Table of Contents

SECTION C: Satellites and Education

AMSAT®
The Radio Amateur Satellite Corporation
850 Sligo Avenue, # 600
Silver Spring, MD 20910
Phone 301-589-6062 • Fax 301-608-3410

November 3, 2005

Dear AMSAT Member:

Welcome

Instead of the normal salutation, this year it is my duty to report that the 23rd AMSAT Space Symposium and Annual Meeting that was to be held in Lafayette, LA was cancelled at the last minute due to the effects of Hurricane Katrina. The devastation that this storm brought to the Gulf Coast was extensive and not only touched those who were in the storm's path, but the rest of the United States as well. While Lafayette was spared the brunt of the storm's fury, it became a hub for relief efforts and served as a refuge for thousands that were forced to flee their homes. Every hotel in Lafayette became the home of evacuees. Consequently, AMSAT was not able to hold the Symposium in Lafayette.

The hard work of Nick Pugh, K5QXJ and his team of volunteers to prepare for our Symposium in 'Cajun Country' was extensive and greatly appreciated. Efforts were made to identify an alternative site for our Symposium but there simply wasn't enough time for people to change their plans and for preparations to take place. Reluctantly the AMSAT Board of Directors cancelled the Symposium and voted to hold the 2006 Symposium in the San Francisco Bay Area.

This disappointment doesn't mean that AMSAT sat still. The Board of Directors met in Pittsburgh, PA on the same dates as originally scheduled in conjunction with the original Symposium. For the first time ever, the Annual Meeting of AMSAT-NA was conducted via Echolink which allowed members not present to listen to the President's Annual Report and submit questions to the Board of Directors and the Senior Leadership Team. This 'first' was a resounding success. The Eagle Team Project Committee met at the same location following the BoD meeting and reported significant progress in a number of areas concerning Eagle design and prototyping.

I am impressed by the quality of papers that were prepared for this year's Symposium along with the enthusiasm and hard work of the authors. Even though the Symposium was cancelled, these papers still deserve dissemination that will hopefully generate discussion by those that read them. This exchange of ideas is one of the primary benefits of the Symposium, and I hope that the publication of the 2005 Proceedings will help to keep the spirit of the Annual Symposium alive until we are able to meet together in San Francisco.

'73

Richard M Hambly

Richard M. Hambly, W2GPS
President

STELLA – Satellite Transponder with Equalising Level Limiting Adapter

Howard Long G6LVB

1. Abstract

Traditionally multiple access linear transponders within the amateur satellite service have used a single automatic gain control (AGC) across their entire passband. Single AGCs can often limit transponder access due to interference from other services or high power uplinks of some users. Using DSP technology, it is now possible to provide automatic multiple adjustable notch filtering, facilitating equal access opportunities for all transponder users.

2. Introduction

Described is the design of a new genre of satellite linear transponder IFs that can be used as and alternative to the traditional analogue single AGC IF.

The design features low power consumption (<1W), and is a plug-in replacement for standard linear transponder 10.7MHz IF stages. It expands on the single traditional passband AGC by providing frequency selective filtering automatically that is, for practical purposes, continuously adjustable across the entire transponder passband.

Much of the software prototyping has been performed on a PC using cross platform standards and libraries. This technique allows rapid development on native hardware while ensuring ease of porting to embedded hardware.

3. Analysis of traditional single AGC linear transponders

The traditional IF will consist of a passband filter followed by a variable gain amplifier (VGA) (see figure 1). The VGA's gain is set by using a peak detector on the output of the VGA to maintain the maximum output at a fixed level. The VGA in conjunction with the peak detector is known as the AGC.

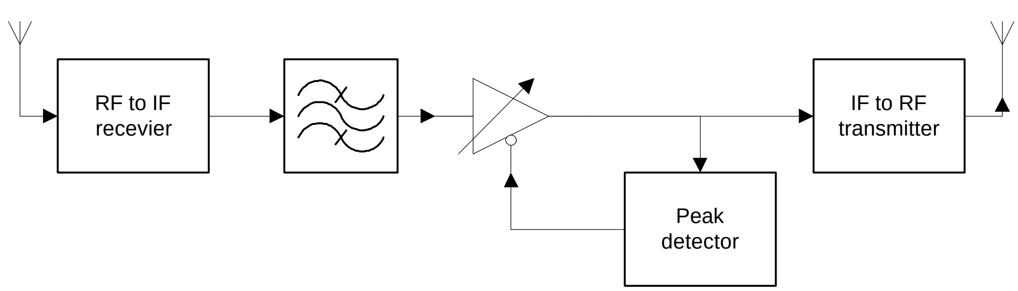


Figure 1 Traditional linear transponder IF

If a fixed gain amplifier were to be used, when the input to the IF is too high, the transponder output will saturate, leading to a non-linear distorted output. The point of the AGC is to maintain the transponder in its linear region.

Linear transponders are designed to be multiple access devices, allowing several simultaneous uplink users separated by their frequency within the passband (see figure 2). Because there is only one AGC across the entire passband that affects all users, even if only one user is running an excessive ERP to the uplink passband, the AGC's peak detector will use that signal to lower the AGC's gain. Lower power signals will therefore be attenuated even if they are adhering to the recommended uplink power requirements.

