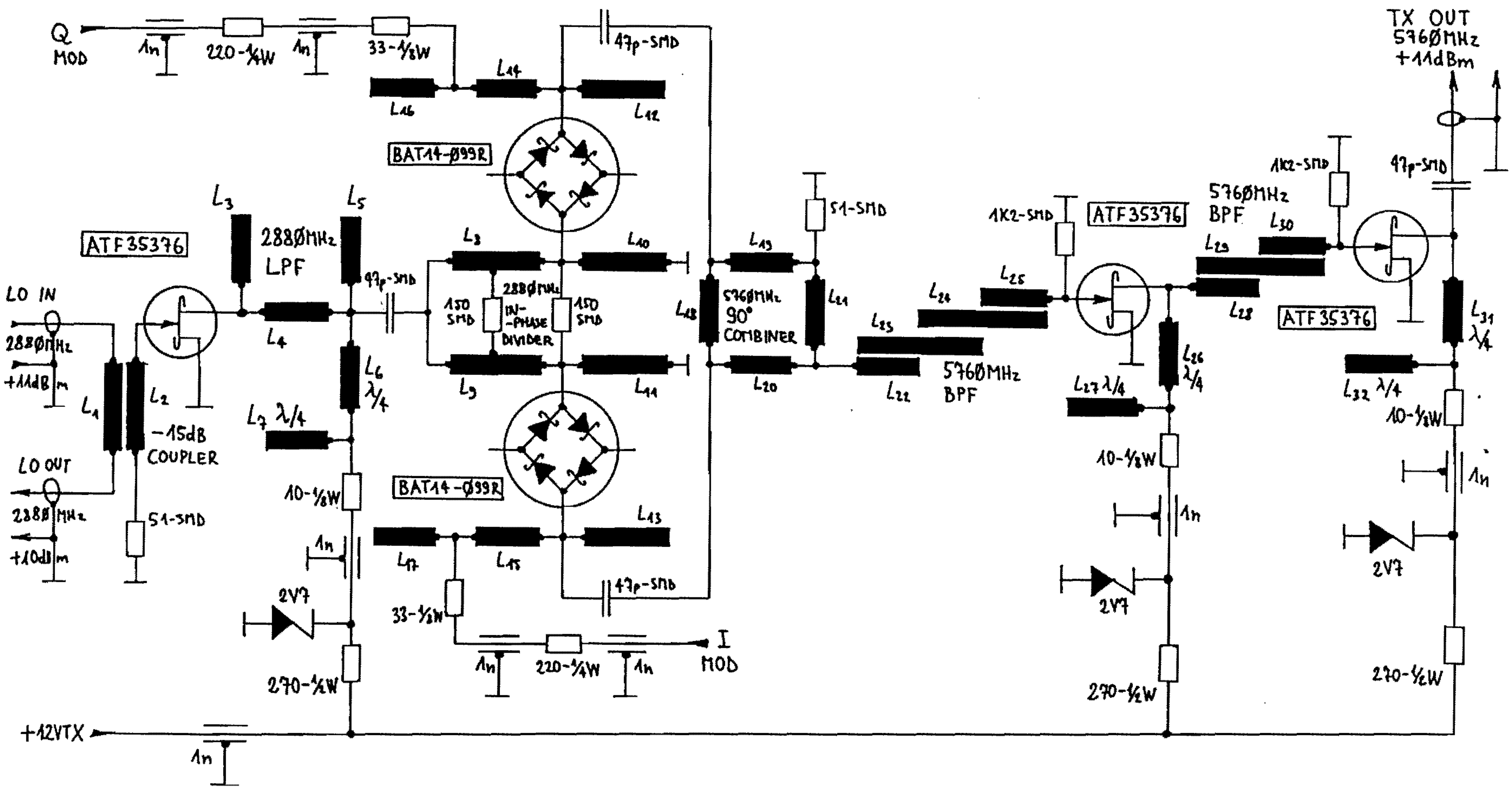


Fig. 21 - Quadrature transmit mixer for 5760 MHz.

147

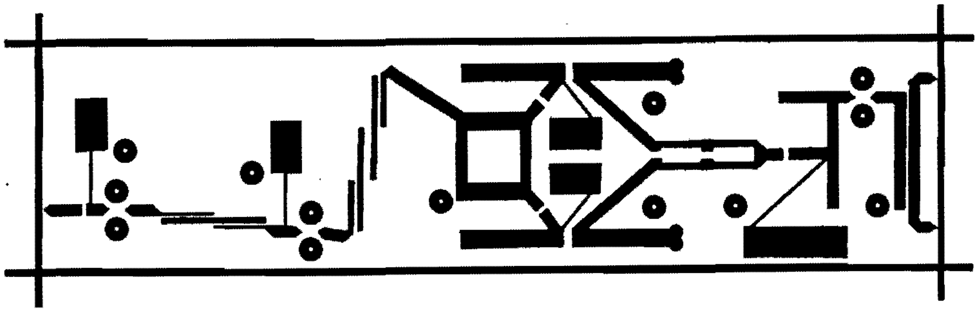


Fig. 22 - 5760 MHz TX mixer PCB (0.8mm double-sided FR4).

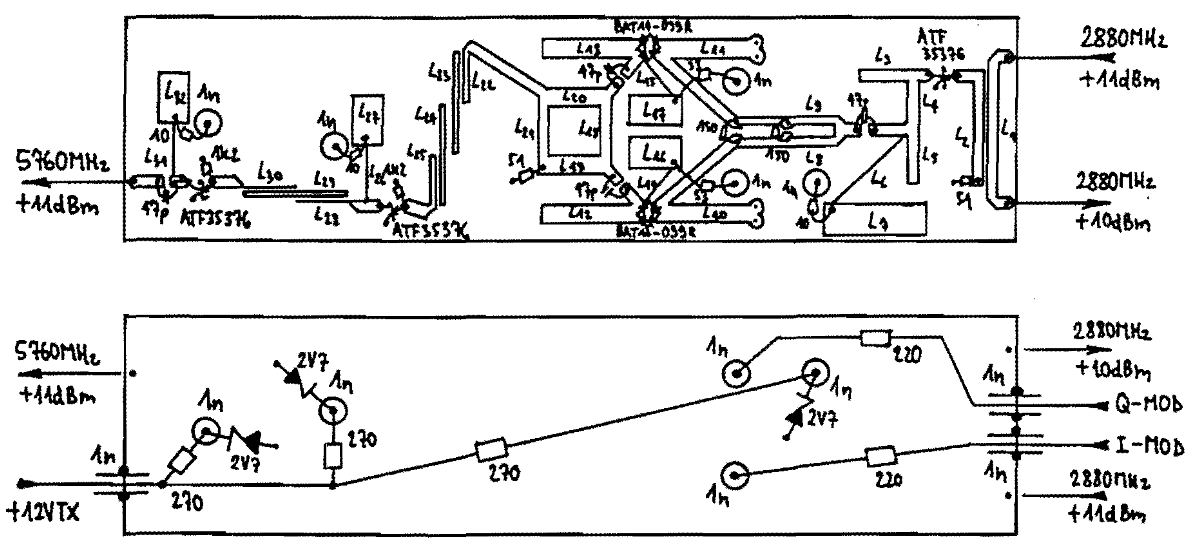


Fig. 23 - 5760MHz TX mixer component location.

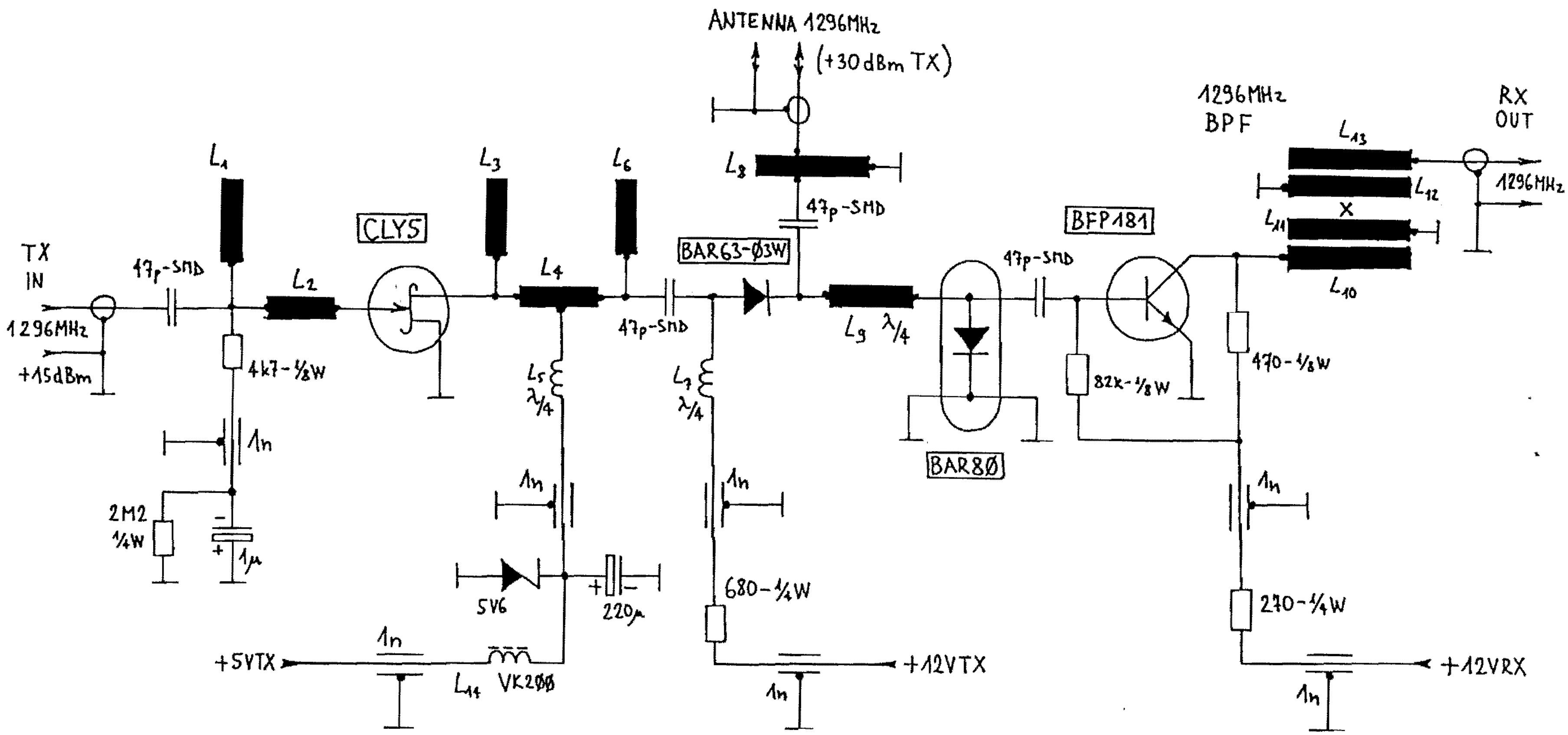


Fig. 24 – RF front-end for 1296 MHz.

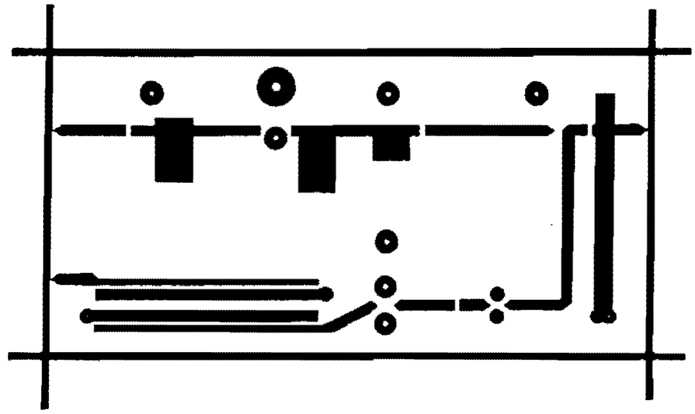


Fig. 25 - 1296 MHz RF front-end PCB (0.8mm double-sided FR4).

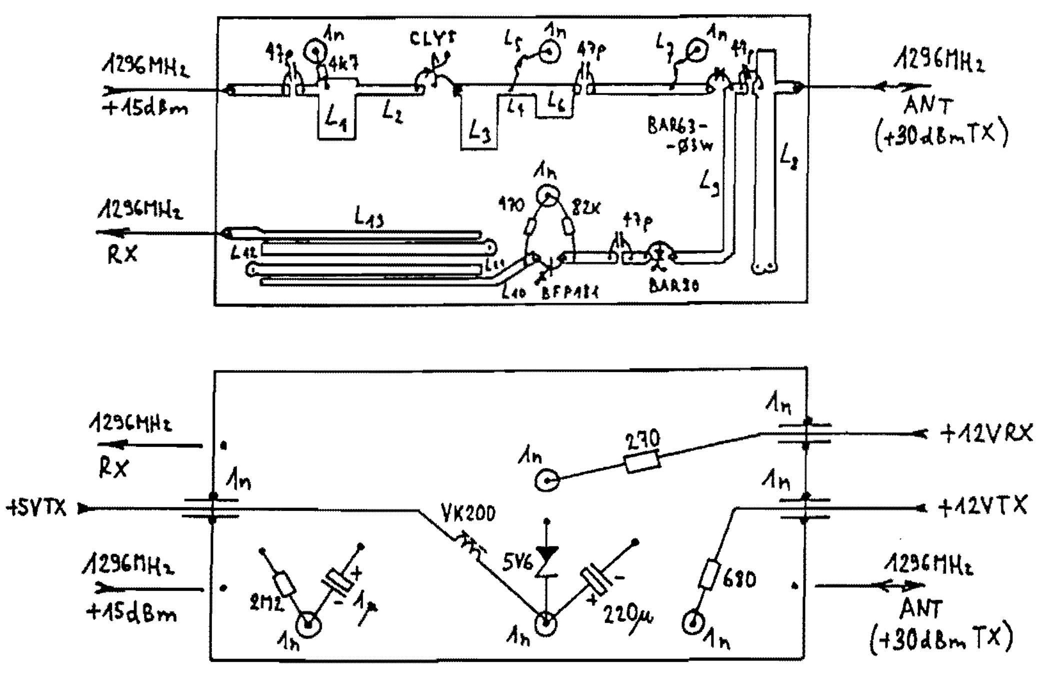


Fig. 26 - 1296 MHz RF front-end component location.

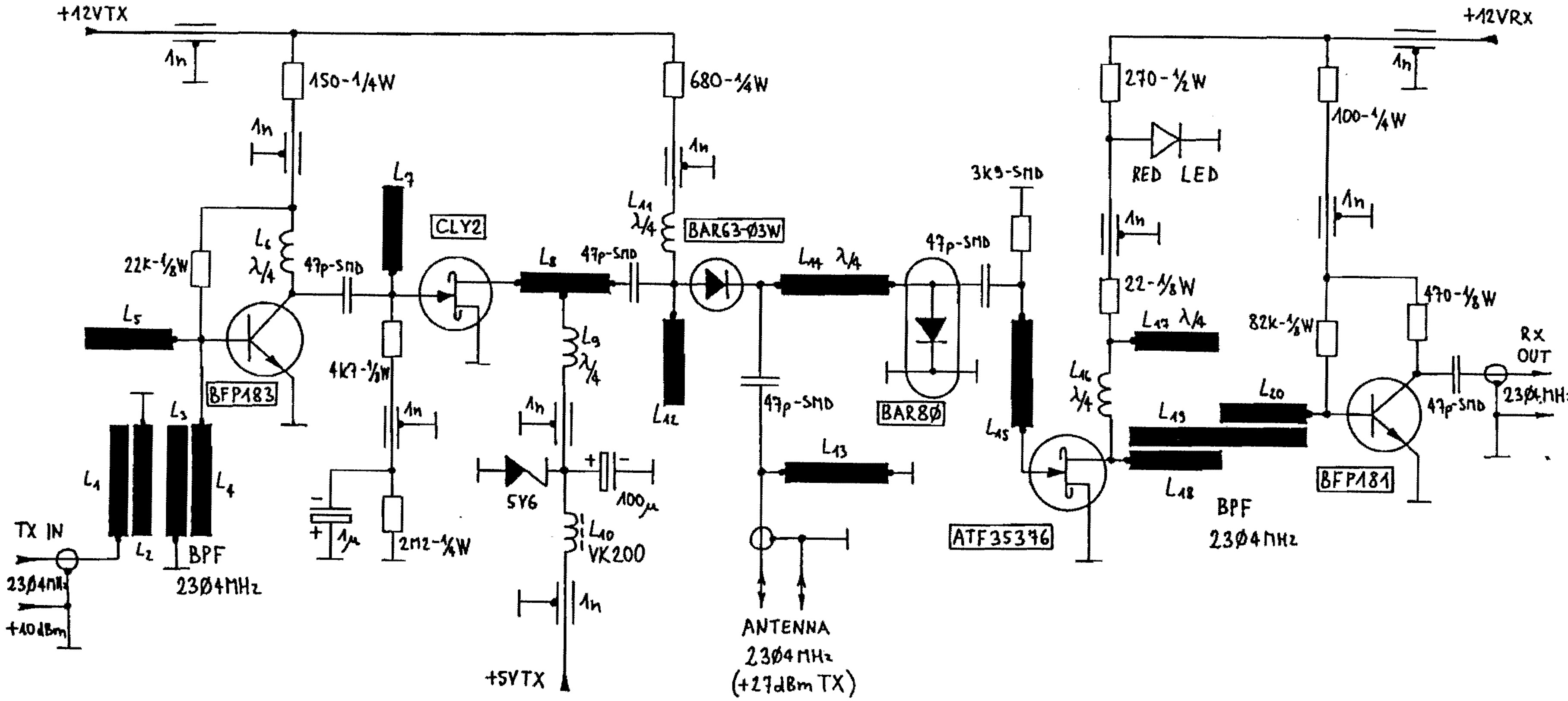


Fig. 27 - RF front-end for 2304 MHz.

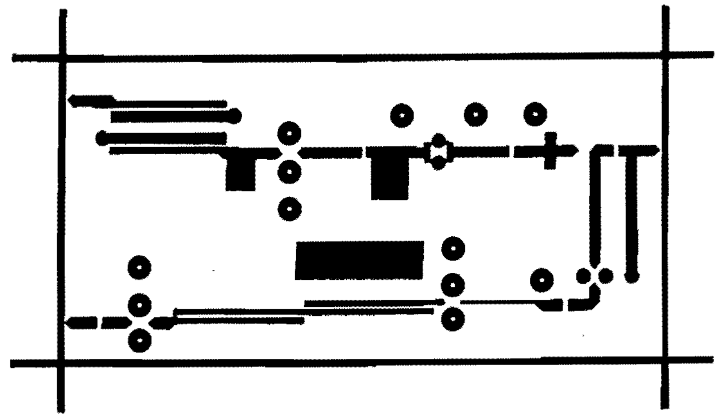


Fig. 28 - 2304MHz RF front-end PCB (0.8mm double-sided FR4).

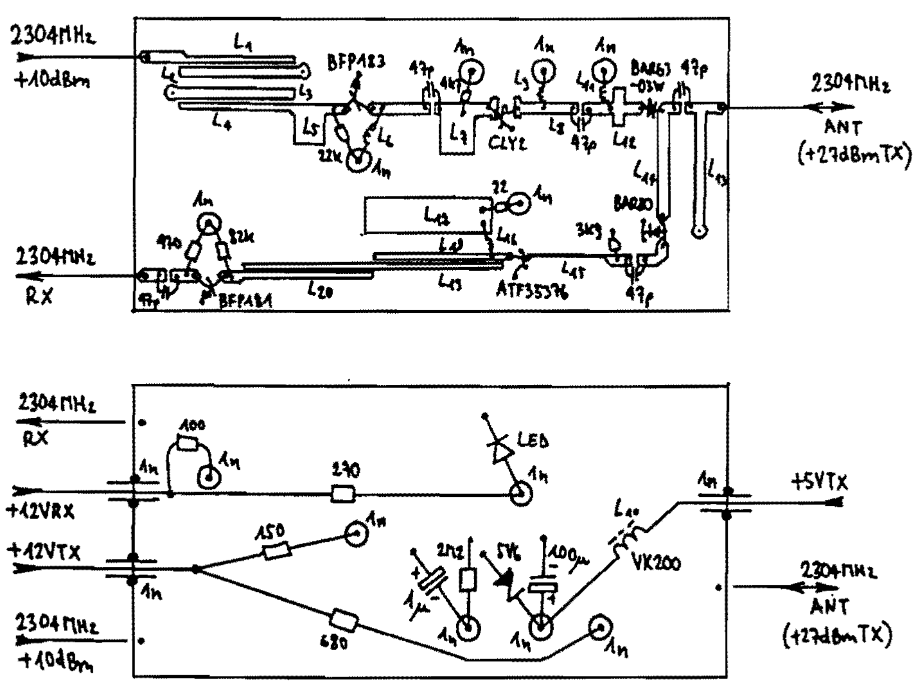


Fig. 29 - 2304 MHz RF front-end component location.