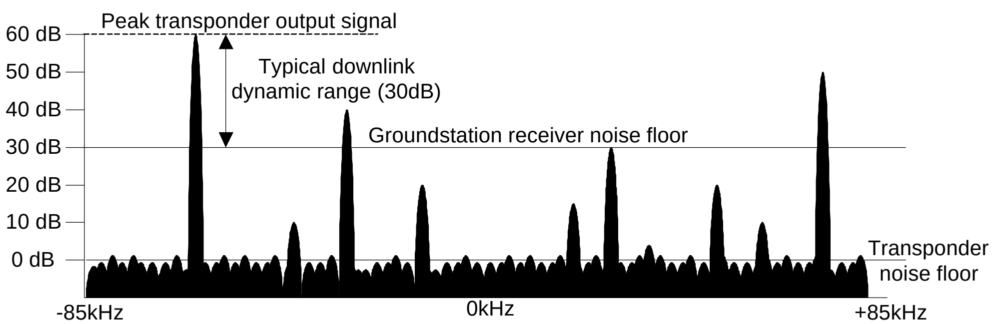


Figure 2 Example of signals received by the transponder passband

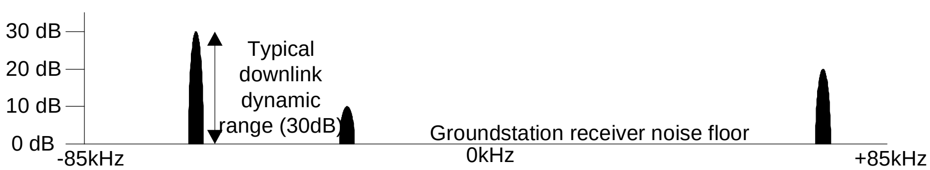


Figure 3 Reception of passband at groundstation after traditional transponder AGC suppression. Although the groundstation is capable of hearing the transponder's noise floor, in the event of strong signals appearing at the transponder receiver, the transponder noise floor and all other signals in the passband are attenuated by the AGC. After AGC suppression, many of these signals are now below the groundstation receiver noise floor.

Now consider the groundstation receive segment. A well-designed and well-equipped groundstation receive system would just be able to hear the transponder's noise floor when no uplink signals are present at the transponder input. When the groundstation can just discern the transponder noise floor, this will be close to the groundstation receive system's noise floor. The transponder noise floor can be heard by the groundstation either by tuning in and out of the passband and listening to the noise increase and decrease, or deliberately off-pointing the antennas to determine a decrease in noise.

In a typical transponder, the AGC might not start to reduce the passband gain until the peak input signal is, for example, 30dB above the transponder noise floor. As long as all uplink stations stay below this point at which the AGC starts to reduce gain, the well-equipped groundstation would still be able to hear the transponder noise floor.

Consider now an input signal 40dB over the transponder noise floor. The AGC will now reduce the gain by 10dB across the passband. The well-equipped groundstation receiver will no longer be able to hear the transponder noise floor and similarly any other signals that were fully readable 10dB over the noise floor will now be only just discernable. For the purposes of this article, the combination of our example, well-equipped groundstation receive noise floor, and the point at which the AGC starts suppression is referred to as the typical downlink dynamic range.

In the more extreme situation of figure 2, there is a signal 60dB above the transponder's receiver noise floor, and this will provide 30dB of AGC suppression. Only signals over 30dB above the transponder's noise floor will be discernable by the groundstation receiver (see figure 3).

To receive the smaller signals, it is possible that the groundstation receive segment may be improved, usually by using a larger receive antenna array. However it is undesirable for many groundstations to have to upgrade their systems purely because of one or two excessively high power uplinks.

There is also AGC suppression from less obvious sources. For example this may be from non-amateur traffic, spin modulation on the transponder uplink or amateur traffic not reducing uplink power as the satellite draws closer.

In an attempt to reduce sources of amateur-borne AGC suppression, the AO-40 amateur satellite employed a device called LEILA in the transponder IF. LEILA is able to automatically notch one or two strong signals in the passband and still includes a single AGC covering the entire passband. Because LEILA is an analogue hardware device, it has somewhat limited reconfiguration opportunities in space. In practice a limitation of LEILA has been false triggering, believed to be due to non-amateur traffic sharing the uplink passband frequency range. Despite LEILA, AGC suppression has remained an issue for AO-40.

4. Hardware

As an alternative to using analogue devices, DSP techniques can be used, allowing the entire passband to be continually monitored and selectively notched, and with the ability to be reconfigured in space.

The IF passband is downconverted to baseband in hardware, then the software takes over. Once processed, the resulting baseband is upconverted back to the IF in hardware. The downconversion and upconversion may use digital, analogue or hybrid methods.

The first design to be considered (figure 4) relied on the use of ADCs and DACs operating at the IF frequency, together with digital downconverters and upconverters using devices more often used in the cellular telephone industry.

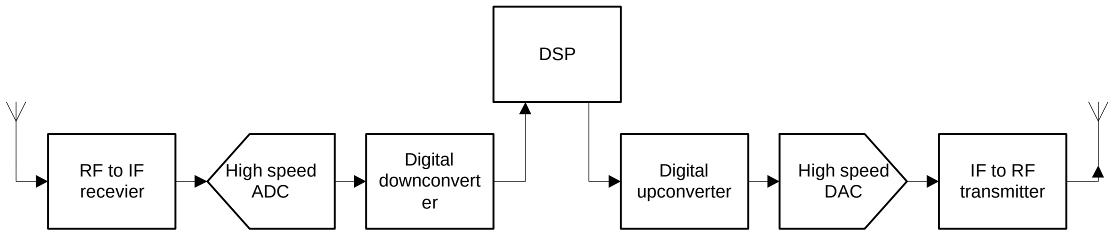


Figure 4 Original DSP linear transponder design

Using such high frequency ADCs and DACs allows for IF conversion from anywhere from baseband up to hundreds of megahertz, with the only analogue components being low pass anti-aliasing filters at the IF input and IF output.

After some significant initial development, it was realised that although possible, the use of such devices at the current state of the art are not compatible with the low power budget available on board amateur spacecraft.

After referring to the article "A Software Defined Radio for the Masses"[i] by Gerald Youngblood AC5OG/K5SDR, a different approach was taken. Rather than performing the A/D and D/A conversions at the IF, Youngblood uses a hybrid concept originally referred to as a quadrature sampling detector and exciter that is described in "A Low-noise, High-performance Zero IF Quadrature Detector/Preamplifier"[ii] by Dan Tayloe N7VE. The design of this DSP IF transponder is based heavily on these articles (see figure 5).