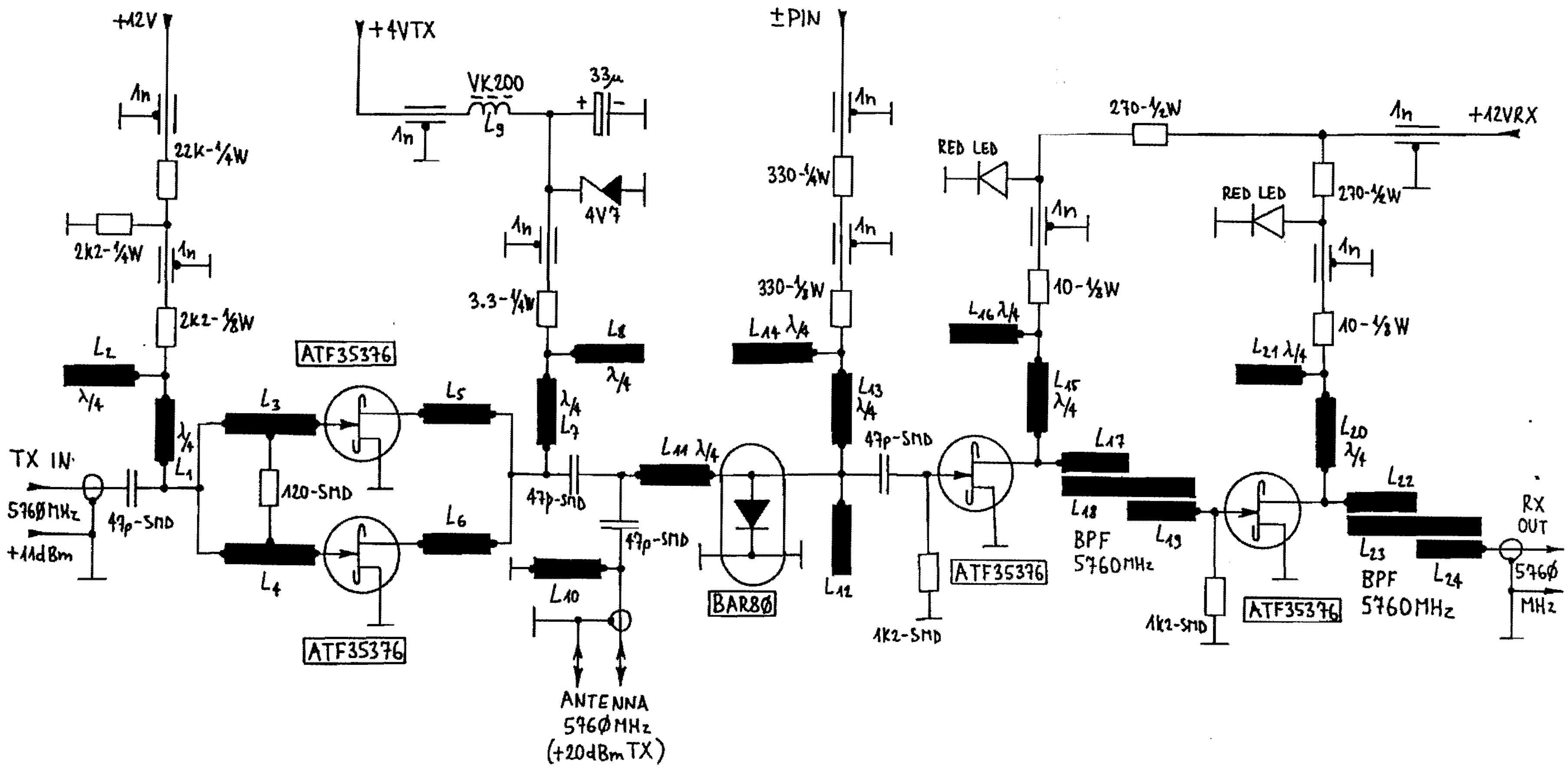


Fig. 30 – RF front-end for 5760 MHz.

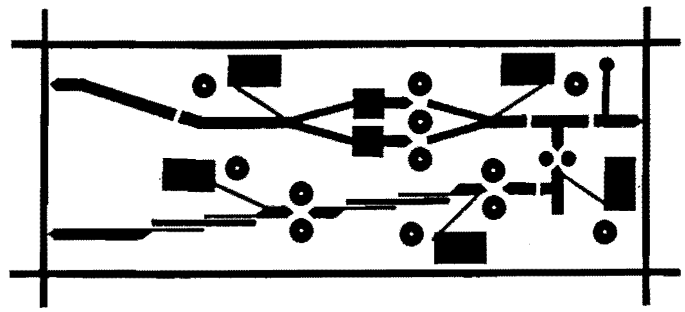


Fig. 31 - 5760 MHz RF front-end PCB (0.8mm double-sided FR4).

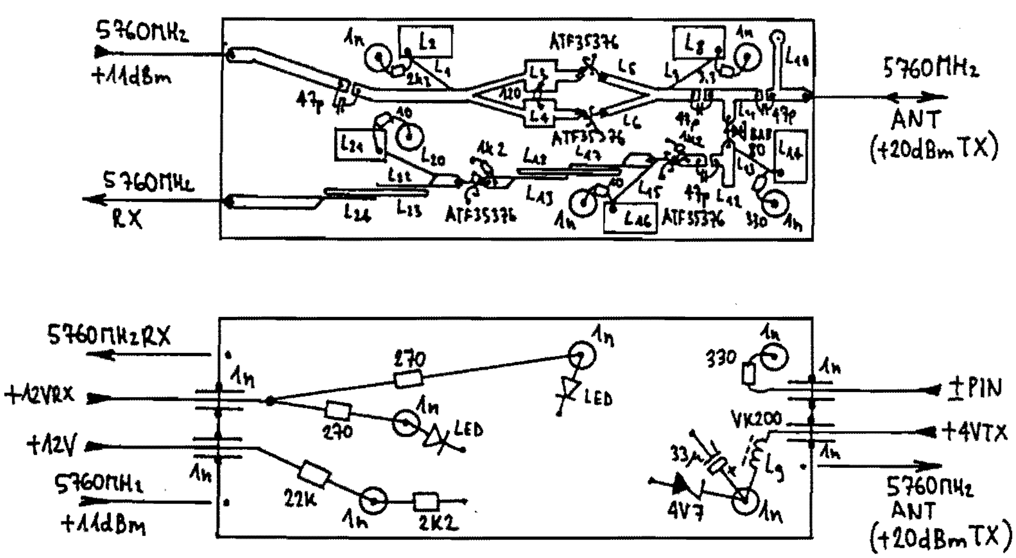


Fig. 32 - 5760 MHz RF front-end component location.

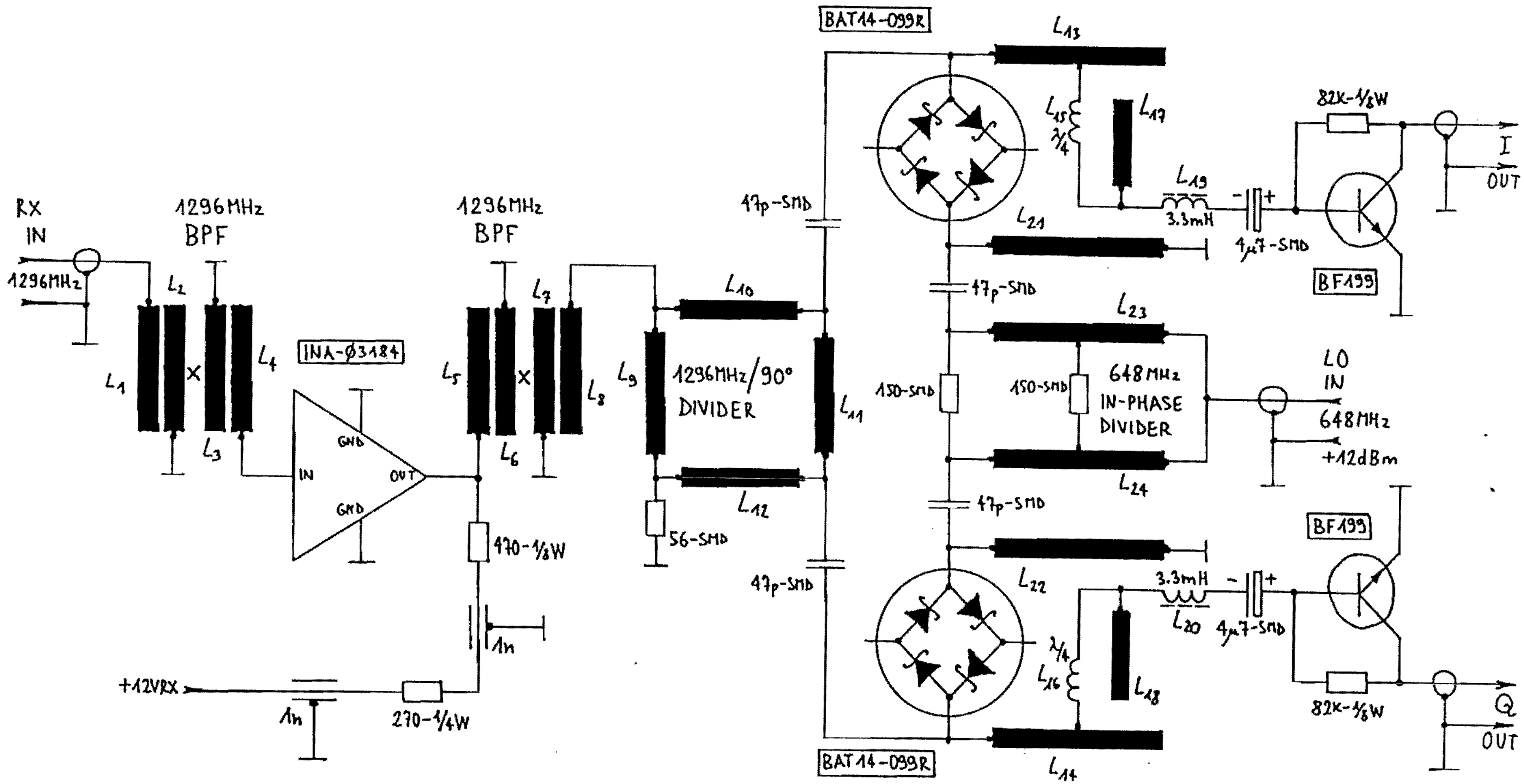


Fig. 33 - Quadrature receive mixer for 1296 MHz.

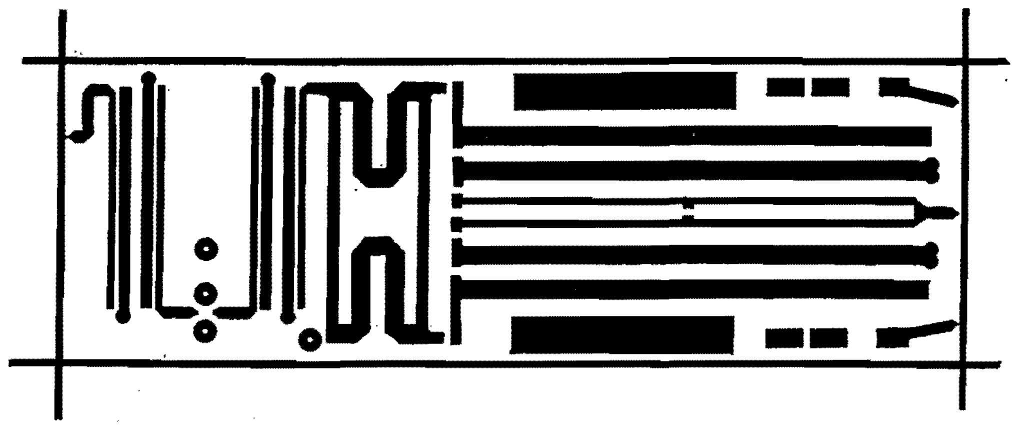


Fig. 34 - 1296 MHz RX mixer PCB (0.8mm double-sided FR4).

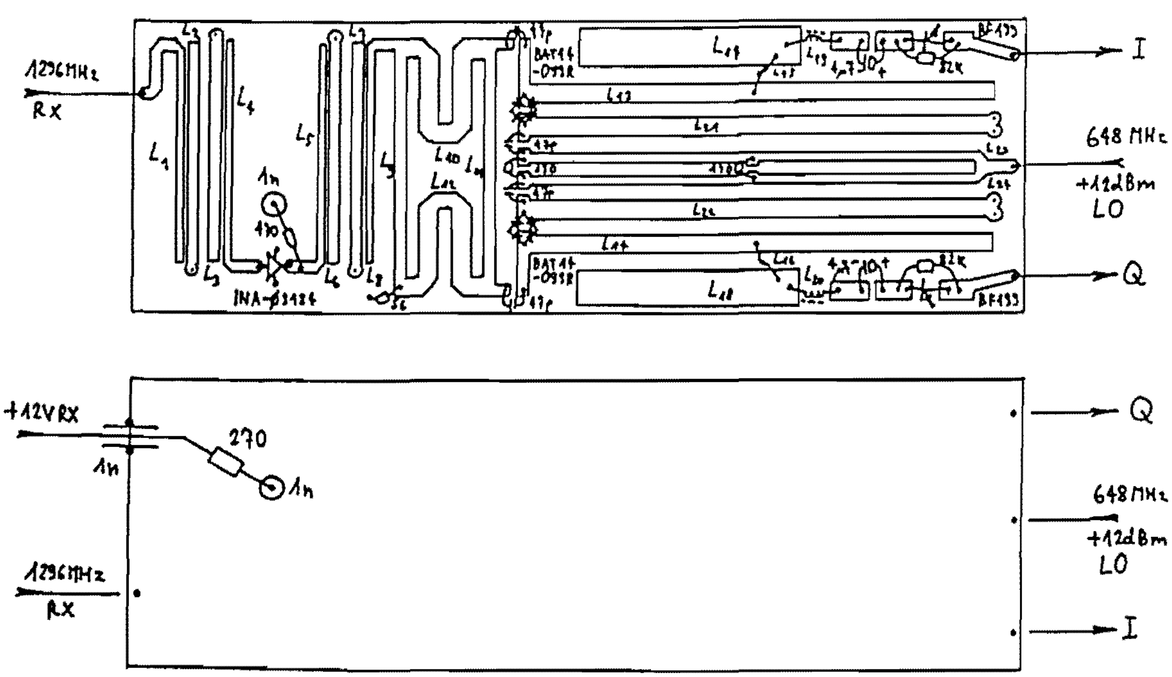


Fig. 35 - 1296 MHz RX mixer component location.

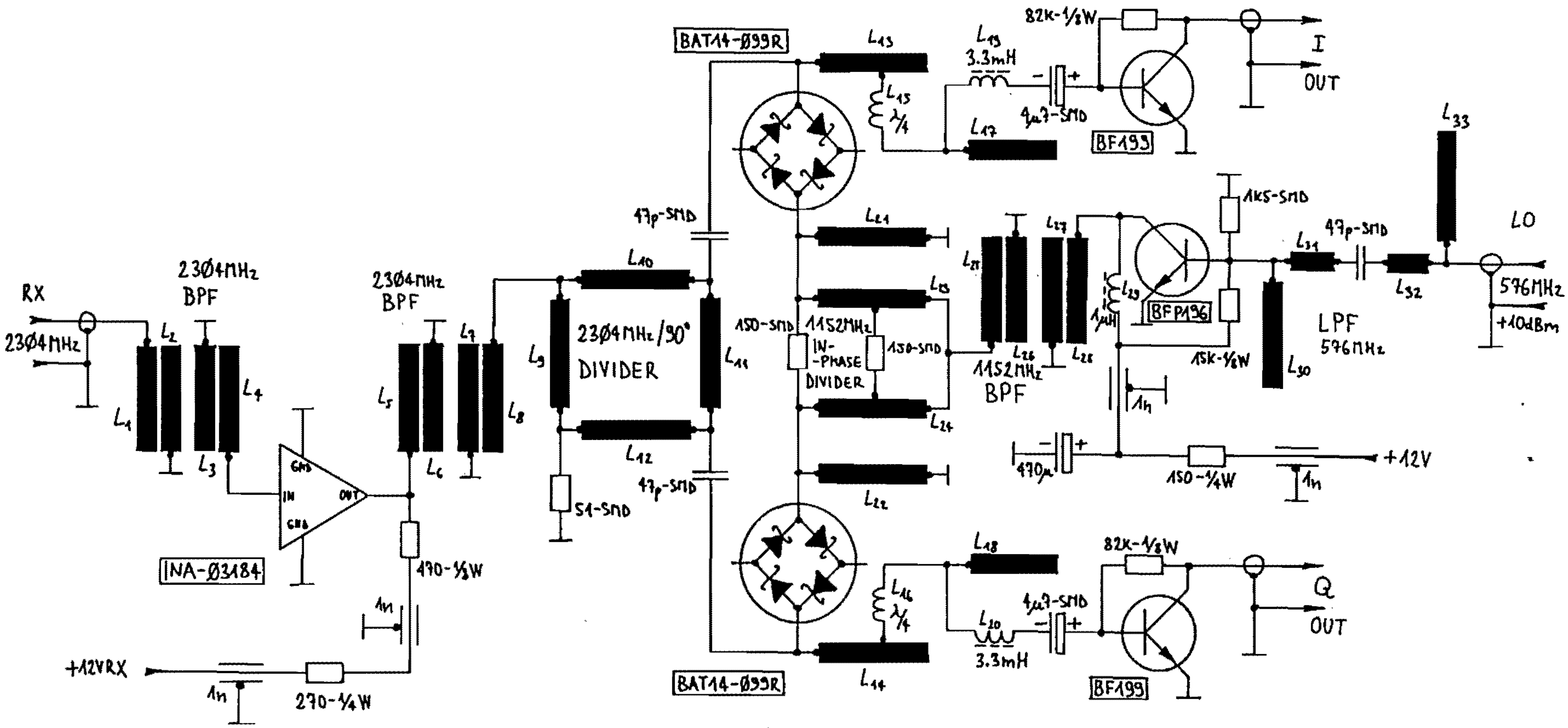


Fig. 36 – Quadrature receive mixer for 2304 MHz.

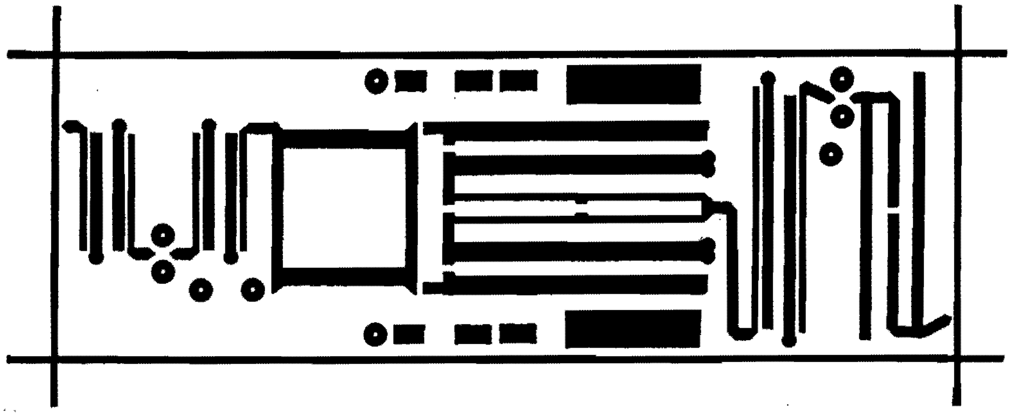


Fig. 37 – 2304MHz RX mixer PCB (0.8mm double-sided FR4).

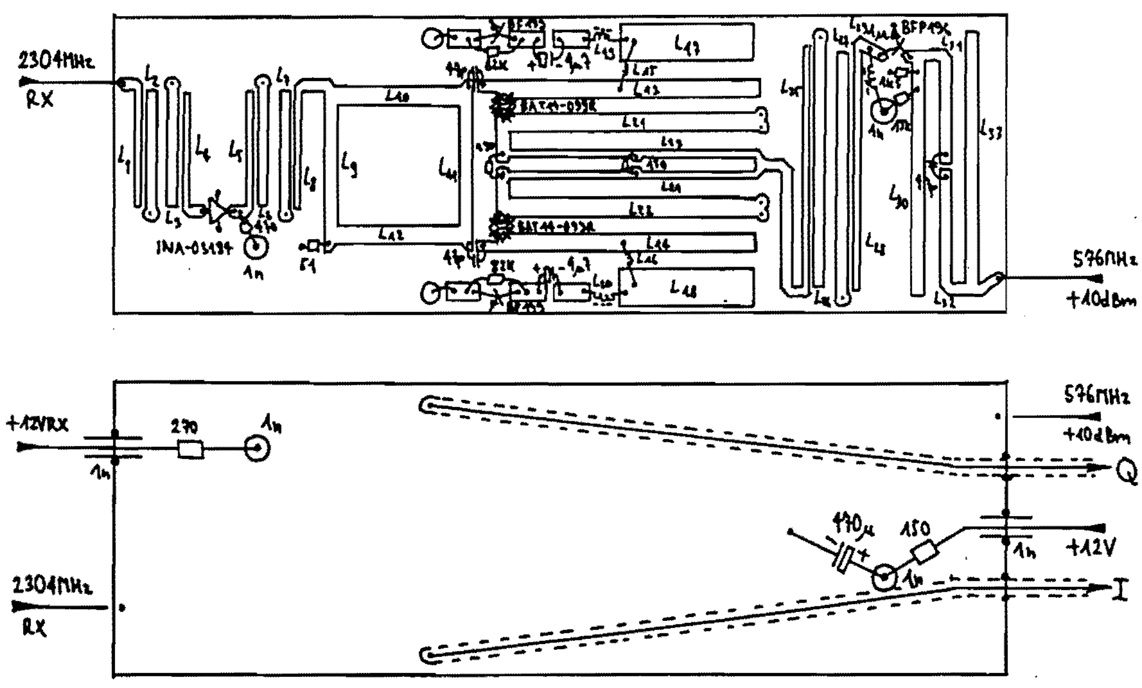


Fig. 38 – 2304MHz RX mixer component location.

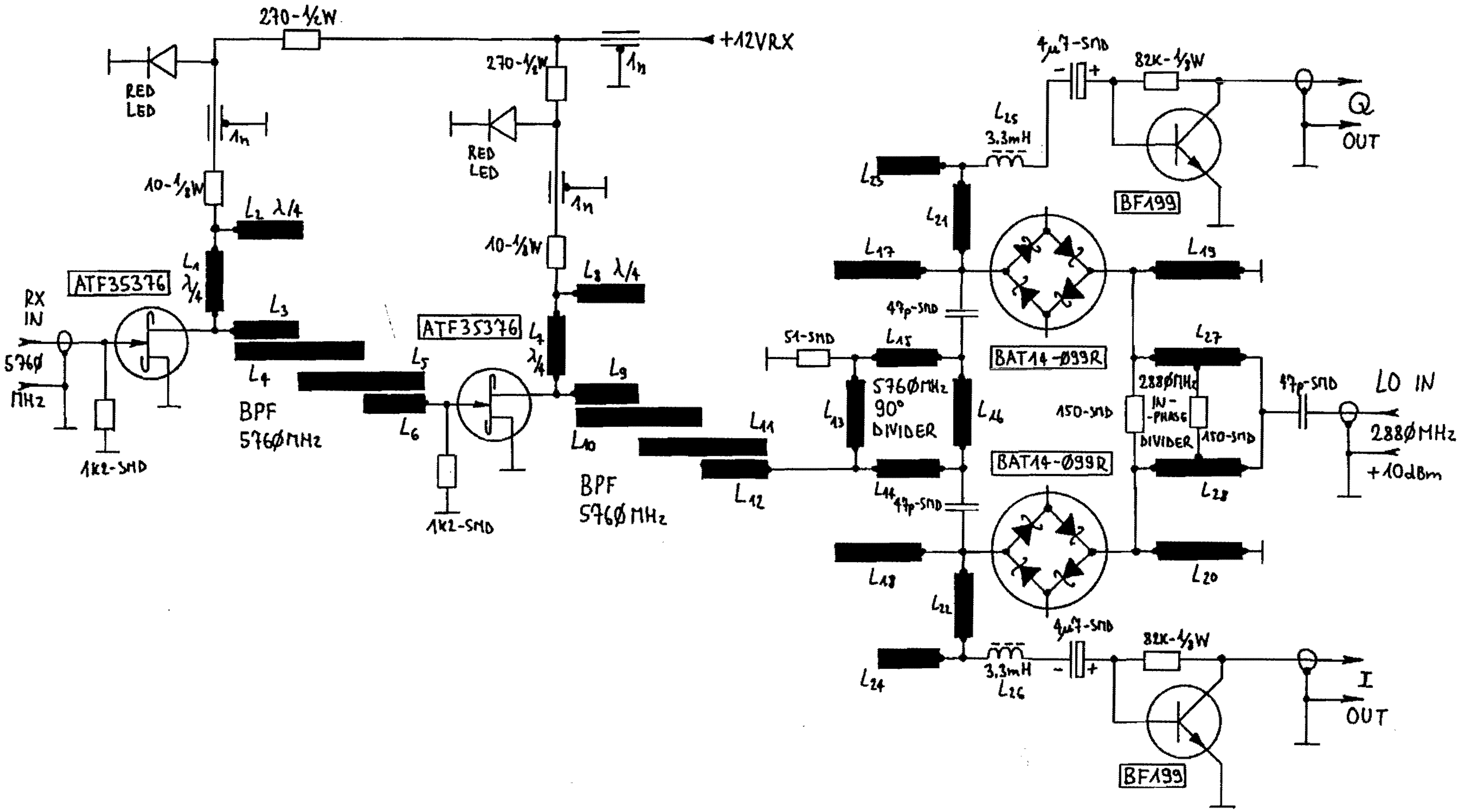


Fig. 39 - Quadrature receive mixer for 5760MHz.

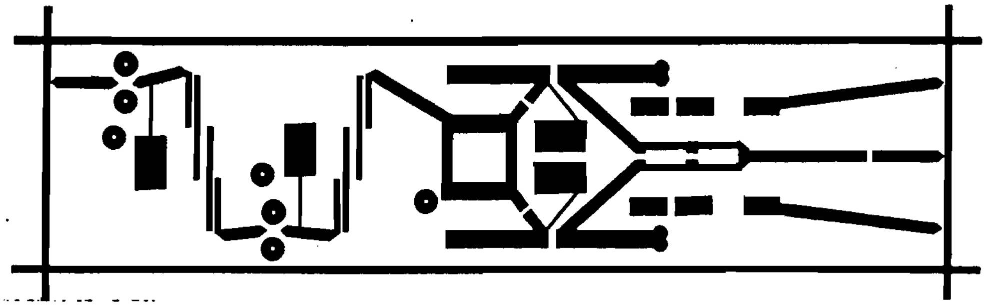


Fig. 40 - 5760MHz RX mixer PCB (0.8mm double-sided FR4).

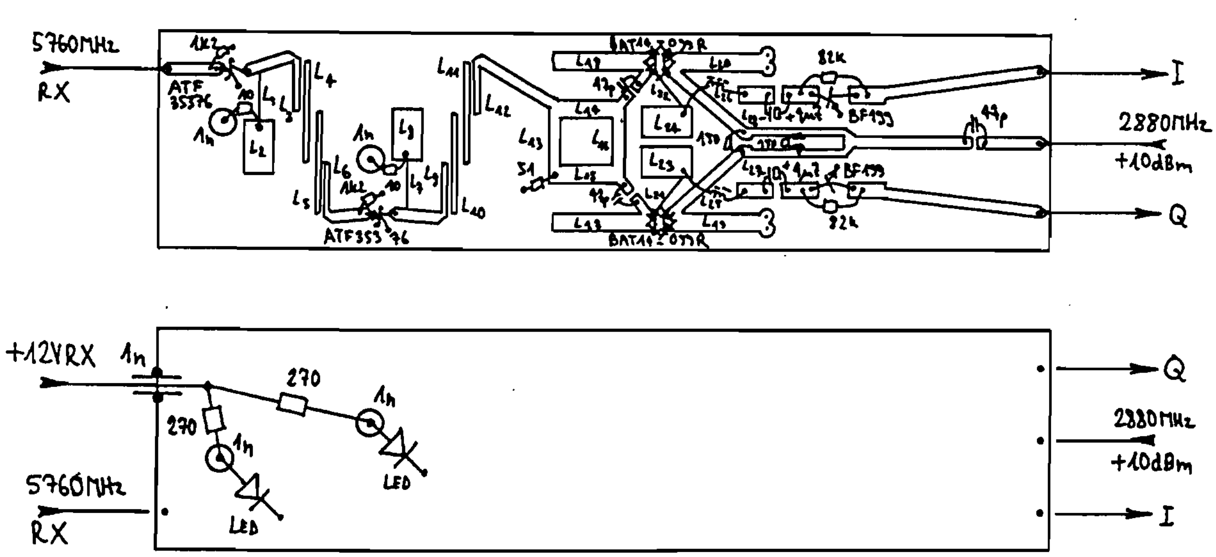


Fig. 41 - 5760MHz RX mixer component location.

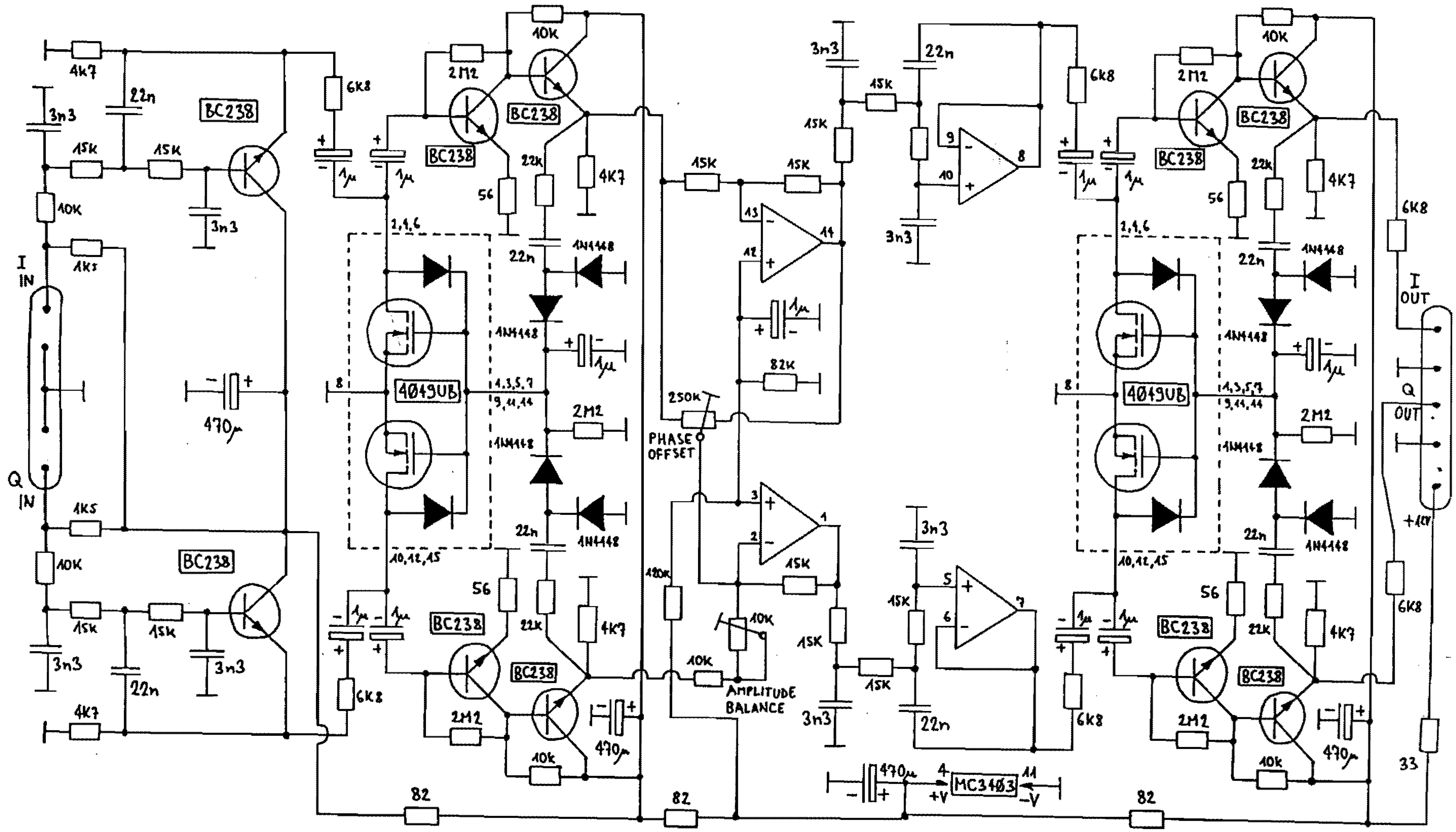


Fig. 42 - Quadrature SSB IF amplifier with AGC.

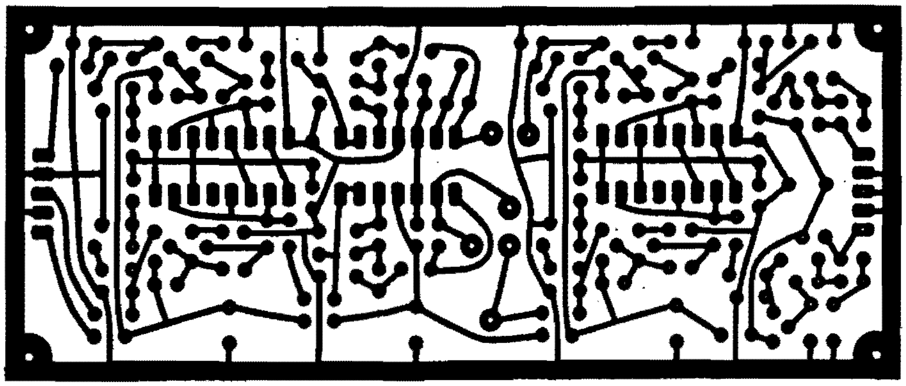


Fig. 43 - IF amplifier PCB (0.8mm single-sided FR4).

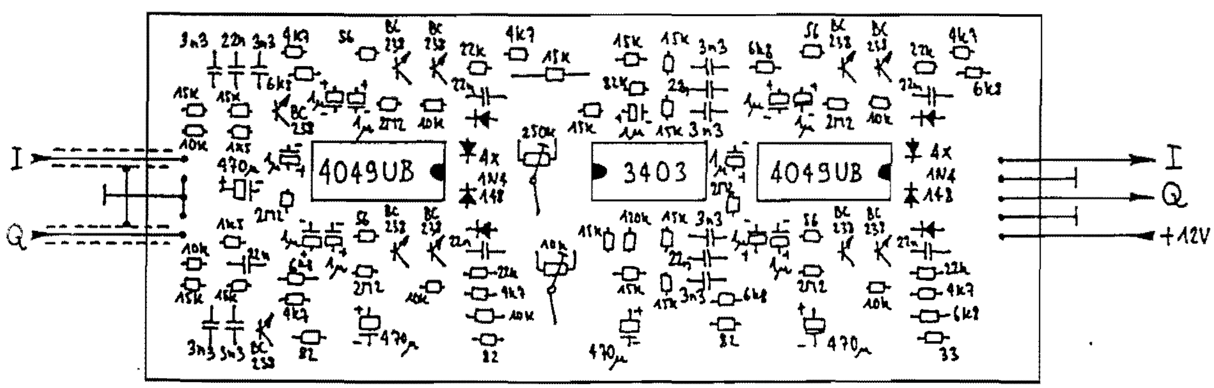


Fig. 44 - IF amplifier component location.

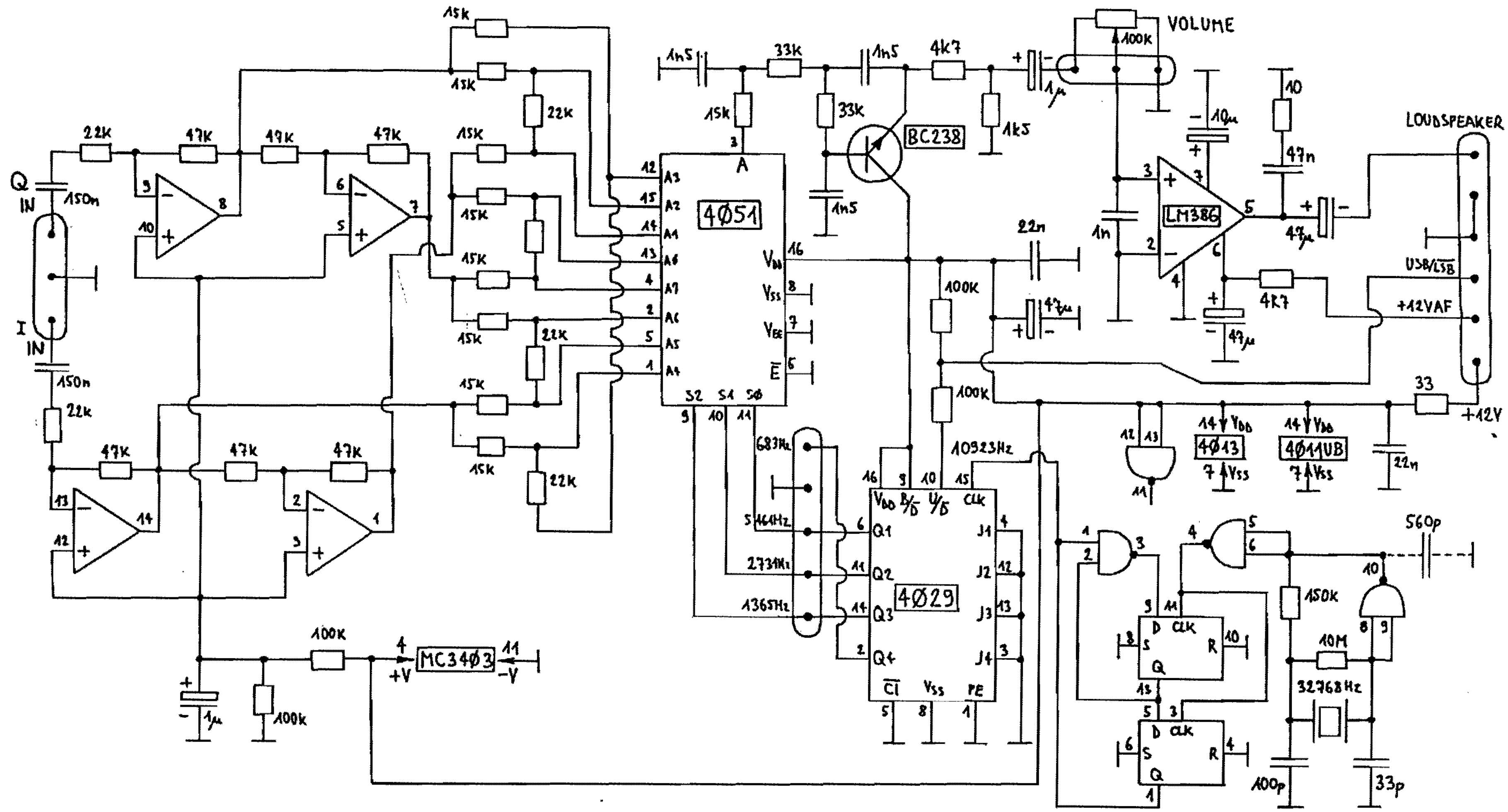


Fig. 45 - Quadrature SSB demodulator and AF amplifier.

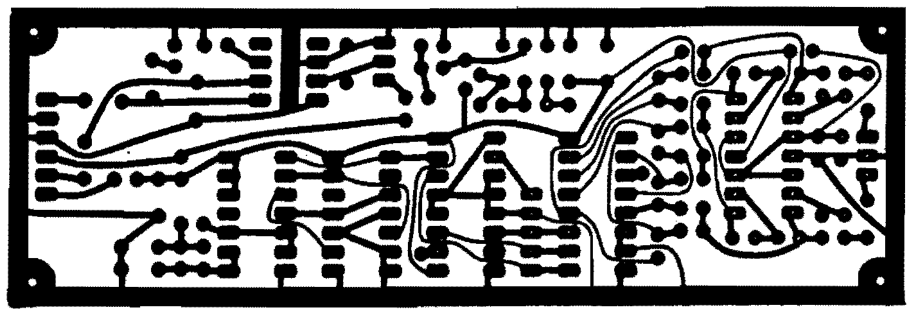


Fig. 46 - Demodulator PCB (0.8mm single-sided FR4).