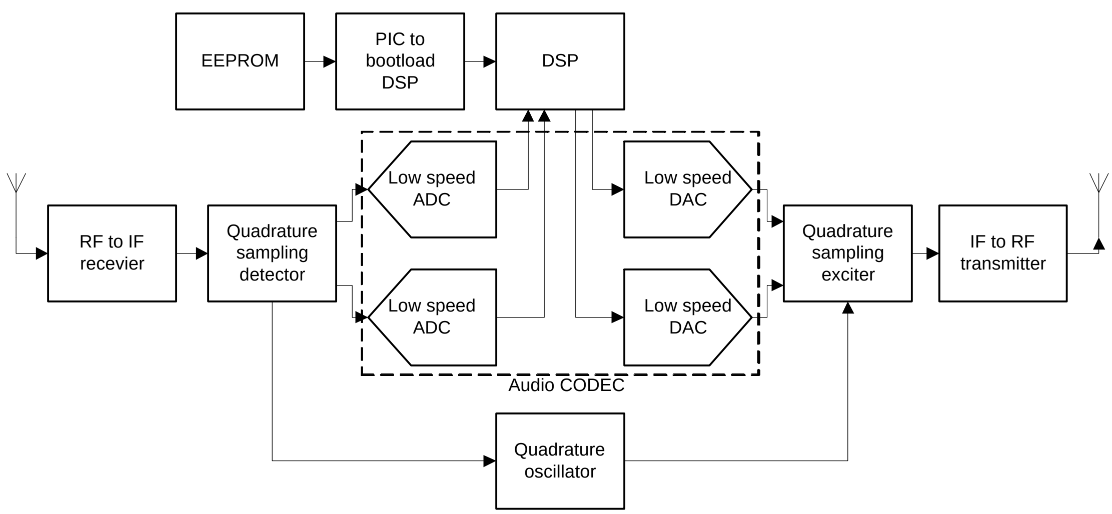


Figure 5 Low power budget linear transponder design

Considering the receiver, rather than performing the analogue to digital conversion at the IF, A/D conversion is performed at (or very close to) the baseband. It is possible to use a technique known as quadrature sampling on the IF that mixes the input signal with a quadrature oscillator. The nature of quadrature signals and quadrature sampling itself is described in "Quadrature Signals: Complex, but not complicated" by Richard Lyons[iii]. A quadrature oscillator provides two outputs, both at the same frequency, but 90 degrees out of phase. These two outputs are mixed with the input signal to provide a baseband signal of both in phase (I) and quadrature (Q) outputs.

The transmit side operates very similarly to the receiver but in reverse.

In order to facilitate software uploads while in space, a PIC with serial EEPROM is used to capture new firmware. This is then uploaded to the DSP using its integrated bootloader.

5. The Quadrature Oscillator

To make quadrature sampling work, it is necessary to be able to positively and accurately differentiate between sidebands, and this would traditionally require a very precise quadrature oscillator to achieve the 90 degree phase difference. With DSP techniques, although it is desirable to have a fairly accurate 90 degree sampling separation, minor aberrations may be adequately corrected in the DSP software.

Devices are readily available to provide LOs for quadrature sampling, such as the AD9854 DDS used in the SDR-1000. The problem with using such a device in our payload is that it can draw a lot of power, up to 4W in some circumstances! Clearly as the entire power budget for the digital transponder IF is 1W, other options need to be considered.

An alternative is to use a conventional oscillator running at 4Fs (four times the sampling frequency) and a two bit Johnson counter.

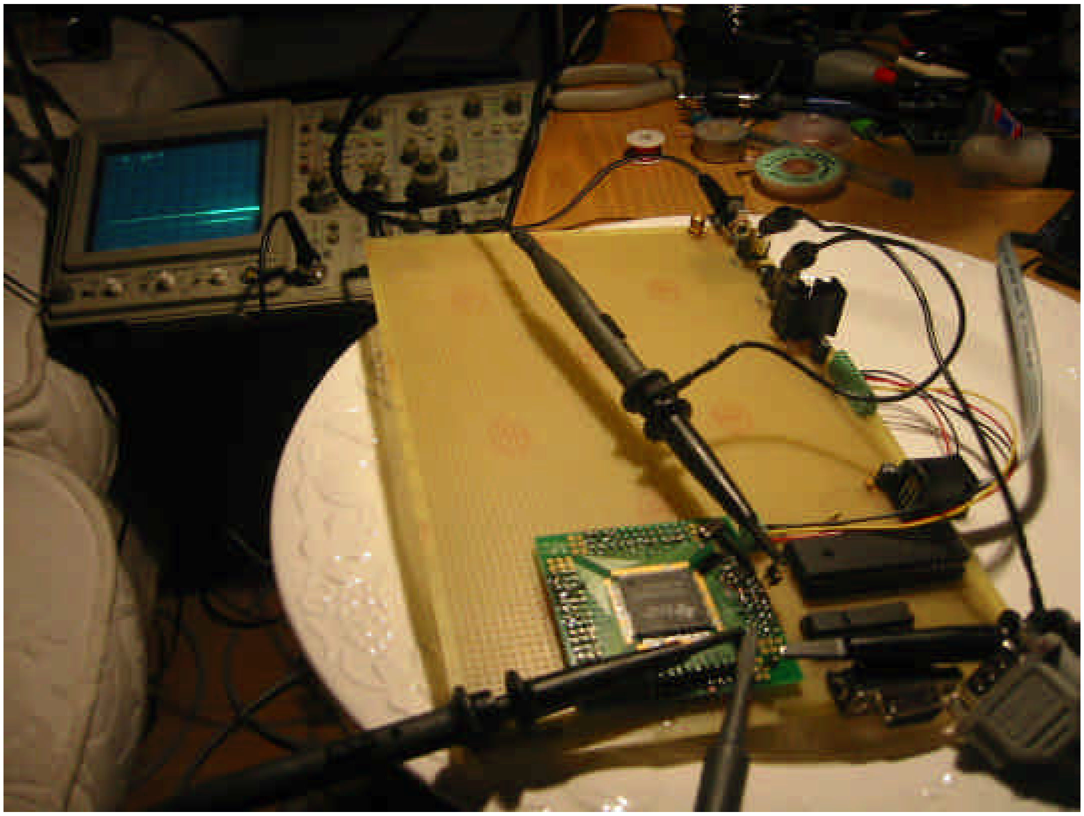


Figure 6 Testing the hardware prototype. When constructing projects with SMT devices on the coffee table, always use a white tray or a large plate to avoid losing the parts in the sofa!