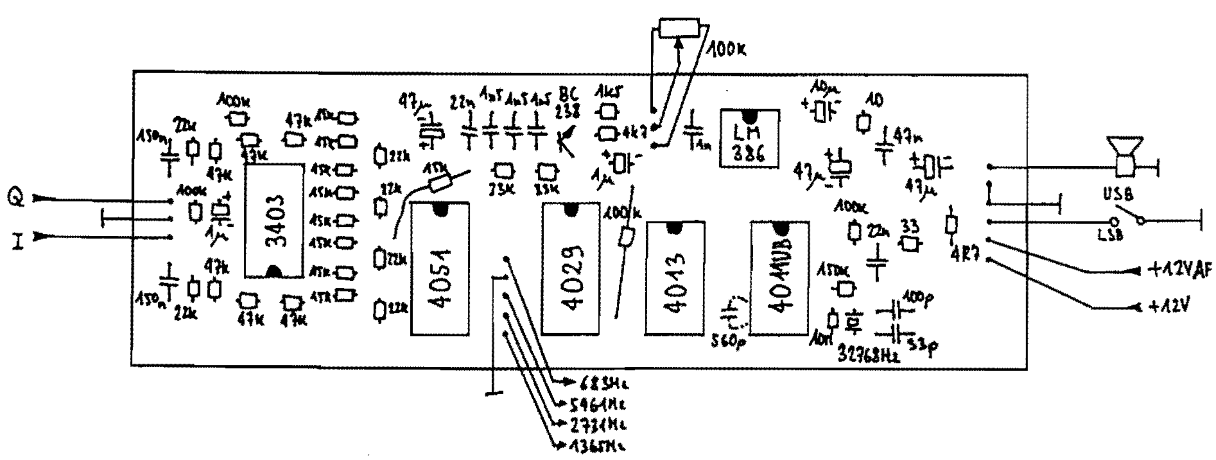


Fig. 47 - Demodulator component location.

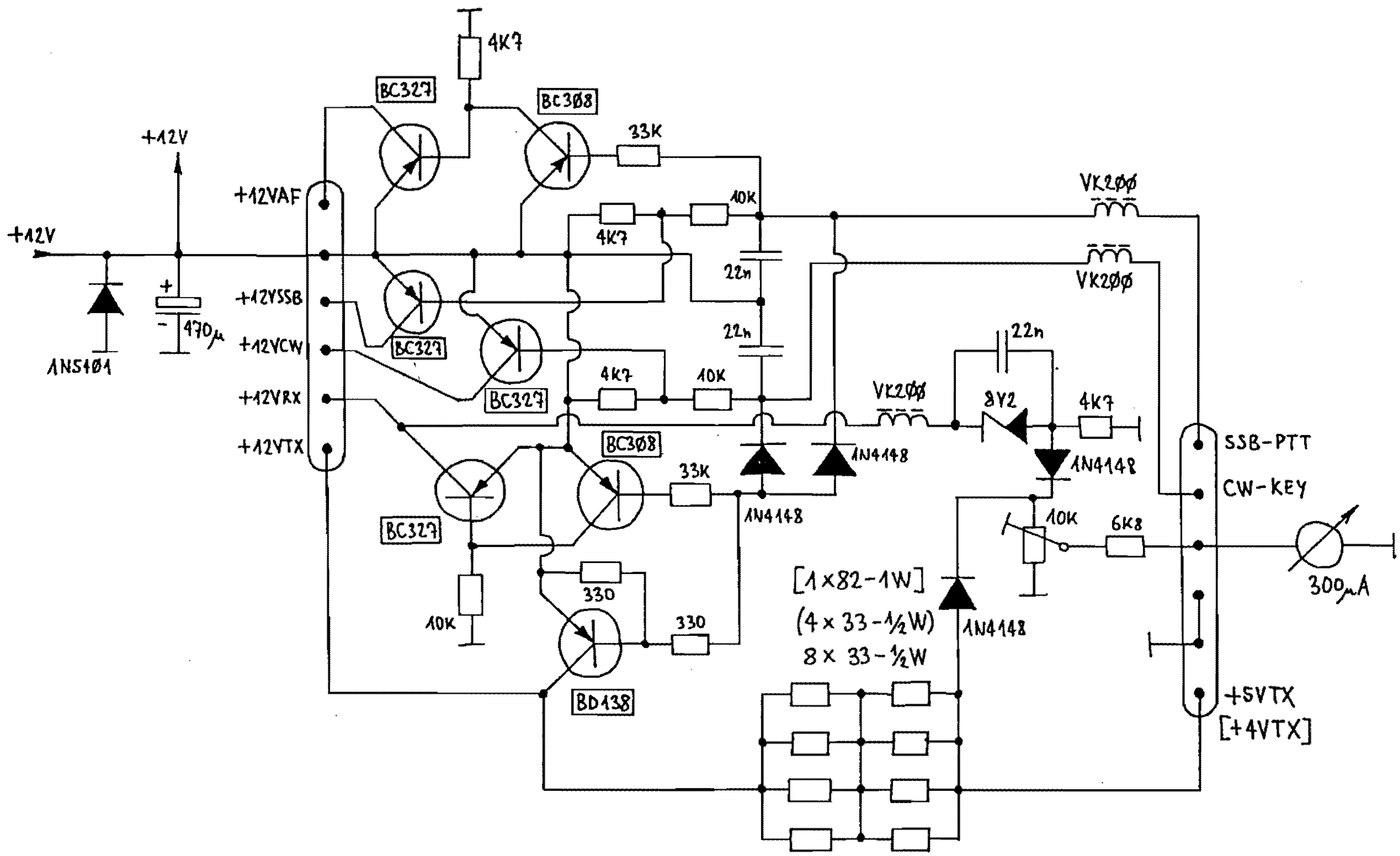


Fig. 48 - SSB/CW switching RX/TX, 1296MHz (2304MHz) [5760MHz].

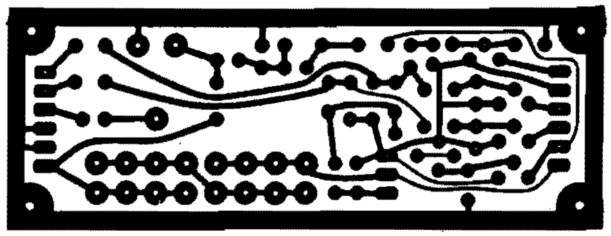


Fig. 49 - SSB/CW switching RX/TX PCB (0.8mm single-sided FR4).

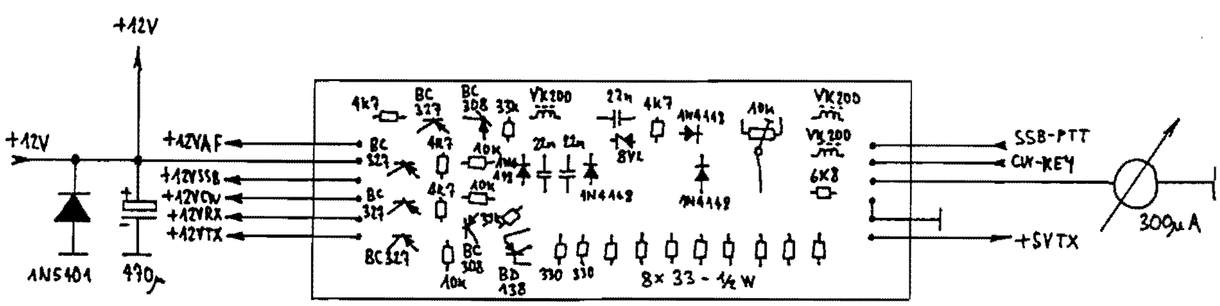


Fig. 50 - SSB/CW switching RX/TX component location.
(1296 MHz).

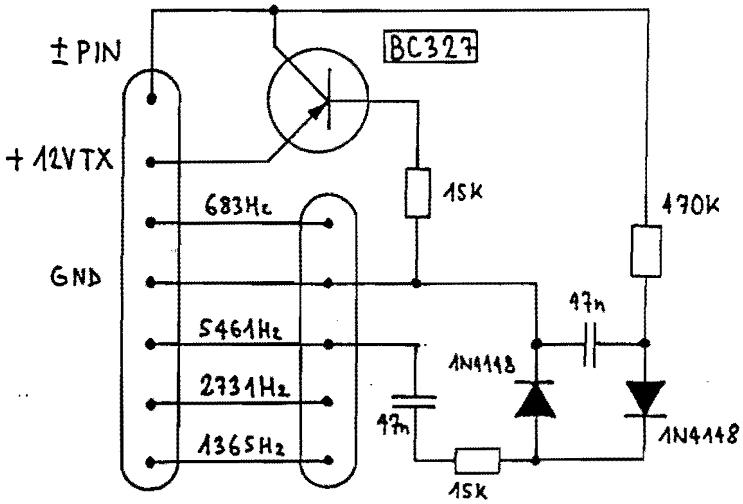


Fig. 51 - PIN driver for 5760 MHz.

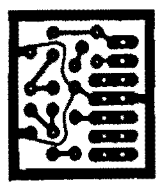


Fig. 52 - PIN driver PCB (0.8mm single-sided FR4).

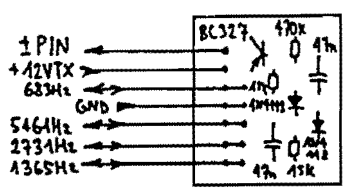


Fig. 53 - PIN driver component location.

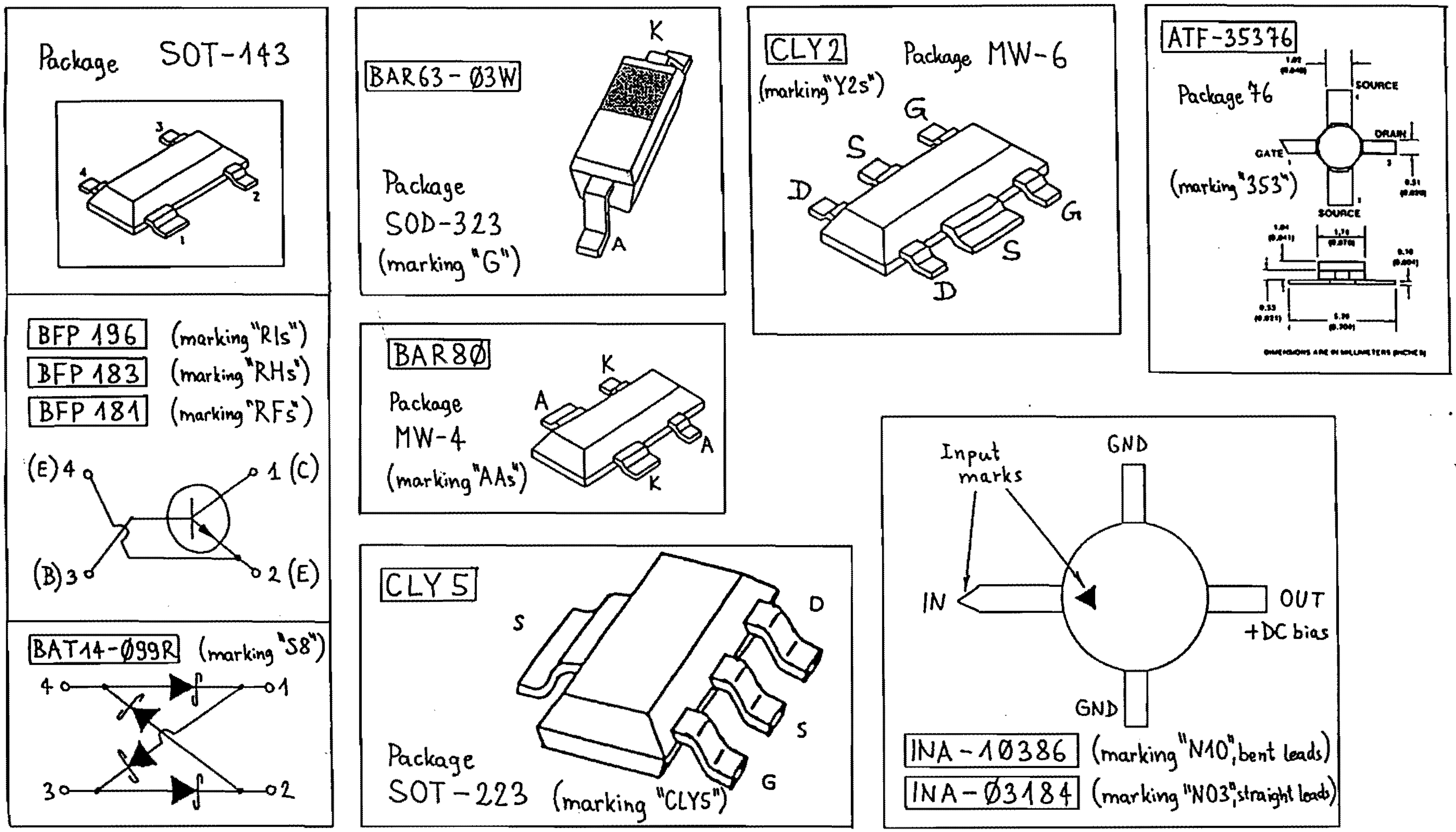
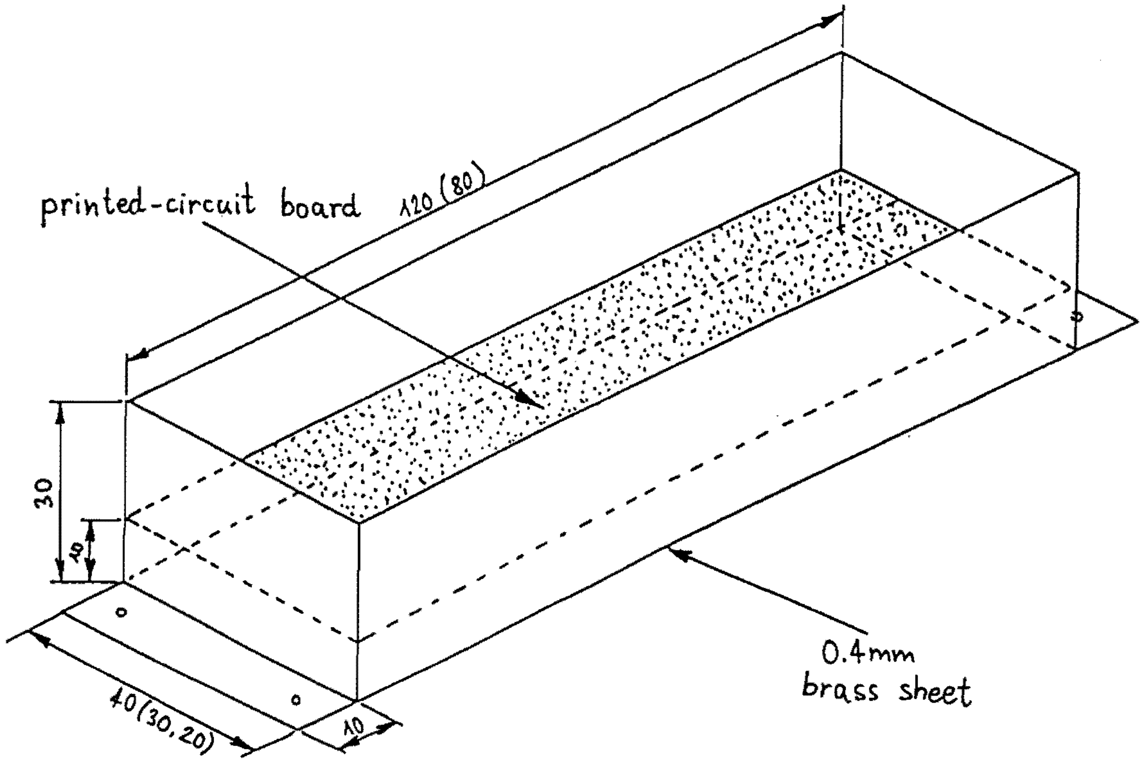


Fig. 54 - SMD semiconductor packages and pinouts.



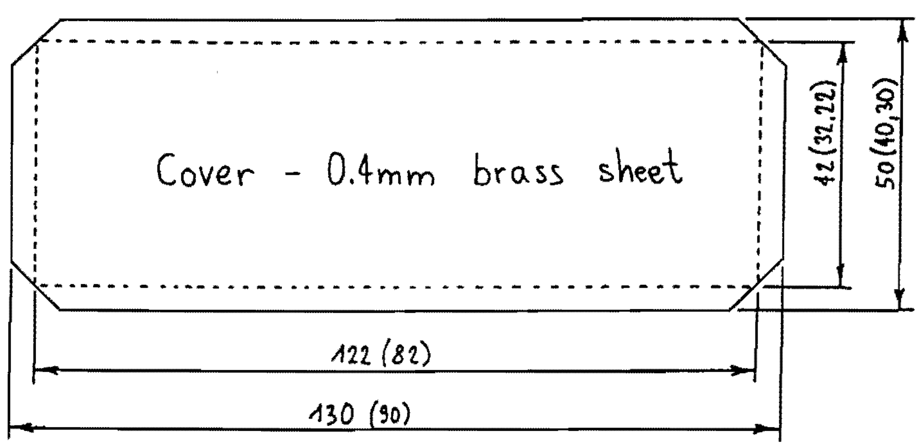


Fig. 55- Shielded RF module enclosure.

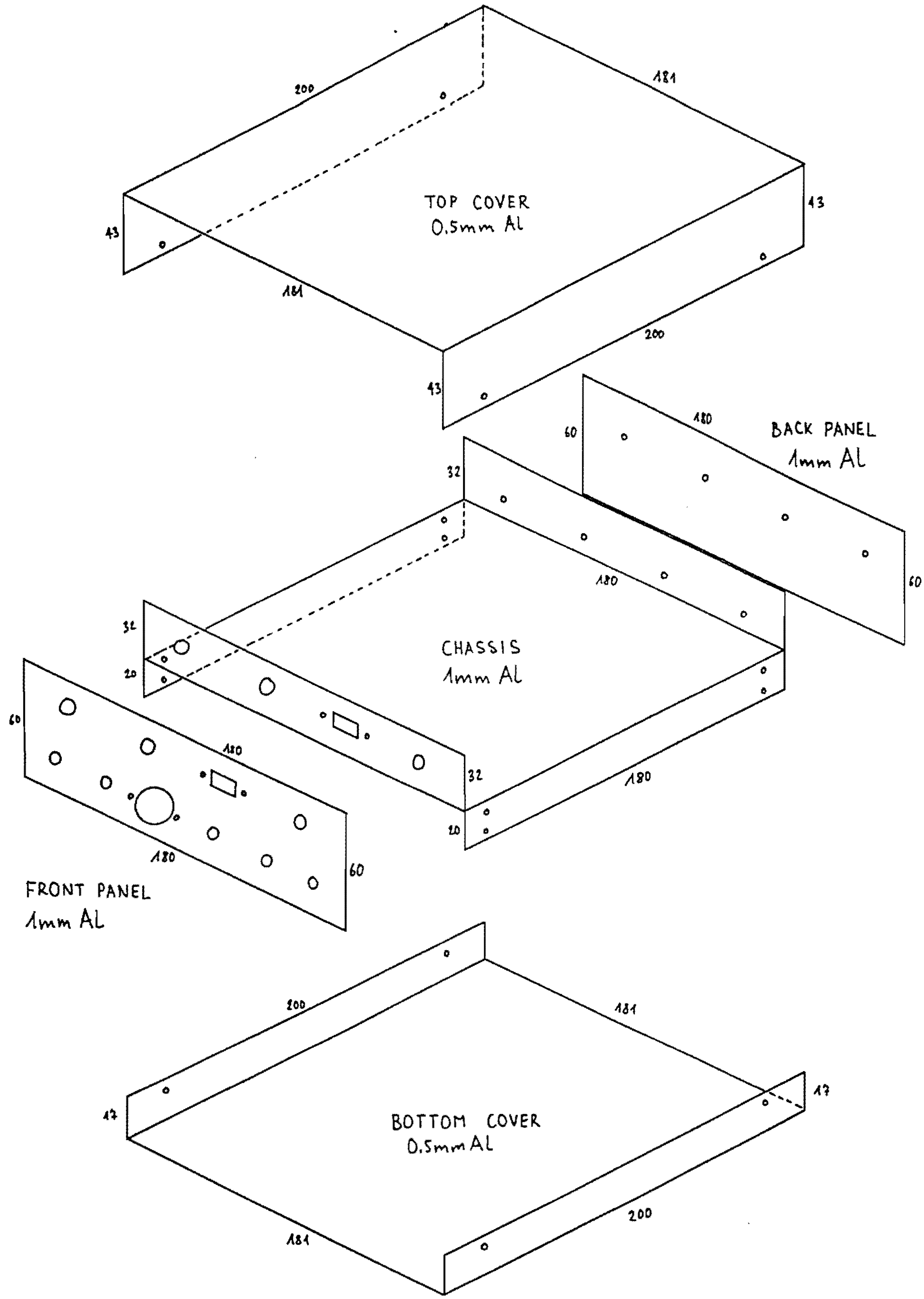


Fig.56 - Zero-IF SSB/CW transceiver enclosure.

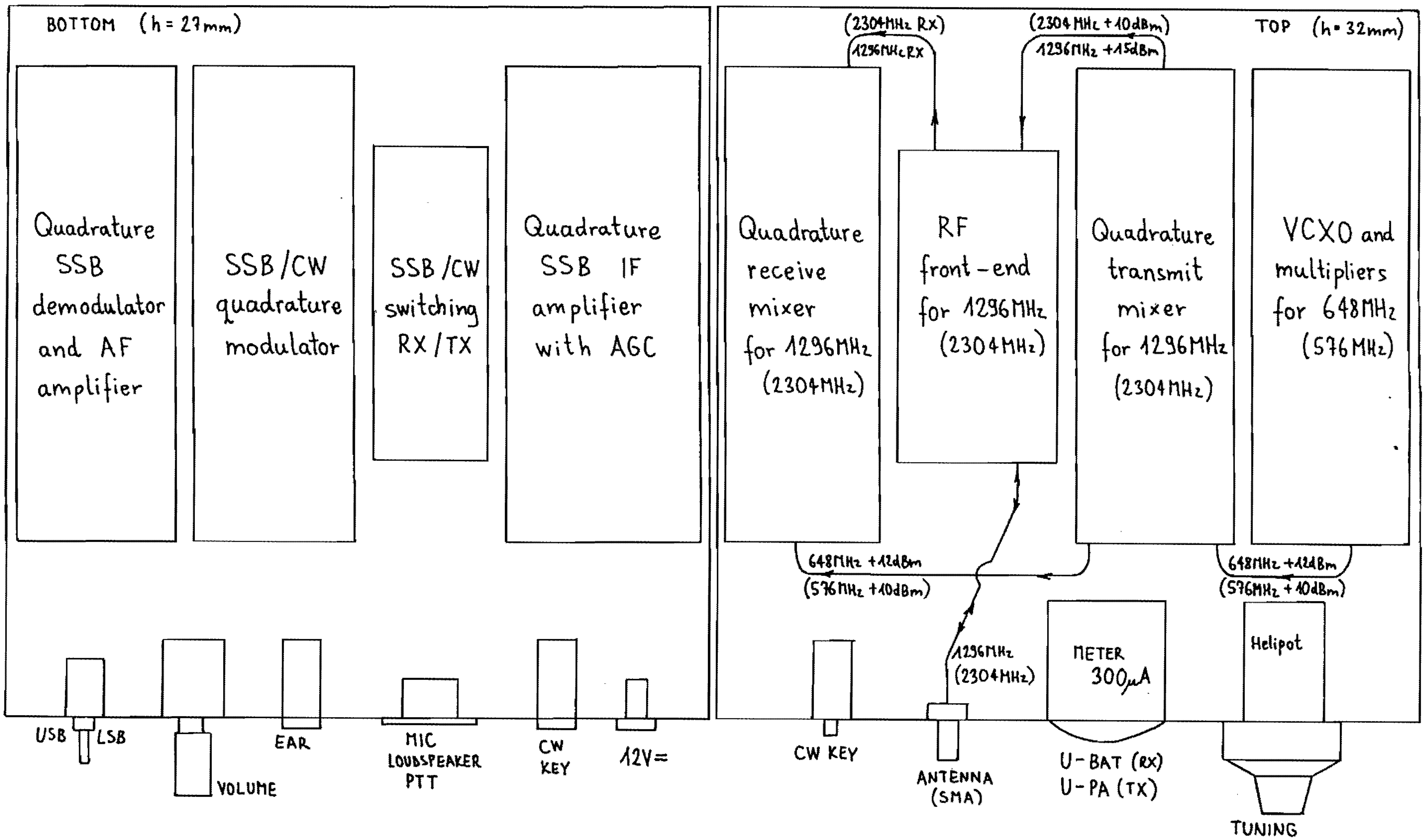


Fig. 57 - 1296 MHz (2304MHz) SSB/CW transceiver module location.

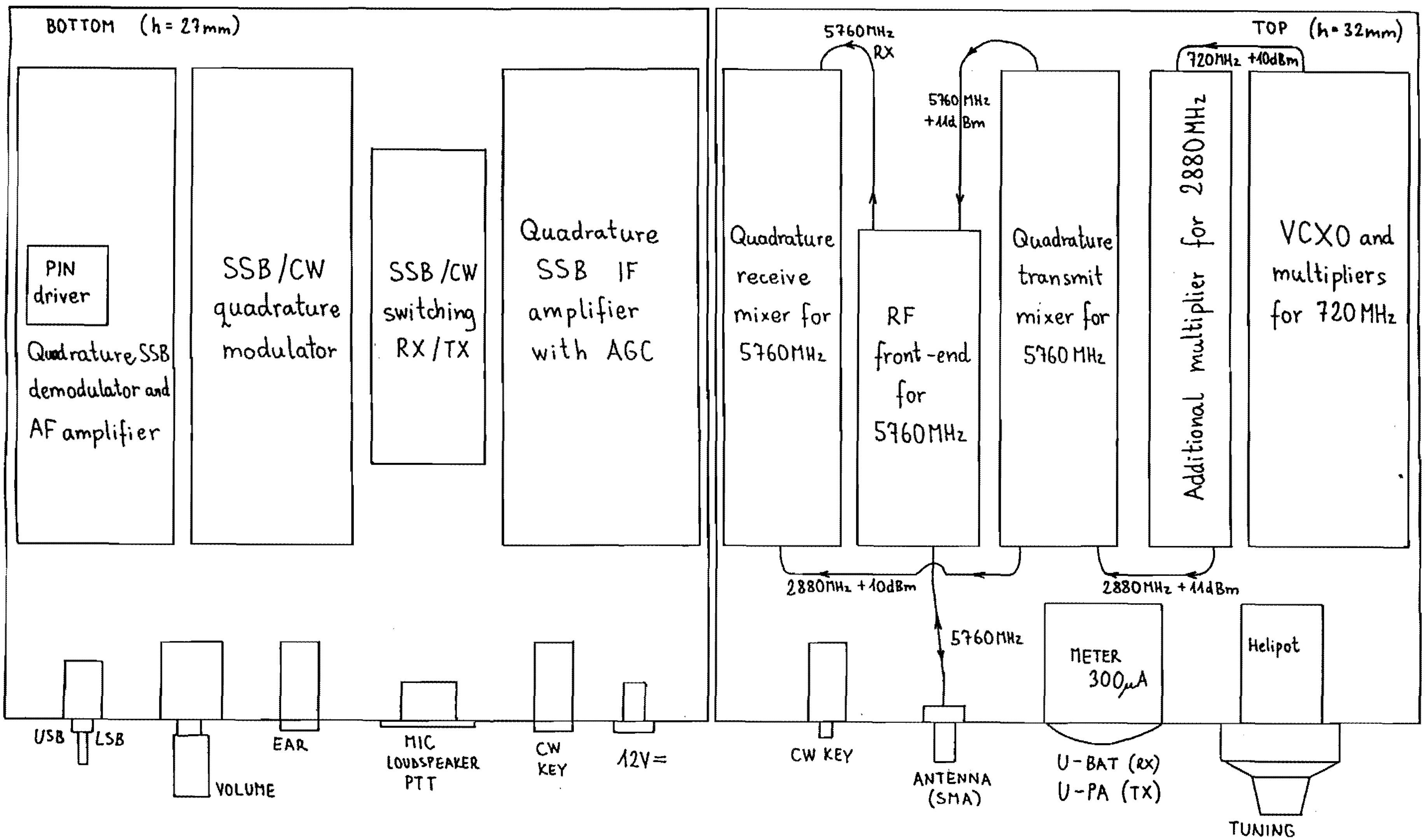


Fig. 58 – 5760 MHz SSB/CW transceiver module location.

NO-TUNE SSB/CW TRANSCEIVER FOR 10GHz

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1. Advantages and drawbacks of zero-IF transceivers

Zero-IF transceivers have both advantages and drawbacks when compared to conventional SSB transceivers with crystal filters and many frequency conversions. Considering the current state of technology, zero-IF transceivers are probably most suitable for the low amateur microwave bands: 1296 MHz, 2304/2320 MHz and 5760 MHz. Therefore working radios for the above mentioned frequency bands were developed first [1].

Although the published zero-IF transceivers for 1296 MHz, 2304/2320 MHz and 5760 MHz allow many modifications and improvements of the original design, one would like to extend the zero-IF design to other frequency bands as well. However, the transfer of a transceiver design to another frequency band may not be straightforward.

Amateur-radio SSB transceivers for 432 MHz and especially 144 MHz require a very high dynamic range. A 144 MHz SSB receiver should both withstand local stations with kilowatt transmitters as well as achieve a low noise figure. The dynamic range requirement for a 144 MHz SSB receiver is probably even more demanding than for a HF (3-30 MHz) receiver.

Extending the published 1296 MHz SSB transceiver design to 432 MHz or even to 144 MHz does not make much sense. The dynamic range of the sub-harmonic mixers used in the 1296 MHz RTX is certainly not sufficient for the current usage of the 144 MHz amateur band. Due to several high-power stations, even direct AM demodulation in the simple sub-harmonic mixers would become a problem. A zero-IF SSB transceiver for 144 MHz requires much better mixers operating at the fundamental LO frequency.

On the other hand it is not easy to find suitable components for very high frequencies. Only components for 10 GHz (transistors, diodes etc) can be readily found on the market and it takes much effort to make them work on 24 GHz. There are few parts suitable for 47 GHz or higher frequencies. In addition, frequency accuracy, mixer balance and quadrature, mechanical stability and efficient shielding are more difficult to handle at higher frequencies.

In this article a zero-IF SSB transceiver for 10368 MHz will be described. The design is based on the same components as the 5760 MHz transceiver: HEMTs are used as amplifiers and BAT14-099R schottky quads are used as sub-harmonic mixers. Although 10 GHz does not represent a problem for HEMTs yet, this seems to be the upper limit for the BAT14-099R quads. The BAT14-099R quads are packaged in the relatively large and unsymmetric SOT-143 package causing severe mixer unbalance problems.

The 10 GHz SSB transceiver also includes PIN-diode antenna switching. The RF front-end is built on teflon laminate, while all other micro-strip circuits are built on conventional FR4 glass fiber epoxy, including several bandpass filters for 10 GHz. The IF and AF sections are of course identical to those used in the transceivers for 1296, 2304 and 5760 MHz.

2. Modified VCXO and multiplier stages

Although the radio-amateur 10 GHz frequency-band allocation extends from 10000 MHz to 10500 MHz, most narrow band operation is concentrated slightly above 10368 MHz. In the near future one may also expect narrow band activity in the satellite segment (10450-10500 MHz), probably concentrated around the lower end around 10450 MHz.

10368MHz is an integer multiple of many popular frequencies. For example, 10368 MHz is the ninth harmonic of 1152 MHz, a reference frequency that also generates 2304 MHz, 3456 MHz, 5760 MHz and 24192 MHz. 10368 MHz is also the eighth harmonic of 1296 MHz suggesting the use of the same VCXO and multiplier chain for 648 MHz with some additional multiplier stages (X8) to obtain 5184 MHz for the sub-harmonic mixers.

However, it makes sense to modify the VCXO itself for operation in the 10 GHz transceiver. The relative crystal frequency pulling should be eight times smaller at 10 GHz due to the additional multiplier stages. On the other hand, frequency stability is much more critical at 10368 MHz than it is at 1296 MHz.

Both requirements can be met by replacing the original VCXO using a 18 MHz fundamental-resonance crystal with a modified VCXO using a 27 MHz third-overtone crystal. Overtone crystals have a higher Q than fundamental crystals therefore providing better frequency stability. On the other hand, the frequency-pulling range of an overtone crystal is very restricted and it is barely sufficient for a 10 GHz transceiver.

Fortunately the circuit diagrams of both VCXOs are similar and the same printed-circuit board can be used for both of them, including the multiplier chain up to 648 MHz. Of course the 10 GHz transceiver requires an additional multiplier for 5184 MHz built in microstrip technology just like in the 5760 MHz transceiver. The 648 MHz input frequency is first multiplied by four to 2592 MHz and then doubled to 5184 MHz.

The modified VCXO and multiplier chain up to 648 MHz are shown on Fig. 1. A 27.000 MHz crystal is required for operation at 10368 MHz. The frequency-pulling range is very small in spite of the large capacitance ratio of the MV1404 varactor. The frequency coverage amounts to only 150-200 kHz at the final frequency centered around 10368.100 MHz.

A coverage of 150 kHz is however sufficient for normal 10 GHz narrow band work, provided that the frequency stability is reasonable. Fortunately the 27.000 MHz crystal is used in teletext decoders inside many TV sets. Thanks to very high volume production these inexpensive crystals have an excellent frequency stability.

The overtone oscillator itself (BFX89) is designed to reduce the loading and therefore the heating of the crystal, to further improve the frequency stability. The VCXO is followed by two resonant circuits (L2 and L3) tuned to 54 MHz. The following multiplier stages are identical to those used in the 1296 MHz transceiver and are tuned to 162 MHz (X3), 324 MHz (X2) and 648 MHz (X2).

Since the VCXO module is followed by an additional multiplier for 5184 MHz in the 10368 MHz transceiver, an output power of 10 mW (+10 dBm) is sufficient at 648 MHz. Therefore the power-supply resistors of the multiplier stages inside the VCXO module are increased to 330 ohm, 330 ohm and 220 ohm. Since the printed-circuit board is the same as in the 1296 MHz version and there are just a few minor variations in the component location, the corresponding drawings will not be published once again.

The circuit diagram of the additional multiplier for 5184 MHz is shown on Fig.2. The circuit includes four HEMTs ATF35376. The first HEMT is overdriven by the 648 MHz signal to produce many harmonics. The following microstrip bandpass (L3, L4, L5, L6, L7 and L8) selects the fourth harmonic at 2592 MHz. The second HEMT amplifies the 2592 MHz signal to drive the third HEMT operating as a frequency doubler. The doubler is followed by a 5184 MHz bandpass (L15, L16, L17, L18, L19 and L20) and the 5184 MHz signal is finally amplified by the last HEMT to obtain 20 mW (+13 dBm).

The additional multiplier for 5184MHz is built on a double-sided microstrip 0.8 mm FR4 board with the dimensions of 20 mm X 120 mm as shown on Fig.3. The corresponding component location is shown on Fig.4. The 5184 MHz multiplier should provide the rated output power (+13 dBm) without any tuning, provided that all of the components are installed and grounded correctly.

3. Quadrature transmit mixer for 10368 MHz

The circuit diagram of the quadrature transmit mixer for 10368 MHz is shown on Fig.5. The 5184 MHz LO signal is taken from a -15dB coupler and the LO signal level is restored by the ATF35376 amplifier stage, feeding two sub-harmonic mixers equipped with BAT14-099R schottky quads. The 5 GHz lowpass attenuates the second harmonic at 10 GHz to avoid corrupting the symmetry of the mixers.

The unwanted carrier rejection of the BAT14-099R sub-harmonic mixers is only 10-15 dB at 10368 MHz. The main reason for the rather poor carrier rejection is the large and unsymmetrical SOT-143 package. Pin 1 of this SMD package is wider than the remaining three pins. Unfortunately, microwave schottky quads in suitable symmetric packages are hardly available and much more expensive than the BAT14-099R.

On the other hand, the sub-harmonic mixer balance can be corrected by a DC bias applied to the diodes. The quadrature transmit mixer for 10368 MHz therefore includes two 10kohm trimmers to adjust the mixer balance. In this way the unwanted carrier rejection can be improved to better than 30 dB.

The two 10 GHz signals are combined in a quadrature hybrid. The hybrid is built as a 100 ohm circuit to save board space. Quarter-wave transformers are used to restore the impedances to 50ohms. The circuit diagrams of both sub-harmonic mixers are slightly different from those used in the 1296, 2304 or 5760 MHz versions for the same reason.

The hybrid is followed by a 10368 MHz bandpass filter (L36, L37, L38, L39 and L40). The latter removes the 5184 MHz LO as well as other unwanted mixing products. After filtering the 10368MHz SSB signal level is rather low (around 30uW or -15dBm), so two amplifier stages with ATF35376 HEMTs are used to boost the output signal level to about 2.5mW (+4dBm).

The quadrature transmit mixer for 10368 MHz is built on a double-sided microstrip 0.8mm FR4 board with the dimensions of 30 mm X 120 mm as shown on Fig.6. The corresponding component location is shown on Fig.7. Since only positive bias is available through the 10kohm trimmers for mixer balancing, the BAT14-099R packages should be oriented correctly in the circuit. In particular, one of the two packages has to be installed upside down.

Except for the balancing trimmers, the quadrature transmit mixer for 10368 MHz should not require any tuning. Both balancing trimmers are simply adjusted for the minimum output power when no modulation is present. This adjustment is best performed when the whole transceiver is assembled.

4. RF front-end for 10368MHz

The circuit diagram of the RF front-end for 10368 MHz is shown on Fig.8. The RF front-end includes a transmit power amplifier, a receive low-noise amplifier and a PIN-diode antenna switch. Unlike the RF front-ends for 1296, 2304 or 5760 MHz, all built on FR4 laminate, the RF front-end for 10368MHz is built as a microstrip circuit on 0.5mm thick teflon laminate to reduce RF losses.

Building the microstrip circuit on glassfiber-teflon laminate (thickness 0.5 mm or 0.020", dielectric constant Er=2.55) allows a 1-2 dB increase of the transmitter output power and a 1-2dB improvement of the receiver noise figure. The output power of the 10368 MHz transmitter is in fact even slightly higher than the output power of the 5760 MHz transmitter. Although both transmitters use the same semiconductor devices (HEMTs), the latter is built on lossy FR4 laminate.

The transmitter power amplifier is designed with inexpensive HEMTs, so the output power is limited to 100mW (+20dBm) on the antenna connector. The amplifier includes an ATF35376 HEMT driver stage followed by two ATF35376 HEMTs in parallel in the output stage. The 100ohm resistor between L5 and L6 improves the power dividing and prevents push-pull parasitic oscillations of the output stage.

The two output HEMTs receive a positive bias on the gates both while transmitting and while receiving. During transmission the transistors generate a self-bias just like in the 5760MHz transmitter. Of course the +4VTX supply line requires a current-limiting resistor.

The antenna switch is using a single shunt PIN diode just like the 5760 MHz counterpart with the PIN diode BAR80. However, the parasitic capacitance of the BAR80 is far too high for operation at 10368 MHz, so the new diode BAR81 (SMD component marking "ABs" or "BBs", same MW-4 package) has to be used. The parasitic capacitance of the new BAR81 PIN diode is less than half that of the old BAR80. The insertion loss of the BAR81 is reduced by applying a negative bias (+-PIN) while receiving.

During transmission, the BAR81 is turned on and the short circuit is transformed by L15 into an open circuit at the summing node. The insertion loss of the BAR81 in the receive path exceeds 20 dB and this is sufficient to protect the receiver. During reception, the two transmitter output HEMTs act as short circuits thanks to the positive gate bias. The short circuit is transformed through package parasitics, L7, L8 and interconnecting lines (total electrical length ¾ lambda) into an open circuit at the summing node.

Since there are no strong signals expected in the 10 GHz band, the LNA for 10368 MHz includes two stages with ATF35376 HEMTs. The total insertion gain including the losses in the antenna switching network and the two 10368 MHz bandpass filters amounts to about 23dB.