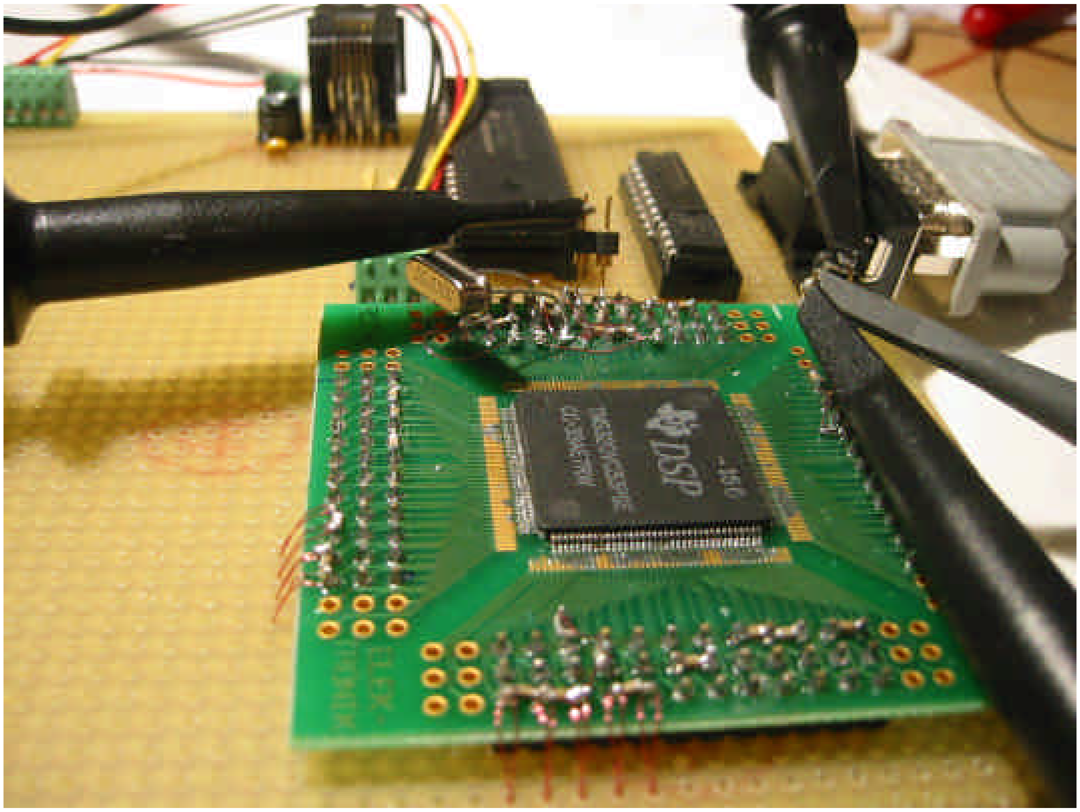


Figure 7 Close up of the DSP chip

A two bit Johnson counter is constructed using a single package dual D type flip flop SN74LVC74A (figure 8). To provide the required Fs, the Johnson counter must be clocked at 4Fs.

The 4Fs frequency may be provided by either a crystal oscillator or a low power DDS such as the AD9850. If frequency agility within the analogue IF's passband is not a requirement, typically a low jitter crystal oscillator will suffice.

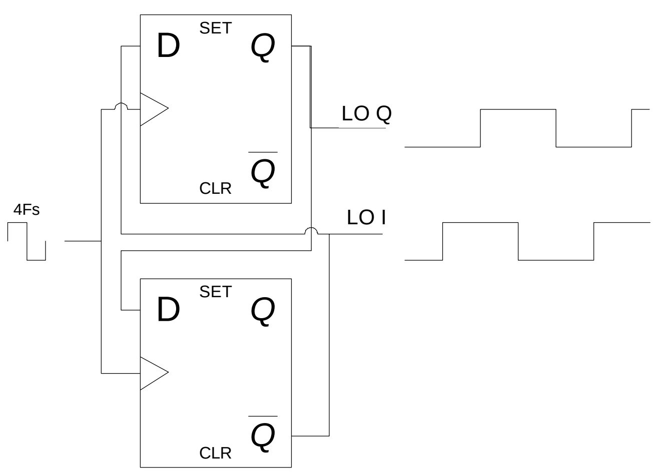


Figure 8 The quadrature oscillator

6. Quadrature sampling detector and exciter

The quadrature sampling detector comprises of a fast analogue multiplexer and a pair of instrumentation amplifiers (figure 9). The values of the sampling capacitors 'C' are chosen dependent upon the passband bandwidth required.

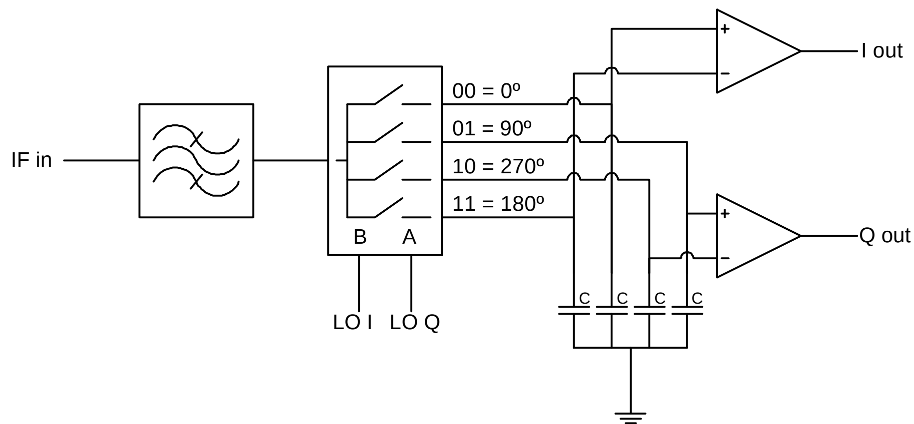


Figure 9 Quadrature sampling detector

The quadrature sampling exciter works very much the same as the detector, but in reverse (figure 10).