The RF front-end for 10368 MHz is built on a double-sided microstrip 0.5 mm glass fiber teflon board with the dimensions of 30 mm X 80 mm as shown on Fig.9. The corresponding component location is shown on Fig.10. A low-loss teflon laminate allows a higher output power and a better noise figure. On the other hand, a low-loss teflon laminate does not suppress the parasitic oscillations of HEMTs in the millimeter frequency range. These oscillations have to be controlled by damping resistors, usually 100ohm connected between gate and source.

The RF front-end for 10368 MHz includes a single tuning point. A capacitive tuning stub (a 2 mm X 3 mm piece of copper foil) is added to L13 to improve the antenna matching, which in turn depends on the installation of the antenna cable and connector. This matching stub will improve the output power by about 1dB or in other words, the output power may be as low as 80 mW without any tuning.

5. Quadrature receive mixer for 10368MHz

The circuit diagram of the quadrature receive mixer for 10368 MHz is shown on Fig.11. It differs from the similar 5760 MHz mixer in the design of the quadrature hybrid and sub-harmonic mixers with BAT14-099R diodes. The module includes two RF amplifiers with ATF35376 HEMTs, two 10368 MHz bandpass filters, two sub-harmonic mixers operating in quadrature and two identical IF preamplifiers with BF199 transistors.

The sub-harmonic mixers are identical to those in the transmitter using BAT14-099R schottky quads. Both mixers are supplied in phase (L49 and L50) with the LO signal. The RF input signal is split by a 100 ohm quadrature hybrid (L25, L26, L27 and L28). Impedance matching is provided by quarter-wavelength lines L23, L29 and L30.

The mixers are followed by two IF preamplifiers with BF199 transistors identical to those used in the 1296, 2304 and 5760 MHz receivers. The 3.3mH chokes can be replaced by lower values, since powerful signals (both amateur and out-of-band) are not expected in the 10GHz band. Lower value chokes are less sensitive to disturbing low-frequency magnetic fields, including disturbing fields generated in the transceiver itself.

The quadrature receiving mixer for 10368 MHz is built on a double-sided microstrip 0.8mm FR4 board with the dimensions of 30 mm X 120 mm as shown on Fig.12. The corresponding component location is shown on Fig.13. In the 10 GHz band, a quarter wavelength is only 4 mm long on FR4 or 5 mm long on teflon boards, so more complicated microstrip circuits can be used. For example, the supply/bias chokes are built as two-section lowpass filters on the RF-front-end teflon board and as three-section lowpass filters on both mixer FR4 boards. These improved RF chokes introduce less insertion loss and allow a lower crosstalk.

The receiving mixer for 10368 MHz requires no tuning. However, the BF199 IF preamplifier transistors should be selected for the lowest noise. It seems that these transistors do not have a guaranteed "1/f" noise specification. In all of the prototypes built the Philips BF199 transistors produced the least amount of noise.

6. Construction of the zero-IF SSB transceiver for 10368MHz

The SSB/CW transceiver for 10368 MHz is using the same quadrature modulator, IF amplifier and demodulator as the similar transceivers for 1296, 2304/2320 and 5760 MHz. Since the same semiconductors are used as in the 5760 MHz version, the current-limiting resistor in the SSB/CW switching RX/TX module has to be set to 82 ohm, 1W.

The new PIN diode BAR81 also requires the small PIN driver module also used in the 5760 MHz transceiver. Since the new BAR81 is much improved with respect to the old BAR80, the resulting receiver sensitivity loss amounts only to a few dB if no negative bias is provided (no PIN driver used) and the +-PIN line is simply connected to +12VTX. It therefore makes sense to use the new BAR81 also in the 5760 MHz transceiver, while the old BAR80 is good enough for 1296 or 2304/2320 MHz.

In the 10 GHz frequency range, even small SMD components are rather large when compared to the wavelength of only 29 mm. The size of the SMD resistors and capacitors is usually indicated in hundredths of an inch (0.254 mm). The first SMD resistors and capacitors were of the size 1206 (about 3 mm X 1.5 mm). Today, most SMD components are available in the sizes 0805 and 0603, while the newest components are of the size 0402 (dimensions 1 mm X 0.5 mm).

Large 1206 SMD capacitors should not be used in the 10368 MHz transceiver, since they have parasitic internal resonances in the 10 GHz frequency range. The resonant frequencies are further decreased by the high dielectric constant of the ceramic used to build these capacitors. In the 10368 MHz transceiver only 0805 or smaller SMD parts should be used.

In the 10 GHz frequency range it makes sense to use small-value capacitors (mainly 6.8pF in the circuit diagrams), since they are built from low-loss WHITE ceramic with a moderate dielectric constant and internal resonances above 18 GHz. Higher-value capacitors made from colored ceramic (purple or brown) have higher RF losses and lower resonance frequencies. Finally, the newest and smallest 0402 resistors and capacitors are useful even at 24 GHz.

The main building block of the RF circuits operating at 10368 MHz are the ATF35376 HEMTs, although there are many similar devices produced by other manufacturers that offer the same S-parameters at similar bias conditions. When selecting these devices one should take care of the Idss, since most of these transistors operate at zero bias for circuit simplicity.

An Idss of about 30 mA is desirable. Devices with higher Idss are only useful in the transmitter output amplifier. If devices with a sufficiently low Idss can not be obtained, then the 270 ohm 1/2W (or similar) resistors should be reduced to allow proper operation of the zener or LED shunt regulator. Lower NF selections of the same device, like the ATF35176 or the ATF35076, usually have a higher Idss!

The intermediate/audio frequency section of zero-IF or direct-conversion transceivers also requires a careful selection of active devices with low "1/f" of "popcorn" noise. Experience accumulated by building many transceivers for 1296, 2304/2320, 5760 and 10368 MHz shows that Philips BF199 transistors perform best in the IF preamplifiers. However, several very noisy samples of the BC238 transistors had to be replaced in the quadrature IF amplifiers as well. It seems that factory rejects fairly exceeding the "1/f" noise requirements are sent to hobbyist shops. On the other hand, industrial leftovers found at flea markets perform best, since these devices had to go through severe input quality controls.

The RF modules of the 10368 MHz SSB transceiver have the same dimensions as the corresponding units of the 5760 MHz counterpart, but the exact locations of the electrical connections are slightly different. Their shielded enclosures should be carefully manufactured out of thin brass sheet, since the 10368 MHz SSB transceiver is even more sensitive to microphonics and RF leakage. Both transmit and receive mixers and the RF front-end require 1 cm thick microwave absorber foam (anti-static foam) installed under the covers of the shielded enclosures.

The VCXO module does not require a bottom cover like in the 1296 MHz version, since 10368 MHz is only the sixteenth harmonic of 648 MHz. On the other hand, the additional multiplier for 5184 MHz and the RF modules should be accurately shielded. Efficient feed-through capacitors should be used elsewhere. All internal RF connections should be made with double-braid flexible teflon coax or UT085 semi-rigid.

The complete 10368 MHz SSB transceiver can be installed in the same enclosure as the 1296, 2304 or 5760 MHz versions with a central chassis and internal dimensions of 60 mm (height) X 180 mm (width) X 180 mm (depth). The module location within the enclosure is the same as in the 5760 MHz version, including a similar wiring among the modules.

The loudspeaker should not be installed in the same case to avoid microphonics. Microphonics could perhaps be reduced by using machined enclosures for the RF modules. Mechanical vibrations can also be controlled by inserting pieces of plastic foam between the modules to act as an acoustic absorber.

7. Checkout of the zero-IF SSB transceiver for 10368 MHz

The checkout of the transceiver should start with the alignment of the VCXO and multiplier stages. The VCXO should be adjusted for the desired frequency coverage. The multiplier stages are simply adjusted for the maximum output at the desired frequency. The maximum is observed as the rectified voltage drop on the base of the following transistor, measured through a suitable RF choke. The maximum on 648 MHz is measured as the drain-current dip of the 2592 MHz multiplier. Although the additional multiplier does not require any adjustments, the output signal level (+13 dBm at 5184 MHz) should be checked.

Since the receiver does not require any tuning, it should already work. First, the overall amplification should be checked. The output noise should drop when the supply to the

LNA is removed. When the IF preamplifiers are disconnected, the noise should drop almost to zero.

Next the receiver is connected to an antenna and tuned to a weak unmodulated carrier (distant beacon etc). Besides the desired signal its rather weak image should also be heard in the loudspeaker. The image can be detected since its frequency changes in the opposite direction when tuning the receiver. The image is then attenuated by adjusting the two trimmers, phase quadrature and amplitude balance, in the IF amplifier.

The transmitter should be first checked for the output power. The full output power should be achieved with the trimmer in the modulator at about 1/3 resistance in CW mode. The DC voltage across the PA transistors should rise to the full voltage allowed by the 4V7 zener. Finally, the output power is optimized with the tuning stub on L13.

The transmitter is then switched to SSB to adjust the balance of both transmit mixers. The two 10 k ohm trimmers are simply adjusted for the minimum output power with no modulation. Unfortunately this setting is sensitive to the mixer-diode temperature and 5184 MHz LO drive level, so the carrier suppression may not stay as good as it was adjusted during the checkout of the transceiver.

The SSB modulation should be checked in a radio contact with another amateur station on 10368 MHz. In particular the correct sideband, USB or LSB, should be checked, since the I and Q modulation lines are easily interchanged by mistake. The other station should also check the carrier leakage or transmit mixer unbalance, heard as a 1365 Hz tone added to the modulation.

Finally, the shielding of the transceiver should be checked. Waving your hand in front of the antenna usually causes a 1365 Hz whistle in the loudspeaker of the receiver. The latter is caused by local oscillator leakage, frequency shifted by the Doppler effect of the moving hand and finally collected by the antenna. While this effect can not be eliminated completely with the suggested mechanical construction, it should be small enough to allow normal use of the transceiver. Of course, the receiver sensitivity and shielding can also be checked with a mains-operated fluorescent tube as described for the 1296, 2304 and 5760 MHz transceivers.

The current drain of the described 10368 MHz transceiver should be around 390 mA during quiet reception at a nominal supply voltage of 12.6 V. The current drain of the transmitter is inversely proportional to the output power and ranges from 550 mA (CW or SSB peak power) up to 580 mA (SSB no modulation). The current drain could be reduced substantially if a more efficient regulator were used to power the several HEMT stages with an operating voltage of only 2 V.

[1] Matjaz Vidmar: "NO-TUNE SSB TRANSCEIVERS FOR 1296, 2304 & 5760 MHz".

List of figures:

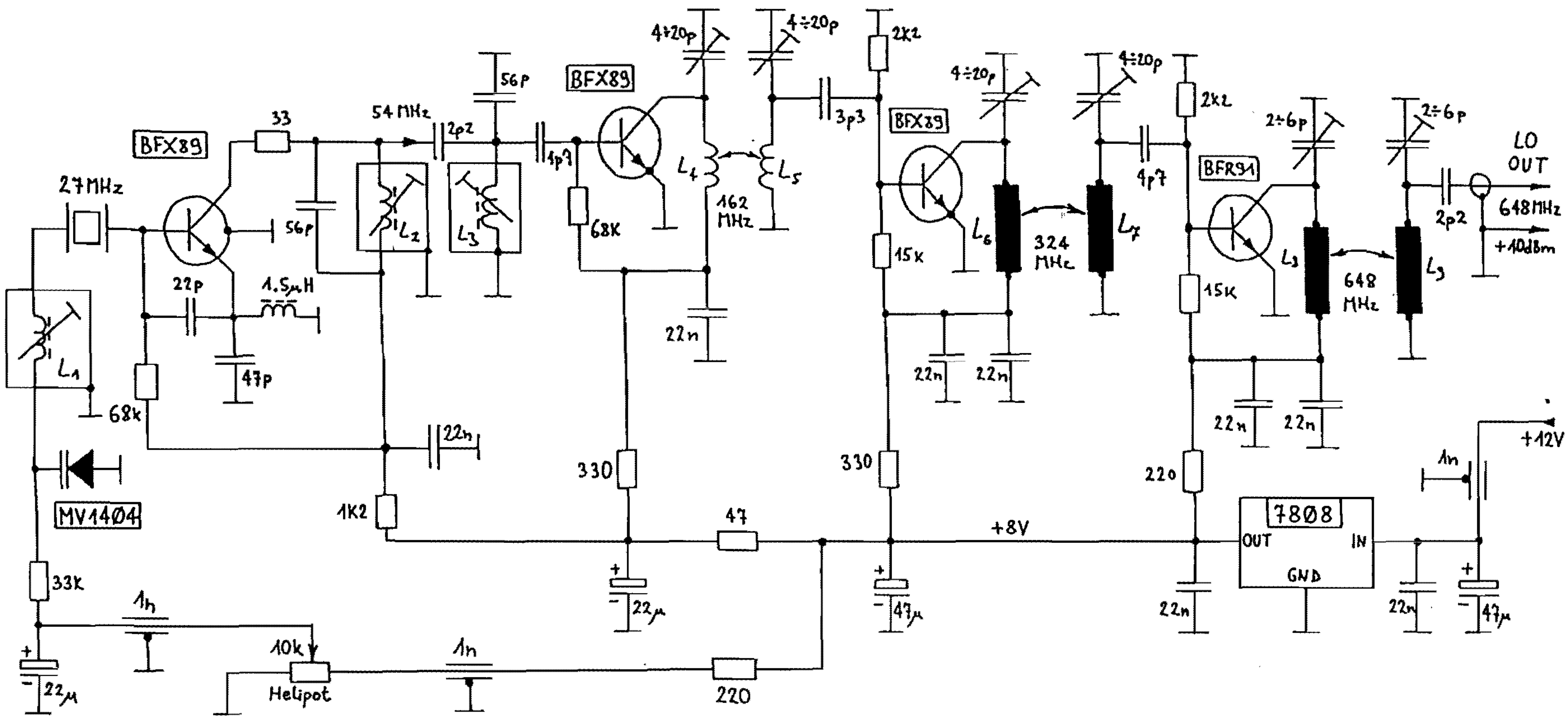

Fig. 1 - VCXO and multipliers for 648MHz.

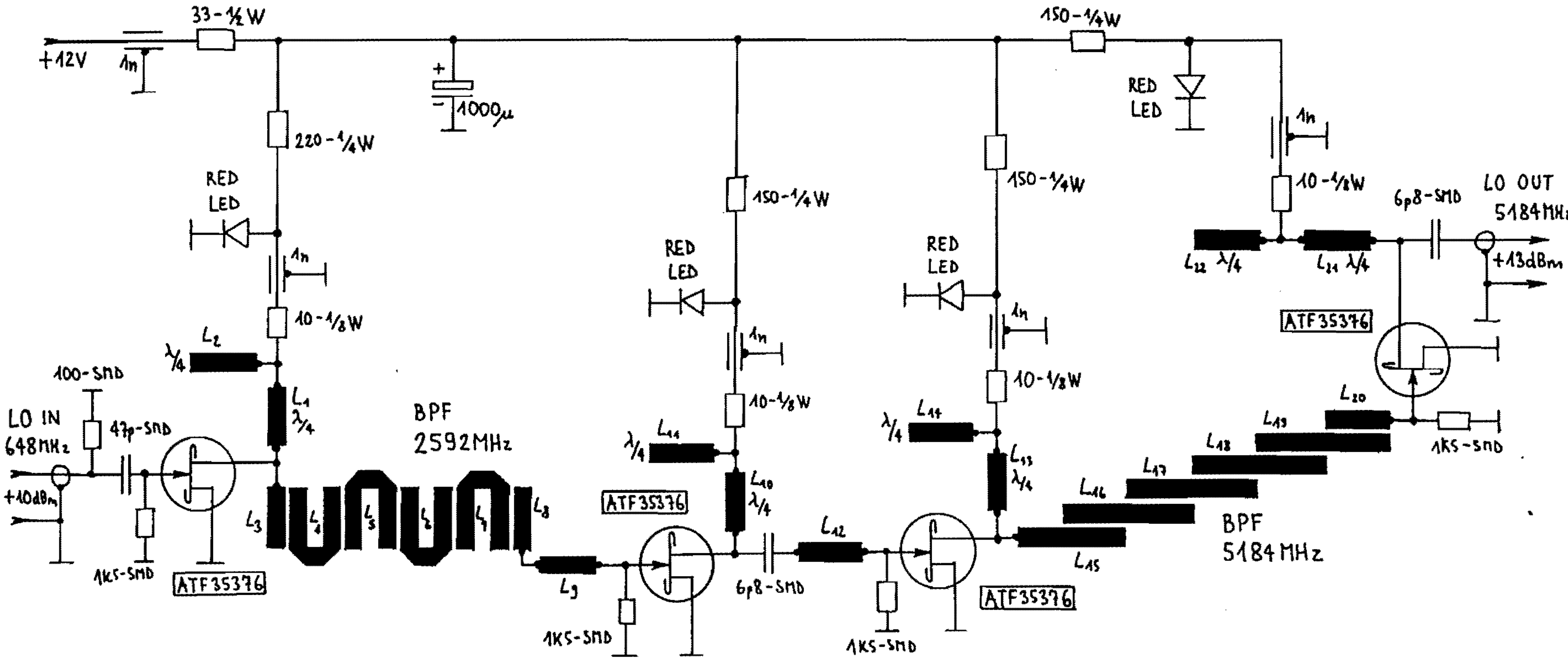

Fig. 2 - Additional multiplier for 5184 MHz.

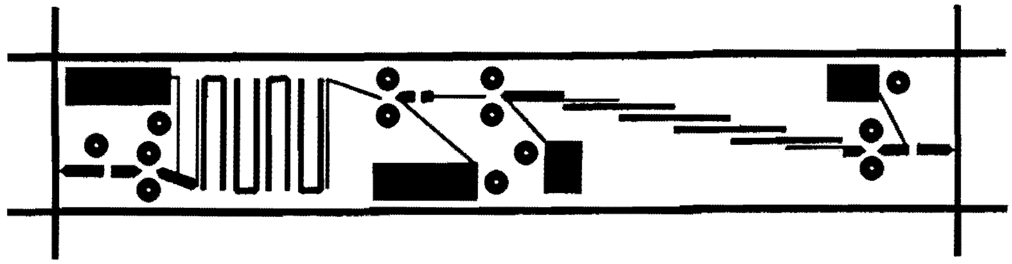

Fig. 3 - 5184 MHz multiplier PCB (0.8 mm double-sided FR4).

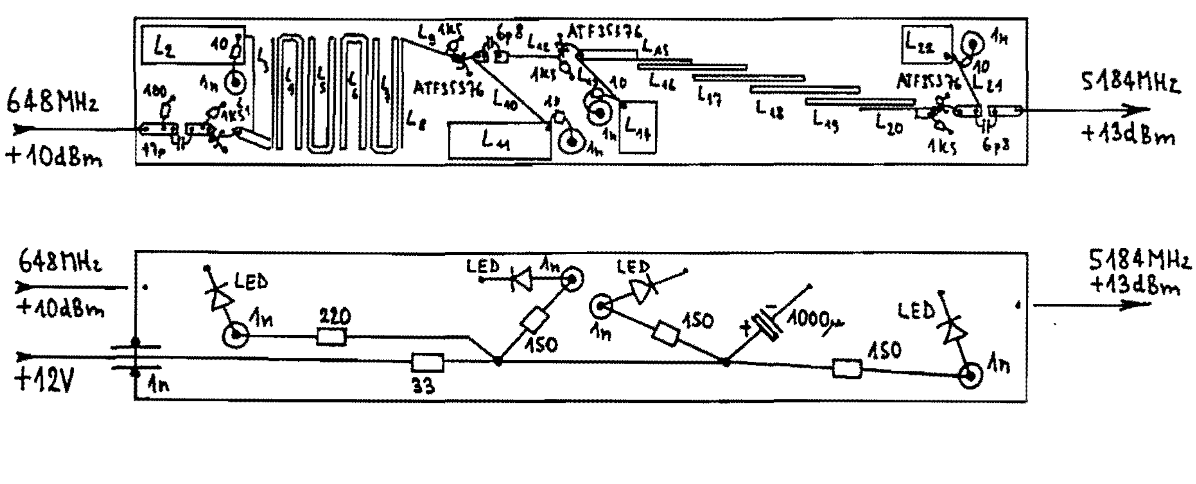

Fig. 4 - 5184 MHz multiplier component location.

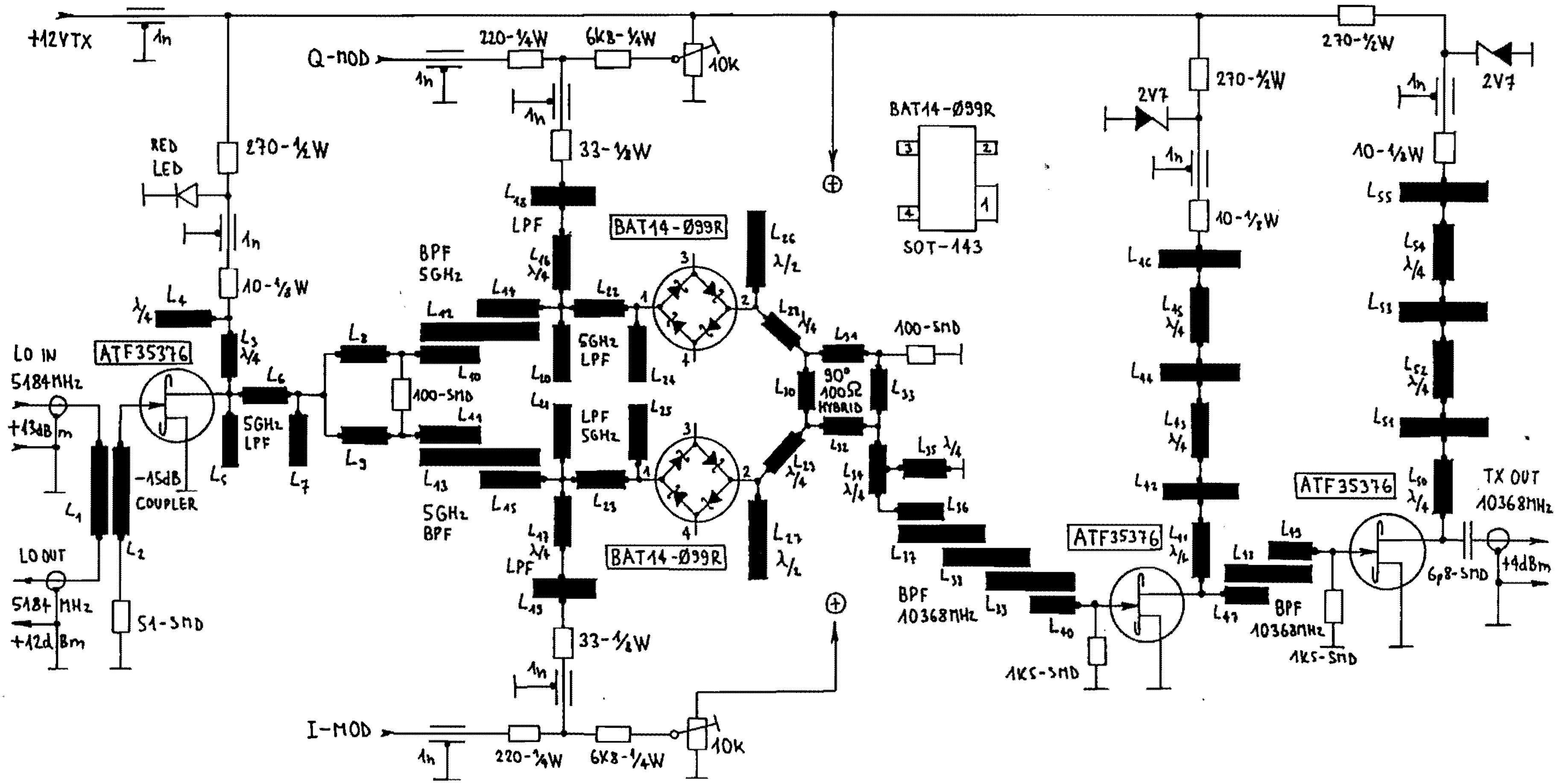

Fig. 5 - Quadrature transmit mixer for 10368 MHz.

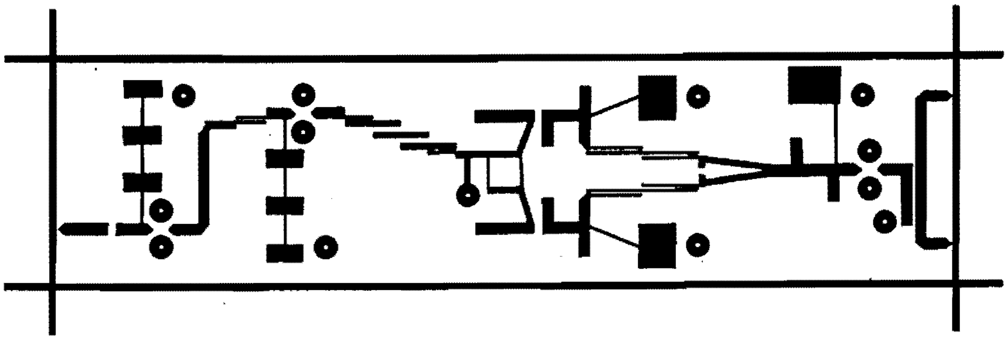

Fig. 6 - 10368 MHz TX mixer PCB (0.8mm double-sided FR4).

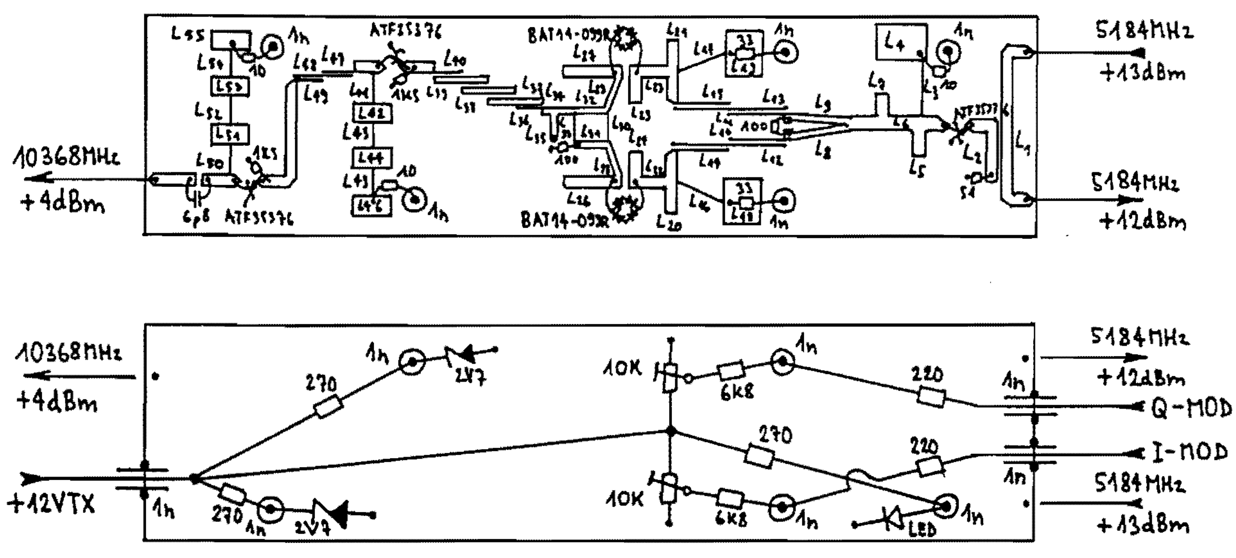

Fig. 7 - 10368 MHz TX mixer component location.

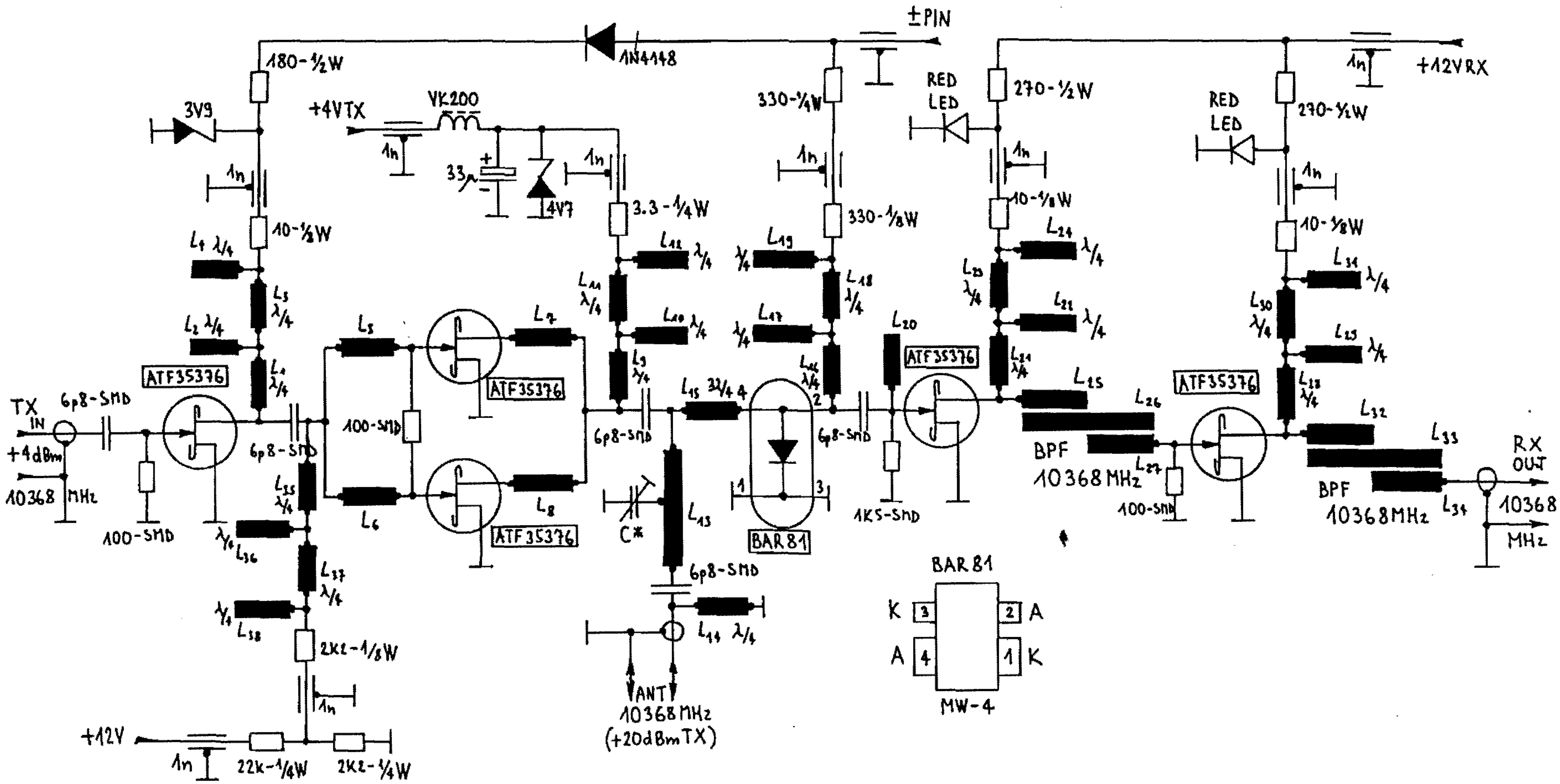

Fig. 8 – RF front-end for 10368MHz.

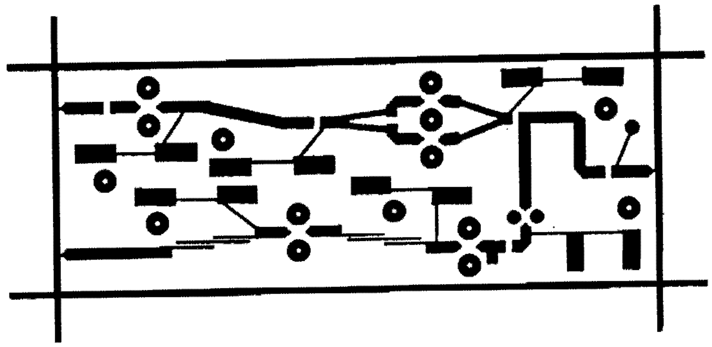

Fig. 9 - 10368 MHz RF front-end PCB (0.5mm glassfiber-teflon $\varepsilon_r = 2.55$).

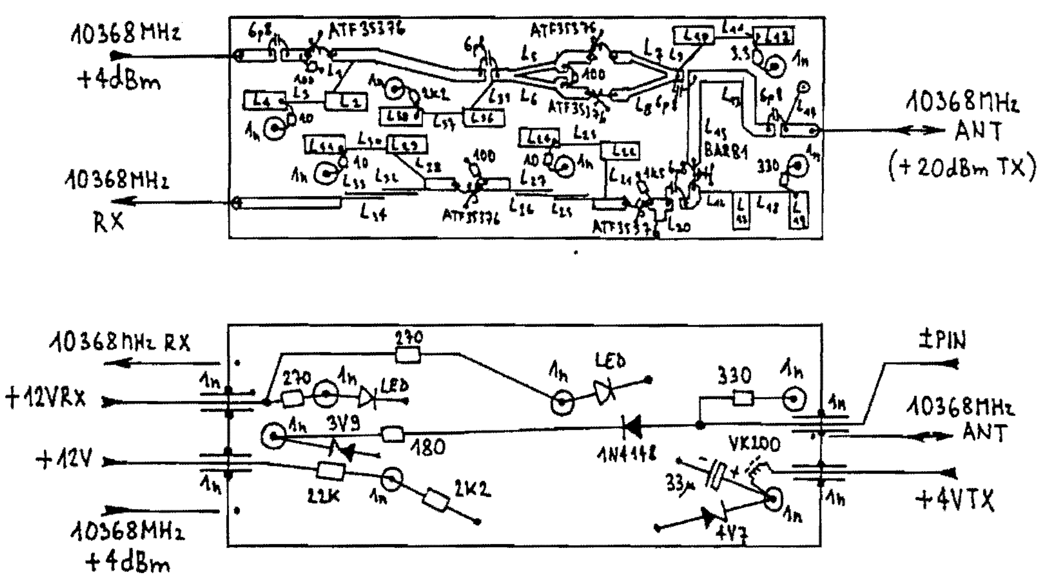

Fig. 10 - 10368 MHz RF front-end component location.

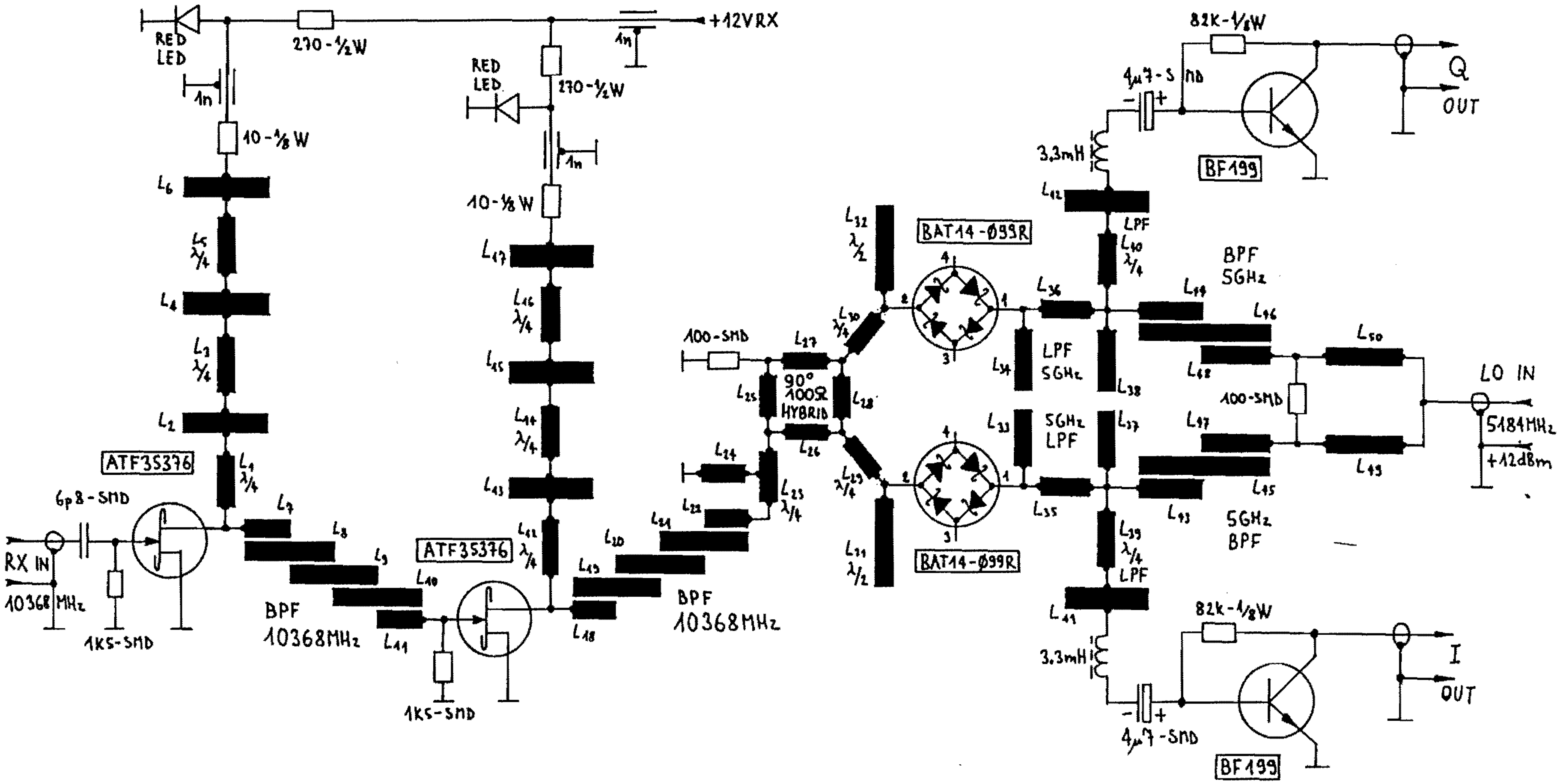

Fig. 11 - Quadrature receive mixer for 10368 MHz.

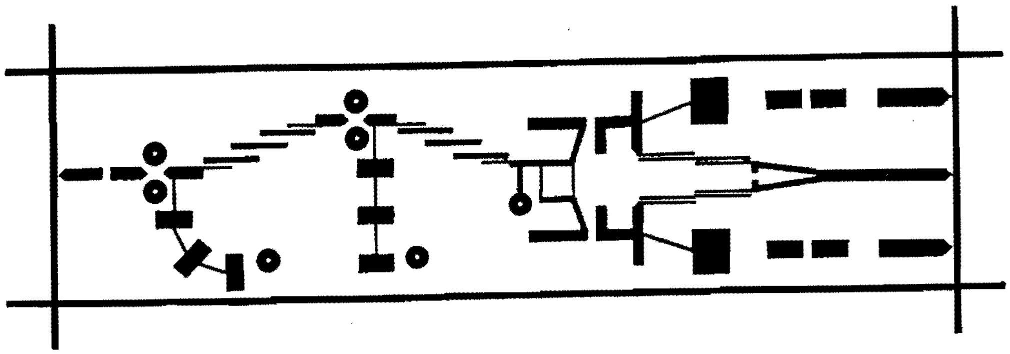

Fig. 12 - 10368 MHz RX mixer PCB (0.8 mm double-sided FR4).

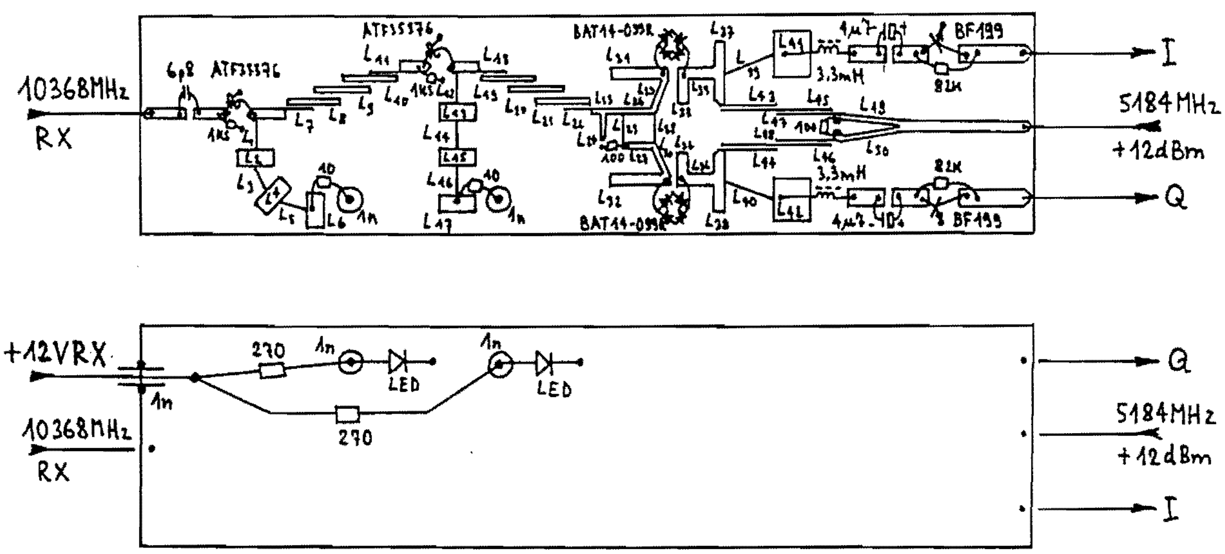

Fig. 13 - 10368 MHz RX mixer component location.