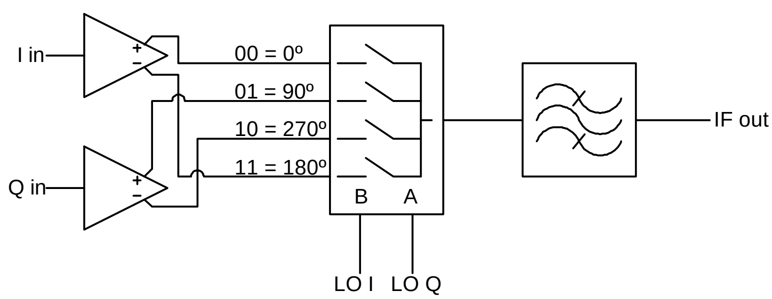


Figure 10 Quadrature sampling exciter

7. Audio Codecs

The baseband I and Q outputs are fed to freely available low power 'soundcard' codec chips. As these chips are designed for PC soundcards, they are usually stereo, allowing I and Q channels to take the left and right audio channels.

Until recently, such audio codecs have been limited to sampling speeds (Fs) around 48kHz, a little above the Nyquist rate (twice the maximum frequency of interest) for the generally accepted 20kHz audio limit of the human ear. The extra headroom (to 24kHz - half the 48kHz sampling rate) allows for the skirt of the low pass anti-aliasing filter (figure 11).

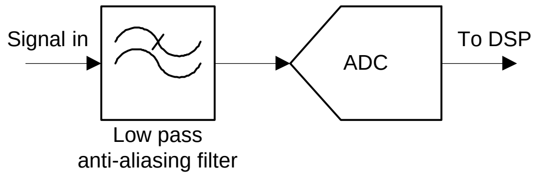


Figure 11 The low pass filter has a cut off frequency that is slightly below half the sampling rate

Typically CODEC filters cut off at about 0.45Fs. Despite being filtered to about 22kHz, because we have both I and Q, it is possible to distinguish whether a signal is above or below the LO, and therefore provide have an effective passband of about 44kHz.

More recently, soundcard codecs have become available that have sampling rates of 96kHz and even 192kHz. Many of these devices have anti-aliasing filters integrated that operate in proportion to the sampling rate, thus allowing the possibility of passbands of 176kHz, still using low power technology (figure 12).

One problem of using the direct conversion quadrature sampling method for satellite transponders is that signals very close to the LO frequency will not be possible to demodulate as the noise increases around this point. For around +/-1kHz around the centre of the passband, this will be notched by the DSP. This area may still be used on the transmit side for a beacon, similar to the AO-40 S band beacon that operated in the centre of the passband. The obvious advantage of notching out this area around the passband is that the beacon cannot be interfered with by any signals present on the uplink.

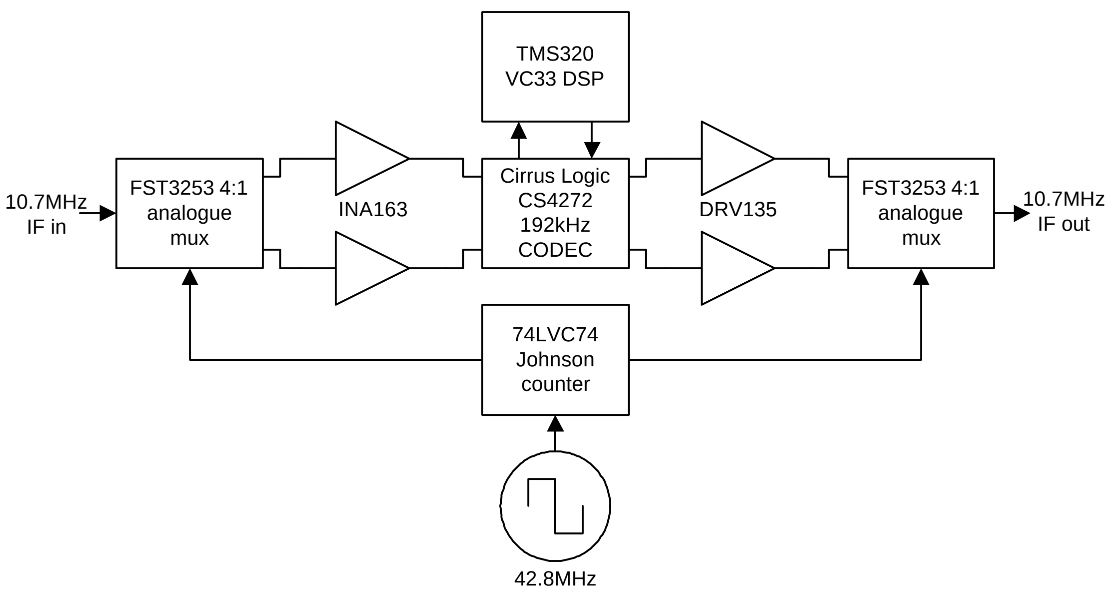


Figure 12 DSP transponder IF hardware

8. DSP Software

It is not the intention of this article to explain the mathematics of the DSP techniques used, as these are covered in many texts including those referenced here, although a practical overview of the software implementation is provided.

Once the baseband I/Q signals have been dissected, it is now necessary to process the input data, limiting the output power of the passband. This limit is made relative to the estimated noise floor, such as 20 or 30dB above.

Initially the I/Q input stream is converted from the time domain to the frequency domain using the Fast Fourier Transform, or FFT in software (figure 13). This segments the input into a number of discrete frequency 'bins', each bin indicating the amount of input power in that particular frequency range. Although not essential, in general FFTs segment the number of bins to an integer power of 2 as this is computationally most efficient.

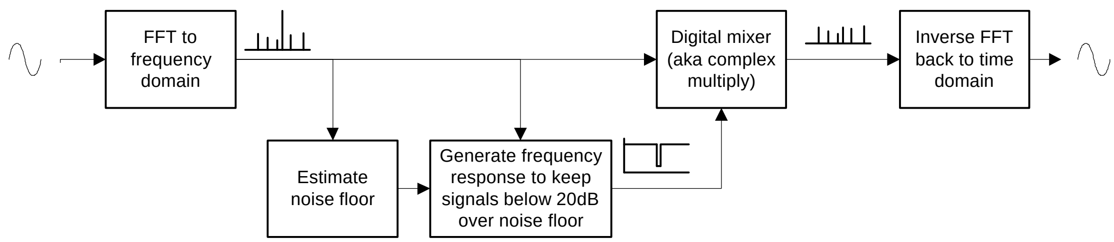


Figure 13 Basic STELLA operation

An estimate of the noise floor is taken by taking the median of the input power spectrum.

An initial assumption of a flat response is made, by creating an array of bins each with a unity (ie, 0dB attenuation) value. The entire input spectrum is then analysed and any signals beyond a specified headroom, for example, 20dB or 30dB, over the notional noise floor, have a notch of appropriate depth applied around the respective frequency bins. In practice, an independent AGC envelope is invoked on each notch with fast attack and slow decay. Additionally, a notch is applied to adjacent bins due to the spreading nature of the FFT.

The resulting filter response is multiplied by the input spectrum. Applying an inverse FFT to the filtered frequency domain spectrum provides the time domain output.

A complication arises in that in normal operation it will be necessary to appear to sample and filter continuously. In reality, overlapping batches are separated out, processed and added back together again. In DSP terms, this process is referred to as the overlap-add method.

Some example spectrum plots are shown in figures 14 through 17 and the actual software in use in figures 18 through 20. These show how effective the STELLA notching technique is, retaining small signals in the passband by attenuating large signals.

The development environment utilises the Numerix-DSP software suite that is a cross-platform DSP library, allowing initial native development on a PC before porting to an embedded solution.

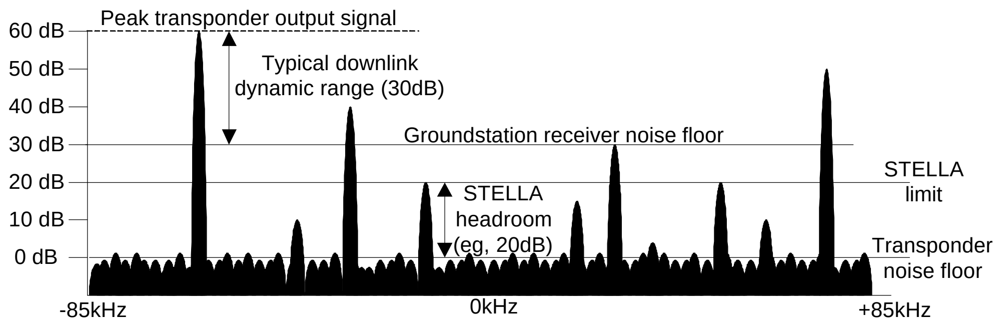


Figure 14 Example transponder passband signals

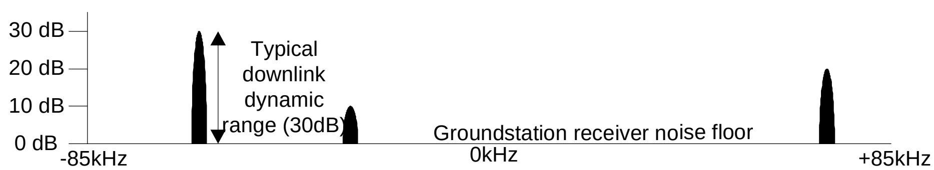


Figure 15 Reception of passband at groundstation after traditional transponder AGC suppression