AMSAT BUILDERS CHANNELS
for HT and MOBILE Satellite Communications

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It's time for mobile and handheld amateur satellite communications and we can do it easily. Proposals for amateur satellite constellations have been made in the past, but they assume a coordinated effort. Such an effort is unrealistic in the catch-as-catch-can amateur environment. This paper suggests that the future growth of amateur satellites can in fact accommodate uncoordinated growth and still provide synergistic advantages to mobile and handheld operations. There are several factors driving this concept making it easier, cheaper and more viable:

* Launches are plentiful, many free rides exist
* Electronics can be smaller than a softball
* The link from a handheld can be done with 1 watt
* Dual band HT's are plentiful
* One HT has a built-in 1200/9600 TNC and kbrd/display
* Mobiles are a convenient time to operate for many
* Travelers need satellite comms in remote areas
* HT/mobiles need little coax, no preamps, nor complex antennas
* Mobiles/Handhelds provide a common user configuration
* HT/omni downlinks are ideal for school demonstrations
* Many Schools want to build satellites for education
* Amateur Satellites should not compete with the free bandwidth of the internet for fixed stations. We should concentrate some of our satellite bandwidth on amateur communications for mobiles and handhelds.

In the past, HAMS were the driving force behind each of our satellites wanting to do something new and different and better for HAM radio. More bandwidth, higher speeds, new digital tecniques, longer ranges. The justification for a new experiment provided the rationale for the project. With that mindset, there were lots of new things to tinker with but little support or peer justification for flying just another one-of-the-same.

The current climate is quite different. Universities want to build satellites for the education of their aerospace students. There are at least a dozen such satellites currently under construction. In this case it is the "design and building" that are the main educational drivers. This means some of these projects are actually looking for a mission, or an excuse to build a satellite. These satellites become "amateur" satellites simply because the spectrum is easy to get. We, "the AMSAT community" should provide guidance so that we get what we want and need for the future of amateur radio while these programs with deep pockets get the educational experience they need.

THE GENERAL MISSION AND BUILDERS CHANNEL:

What we need is a published General Mission requirement and a Builders Channel. This will encourage builders to consider the inclusion of a general purpose FM or digital transponder on a common channel. The resulting simple transponders would all be similar and provide the amateur community with a fleet of general purpose relays for mobile and handheld communications while providing builders with a persistent mission requirement. Actually there are three missions and three builders channels, one for FM voice, one for brief 1200 baud digital position/status/message uplinks and one for bulk downlink of all amateur traffic using the very effecient PACSAT protocol at 9600 baud.

Focusing builders-in-search-of-a-misson on this General Mission and Builders Channel with only one power-class of users (mobiles and HTs) will make much more effecient use of our precious spectrum and also keep the remaining spectrum available for other analog, wide band and experimental modes.

HT and MOBILE STATION CLASS:

Even though HT's and mobiles differ in power by 10 dB (5 versus 50 watts), they are comparable in most respects. The downlink is identical. Both use omni receive antennas with no cable loss. The uplink is also quite comparable. HT's can easily vary their orientation and polarity and/or use small

The popularity of AO-27 is matched only by its own congestion. Imagine, however, if there were 12 other AO-27's on the same frequency giving two passes per hour round the clock *AND* a change in operating habits to let everyone have a chance. Photo by Phillip Fortenberry N5PF at last years AMSAT Conference

handheld gain antennas. The mobile is usually stuck with a vertical which has a null overhead and a good chance of being in the wrong polarity half the time. Thus the mobile's 50 watts is, on average, quite comparable to the handheld's 5 watts.. So, for the purpose of this paper, mobiles and handhelds are considered in the same power class. By having such a well defined user station baseline, it is easy to design a Handheld/Mobile mission for amateur satellites and to make good decisions about their operation on only a minimum set of builders channels as shown below.

BUILDERS CHANNELS:

The following builders channels are recomended for both digital and voice:

2m	FM VOICE:	FM downlink to HT's and mobiles
2m	1200 Baud:	UI packet channel to HT's and mobiles
2m	9600 Baud:	Pacsat protocol message server channel
70cm	FM Voice:	FM uplink from HT's and Mobiles
70cm	1200 Baud:	Alternate uplink from digital mobiles
70cm	9600 Baud:	Uplink for 9600 baud Message Servers

These are single channels to be shared by any number of satellites built by anyone who wants to. The actual practical number is probably about a dozen or so since orbits with free rides will be random and we want to minimize overlaps. Actually, this is not a limitation as many of these payloads may be launched by the shuttle and other missions enroute to ISS and so will have life times on the order of a year or less. Brief periods of overlapping coverage will have minimum impact due to the 10 dB range variance, many dB of antenna pattern variance of both the satellite and users, and the 10 dB or so FM capture effect.

PACSAT MESSAGE CHANNEL:

Notice the provision for a 9600 baud Pacsat protocol downlink on 2m. This single channel with many birds has the potential to deliver to every ham on the planet with an HT, over 300k per pass per satellite. Or with 10 satellites in orbit, over 10 megabytes of personal messages and daily amateur radio news to everyone! This is where everyone monitors for their traffic. The 2 meter downlink is 9 dB better than any of the existing PACSAT 70 cm downlinks using the same power. Thus, easy to do with 1 watt microsats to HT's with rubber ducks. The channel also listens briefly for acks.

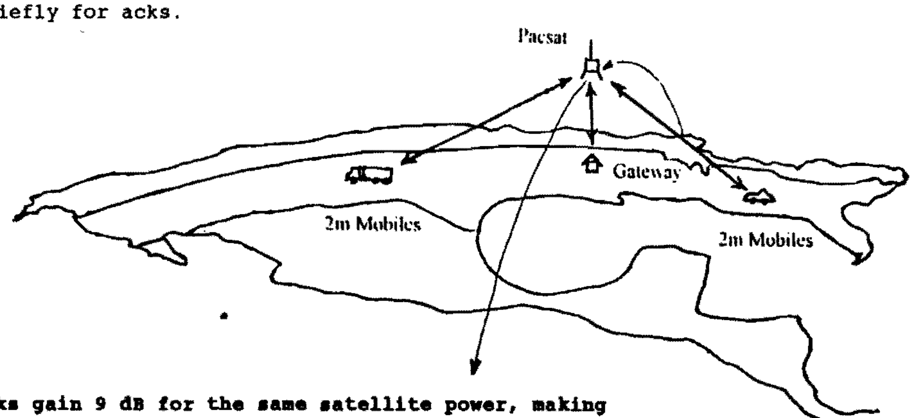
The objective of this channel is not to replace the existing PACSAT store-and-forward message/file systems, but to augment them for the downlink distribution of smaller real-time messages to all users usually in receive only mode. At 9600 baud, that is a tremendous asset for amateur radio. By using 2 meters, the lower path loss means that stations need not track the satellite. Just leave their packet capable HT on the 9600 baud channel and it will receive the traffic whenever a bird flies over even if they are in receive only mode.

Further, this PACSAT protocol downlink can be REGION specific by not putting the file system on orbit, but on the ground! The 9600 baud channel simply operates in bent-pipe mode for major internet linked file servers on the ground. Thus when over the USA, the channel is full of traffic for USA mobiles. While it is over Europe, the bird is supplying all European traffic. Thus, the channel can be optimized for each region. This greatly multiplies overall worldwide capacity.

Since each satellite is only serving as the on-orbit digipeater for regional message servers, each satellite is generic. Which ever one is in view at any time serves to deliver the messages to all mobile handhelds within 1500 miles. The Regional Message Server ground station continuously transmits a stream of all message traffic. New messages are initially repeated more often than older messages on a decaying schedule. For example:

New messages are	repeated every 2 minutes
After 30 minutes	every 3 minutes
After 60 minutes	every 4 minutes
After 2 hours	every 5 minutes
After 4 hours	every 6 minutes
After 8 hours	every 7 minutes
After 16 hours	every 8 minutes
After 24 Hours	every 9 minutes

Thus, at 9600 baud and an average message length of 1K, over 500 messages per pass per satellite can be delivered. Yes, it makes the satellite less valuable over the oceans and most of the 3rd world, but those areas are aptly covered by the existing Pacsats that cannot deliver traffic to handhelds.



PACSATS with 2m downlinks gain 9 dB for the same satellite power, making handheld and mobile receiption very easy to omni antennas. Message delivery to/from anyone anywhere with an HT is possible.

THE VOICE MISSION:

The voice mission is just an extension of the huge success of the AO-21, AO-27 and SO-35 experiments. Although many hams including myself said that this single channel nationwide channel could never work due to congestion, I have changed my mind and now think that it is our challenge to actually "make it work"! Here is how we can make it work:

* Re-define what "work/success" means.
* Set ERP limits to HT's and mobiles for this mission.
* A builders channel of many satellites will greatly improve channel access and thus decrease "pile-ups".
* Routine availablity will reduce peak demand
* 12 satellites on one channel could give 50 times greater access than the single AO-27.

Clearly, congestion will never be solved and it is foolish to believe so. But one thing about congestion is that it certainly shows interest, demand, and exceitement of amateur radio. What HAM band that is "open" does not have a congestion problem? Thus, in a modest sense, "success" of a student built satellite is that "someone is using it"! Conversly, I can list a number of amateur satellites currently in orbit that do not have a congestion problem... and are practically useless to everyone...

VOICE OPERATIONS:

On the other hand, listening to the pile-up on the FM birds gives me a good feel about the future of amateur radio. We need to capitalize on that. One way is to change the way we operate. On an 8 minute nationwide satellite pass, no one should ever expect a normal QSO nor to complete multiple two-way exchanges. On 2m voice repeaters we do not expect to do a 2-way with everyone during the morning show, nor should we on a satellite. The channel should be used as a net with many operators, each station in turn gets to share his brief comment with the group and not expect a personal reply to each transmission.

A comment like "WB4APR in Annapolis Maryland with 3 scouts" or "W3ADO sailing to Boston, ETA 1800" only takes 3 seconds. Almost 200 such exchanges could take place on each 20 minute USA pass even with 50% fratracide. Remember the early days of FM repeaters when one could simply say "WB4APR Demo" and everyone on the channel would respond with their call and location. It was a simple and effecient way to show non-hams the coverage and potential of our FM repeaters. In many cases, the "medium is the message". We do it for fun.

MISSION/POWER STANDARDS:

Space is totally different than terrestrial communications. The communications link power needed for a typical mobile varies over a range of 100,000 to 1 (1 milliwatt to over 100 watts) depending on his proximity to the repeater, terrain and interviening structures and trees. The link power to a satellite only varies by 10 dB and maybe a few trees as the satelite never gets further than say 2000 miles nor any closer than say 400 miles and there is never anything inbetween except for possibly a few trees. Thus, a satellite designed for HT use, only needs an HT to access it. Conversly, a wideband analog satellite designed for base-station use will always require a base station class station to operate it. The two designs should ask users to stick to the system designed for them.

Thus, the AMSAT community needs to publish ERP standards for all spacecraft and users should be encouraged to use only that power for access. There is no reason for AO-10 class stations with 100 watt power into 13 dB antennas (2000 watts ERP) trying to access a LEO bird designed for the 5 watt HT user with an omni antennna (5w ERP).

VOICE ACCESS:

Currently AO-27 provides users with only 2 passes per day and only during daylight hours due to its fixed sunshine only schedule. Just one new FM satellite with better power management can tripple the number of accessible passes. At present, there are at least a dozen or more universities with "small satellite" programs. If only 3 of these satellites carried FM missions on the builders channel, then amateur radio could see a SIX times improvement in FM handheld access and of course a 6 times reduction in congestion. The disadvantage of AO-27 is the severe imballance in its uplink and downlink due to the mode J class operations. The .5 watt downlink suffers a 9 dB penalty for being on 70 cm and the users 5w uplinks have a 10 db advantage due to higher power. Thus there is almost a 20 dB difference in performance requiring the use of handheld beams for normal operations. If this same saatellite were operated with 2m down and 70 cm up, then communications with an HT and rubber duck would be equally possible with no external antenna. Again the disadvantage is greater filtering requirements on the bird due to the 3rd harmonic potential for desense on the 70 cm receiver.

DIGITAL MISSION:

The digital satellite "builders channel" is even easier. Just like the many worldwide commercial satellite pagers and hand-held phones, Amateur radio now has its own "satellite handheld" in the form of the Kenwood TH-D7 with its built in packet TNC and APRS system. Just one packet can contain everything you need to know about a station and it takes less than 0.3 seconds per

The Kenwood THD7 HT is a ready-to-go handheld satellite trasnceiver with buit-in 1200 and 9600 baud TNC's combined with keyboard and displays for position/status reporting and short messaging.

station. This means that 10 times more users per pass will be able to participate on the digital transponder as on the voice channel! In addition, the digital packets containing the stations position and status and messages can be interlinked into the worldwide APRServe internet backbone allowing worldwide communications between these handheld users anywhere to anywhere.

The digital mission using hand-held to handheld communications was recently demonstrated in an impromptu test during the first week in early June when more than 55 HT users easily communicated over 500 UI packets among 160 stations via the MIR digipeater. The presence of thousands of these shirt-pocket digital satellite communicators is an opportunity that should not be overlooked! Even conventional HT's can transmit APRS type position/status using only the match-box sized APRS Mic-Lite Mic-Encoder plugged into the mic jack.

The popularity and functionality of brief APRS UI type communications has been well dsmonstrated and is beyond the scope of this article. Readers can view the worldwide APRServe system live via TELNET to 199.227.86.221 port 23 at any time or check station positions via www.aprs.net. This system provides terrestrial HT coverage to over 90% of the US amateur population. (But less than 20% of the land mass and none of the oceans nor most foreign countries and Europe. Hence, the need to extend links via the digital builders channel).

FREQUENCIES:

One of the reasons for this builders channel concept is to make more effecient use of our existing spectrum and to allow for more orderly growth in the amateur satellite realm. There are many considerations in effectively designing a satellite link. First, 2 meters is, by an order of magnitude, the easiest band for handhelds, because the link budget is 9 dB easier and the doppler is negligible for existing FM radios. Conversly 70 cm has over 16 KHz of doppler and requires 9 times more power for the same performance. Thus, 70cm up and 2m downlink has the following advantages:

* 9 dB less power required on the satelite power system
* Omni spacecraft antennas require no attitude control
* No doppler tracking of downlink by users
* Compatible with all FM amateur radio equipment.
* Compatible with handheld TH-D7 packet HT

The UHF disadvantages are mitigated on the uplink as folllows:

* Ground users can use more power, or gain antennas
* User can compensate for doppler OR
* Satelite receiver can have AFC OR
* Satellite can use a wideband IF to minimize doppler

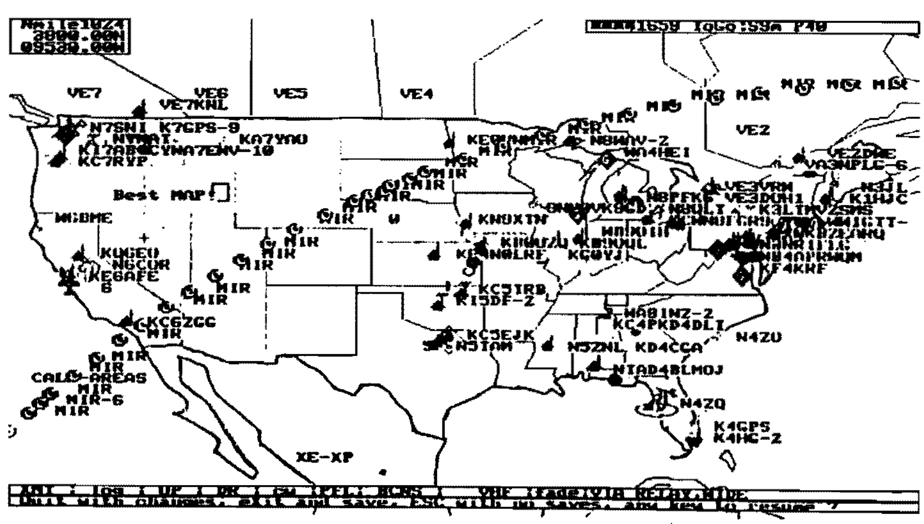
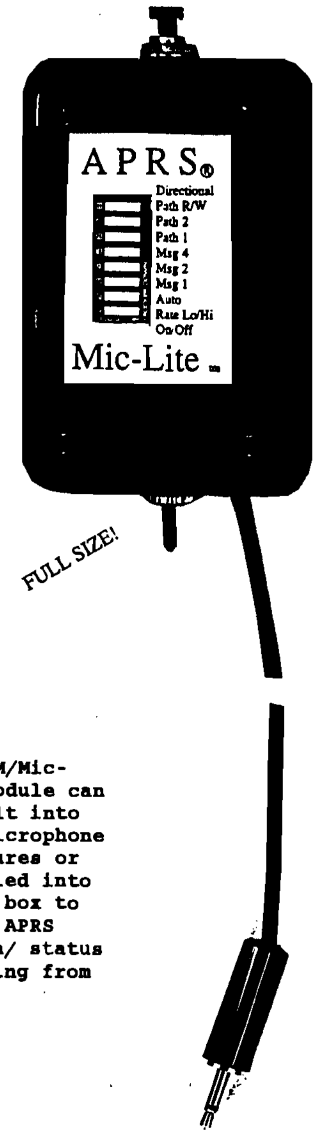


Figure This is an APRS screen capture after the third pass of MIR during the special APRS-MIR tests conducted on 11 March 1998. It demonstrated the potential of using an amateur satellite digipeater for relaying mobile position/status/messages.

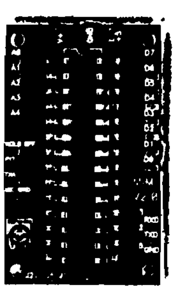
The only downside of this arrangement is the difficulty on the Voice birds of filtering to avoid 3rd harmonic desense of the satellite UHF receiver by its 2 meter downlink. On the 2m 1200 baud digital channel, HT-to-HT operations will usually use the satellite as a single channel digipeater for UI frames thus providing the 9 dB and zero-doppler advantages to everyone with an HT as was demonstrated via MIR. Simplex digipeating is required since the thousands of satellite packet capable HT's contain TNC's that can only operate on one band at a time. To help spread out the uplink load, the mobiles with 10 dB more power can transmit on 70cm, where the satellite can use AFC or a wideband receiver to mitigate the problem of high doppler.

Combining both uplink and downlink for the HT's on one channel is fortunately not a problem for the UI (APRS) application because dozens of ground stations are all linked by the internet. Thus only one ground station needs to receive the packet error free and it is distributed worldwide. Only 5 such ground stations would have a 99.99% chance of at least one of them hearing each packet and delivering it error free to the network even if their channel was more than 30% busy with local traffic.

In conclusion, I believe that establishing Builders Channels and published Common Mission Objectives for mobile/HT worldwide satellite communications could greatly benefit the Amateur Satellite community. It would provide a mission target for schools, a much improved use of or sparse satellite bandwidth on 2 meters and a constant source of satellites for a constellation of mobile communications amateur satellites. Further it defines a consistent user station class and power level for equal access by all, and promotes shorter practical protocols to allow more users brief access.



The MIM/Mic-Lite module can be built into most Microphone enclosures or installed into a mini box to permit APRS osition/ status reporting from any HT.



FULL SIZE!

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115 Old Farm Court
Glen Burnie, MD 21060

APRS MIM Module

Complete APRS Packet TNC transmit module. Transmits Position, BText Telemetry at user specified rate.

wb4apr@amsat.org