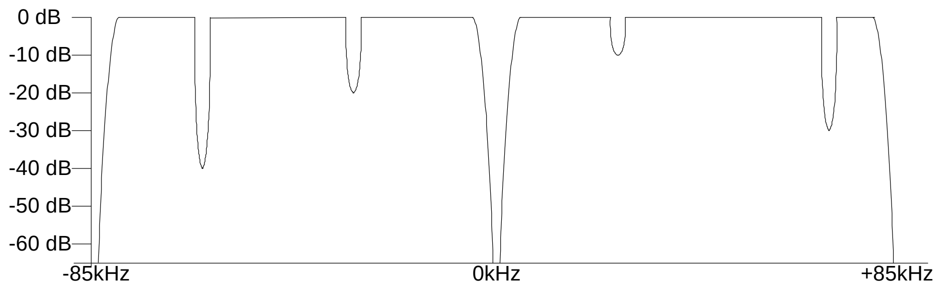


Figure 16 Frequency response generated automatically by STELLA

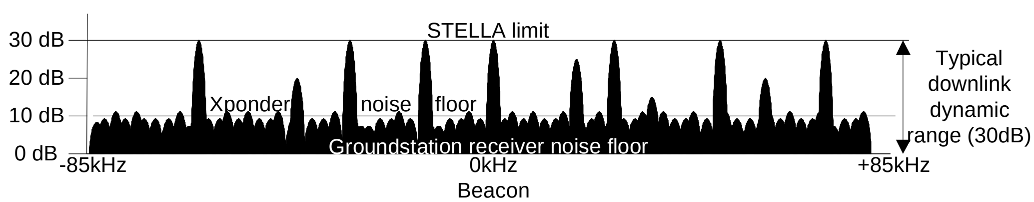


Figure 17 Resulting reception at groundstation with STELLA transponder

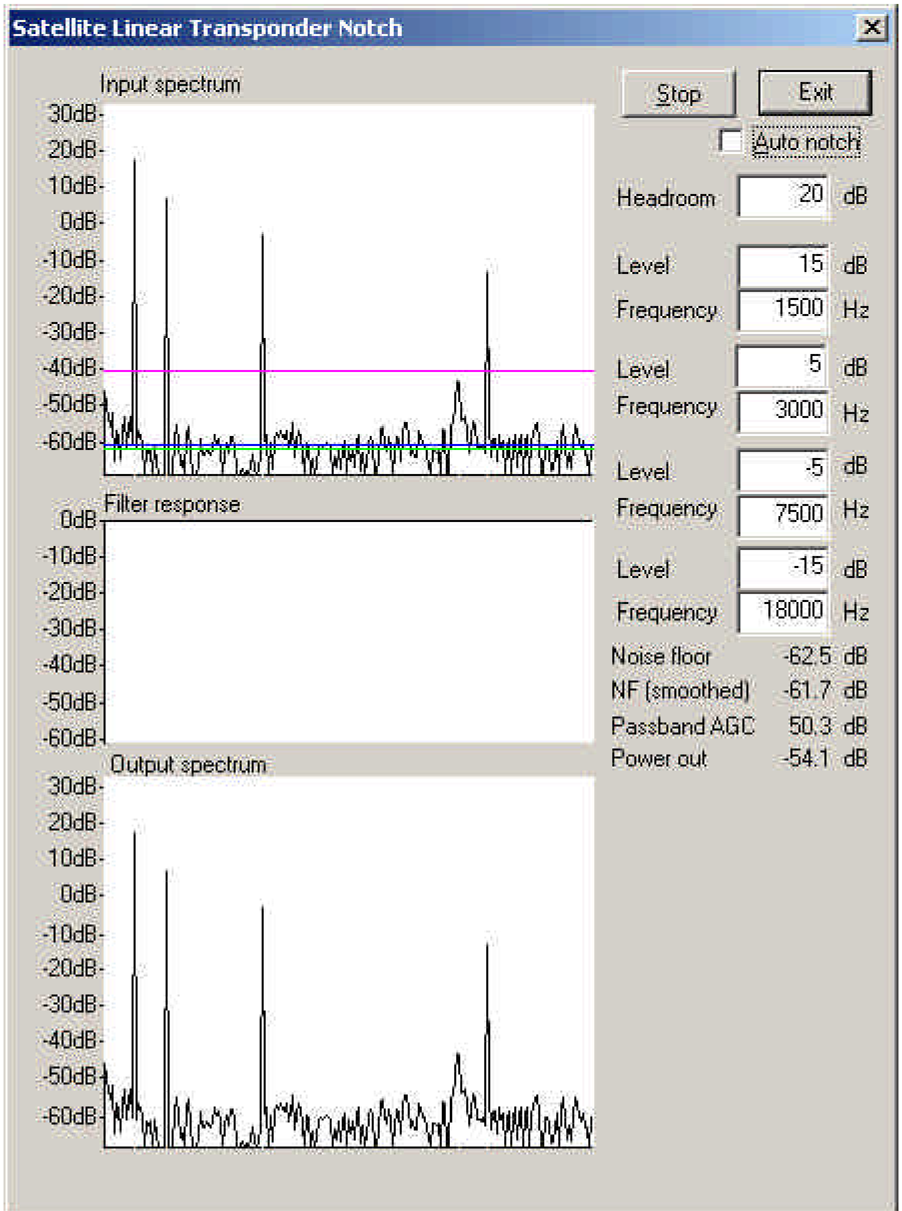


Figure 18 Actual STELLA DSP software running on a PC with auto-notch switched off. Combined with the directly converted RF input spectrum, up to four test signals at various frequencies and levels within the passband can be inserted with this test version.

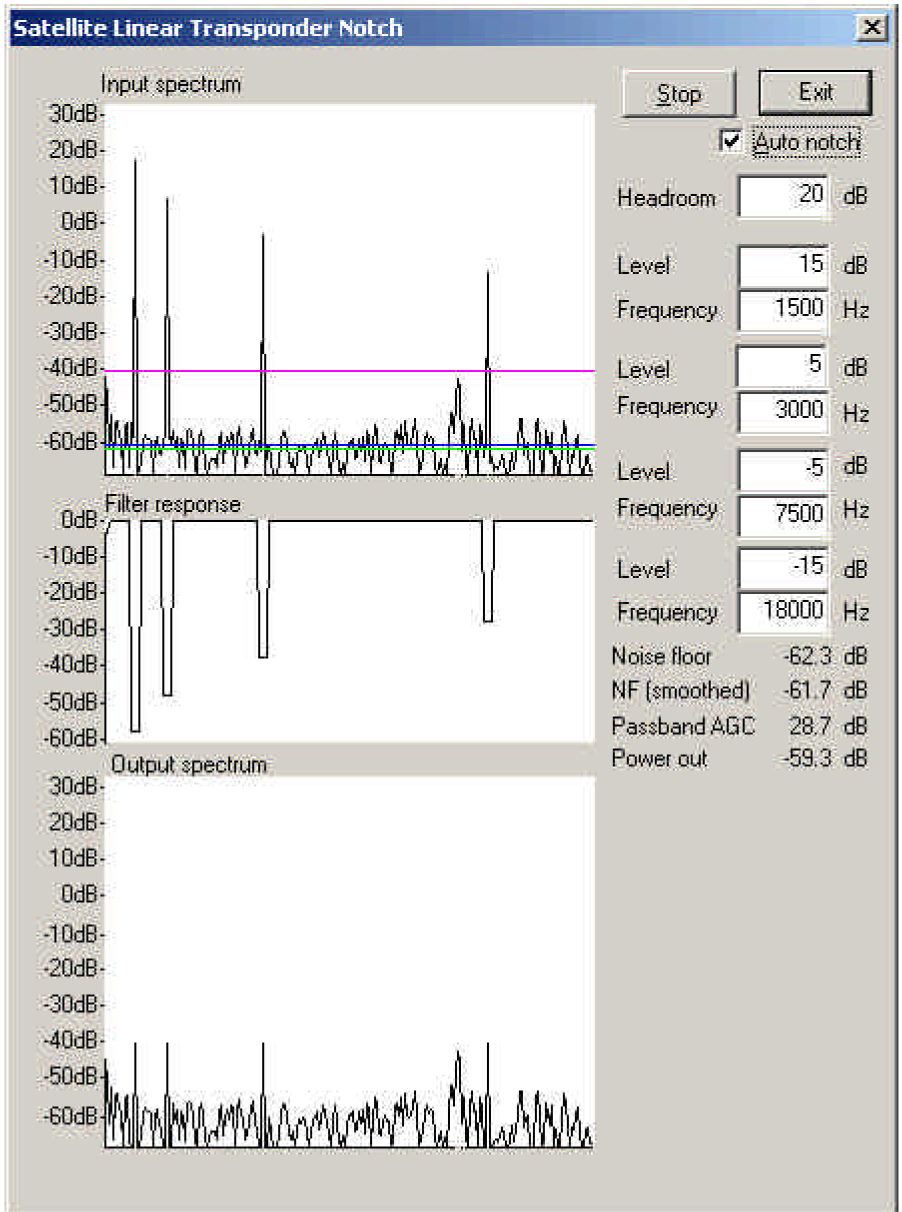


Figure 19 STELLA DSP software running on a PC with auto-notch switched on and 20dB transponder headroom. In the input spectrum, the estimated noise floor is shown by the blue line, and the headroom cut-off point (20dB above the estimated noise floor) is identified in purple. The automatically generated filter frequency response is shown, together with the flattened spectrum.

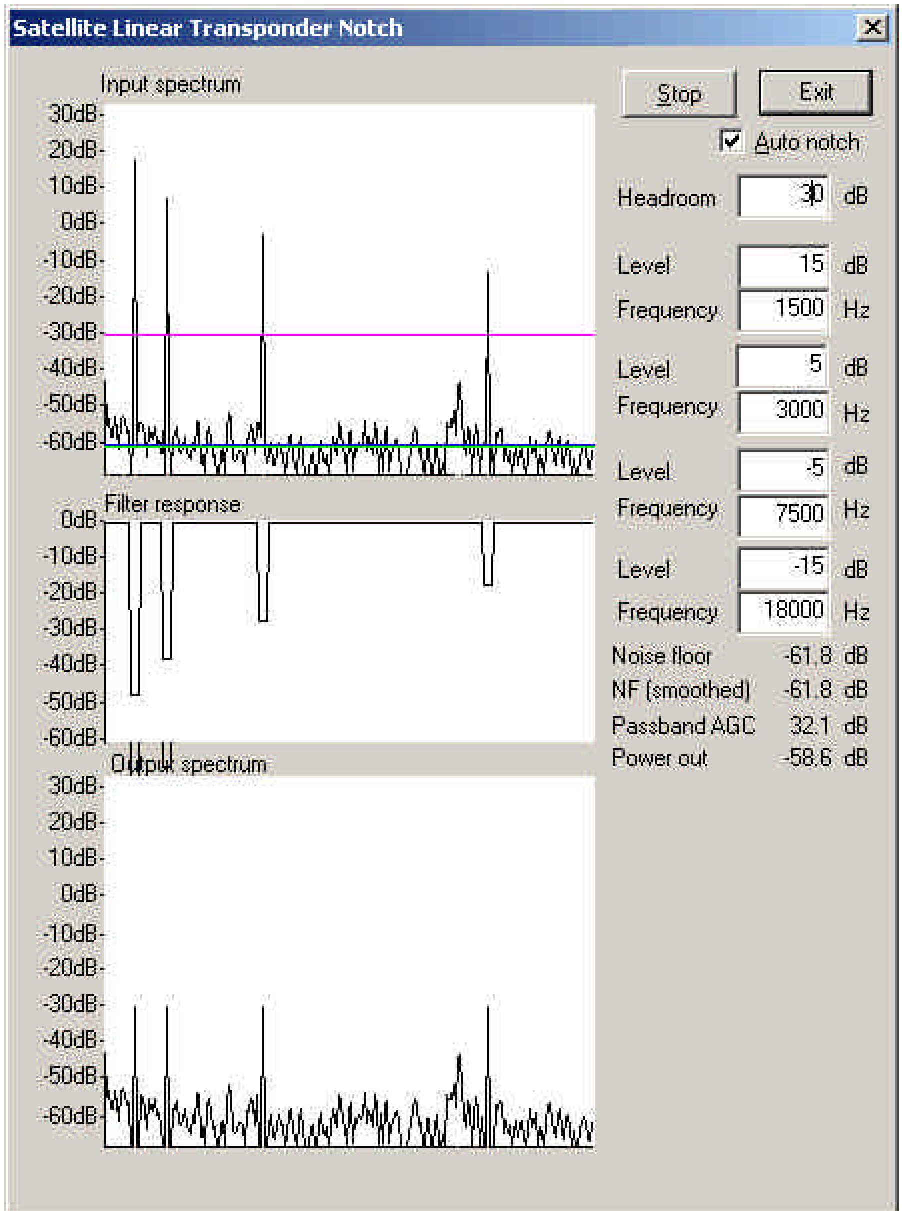


Figure 20 The STELLA DSP software with a 30dB headroom auto-notch. Note the shallower notches in the filter response and the correspondingly higher output spectrum peaks.

9. Future opportunities

Although only the linear bent pipe capabilities have been shown here, digital as well as linear modes could easily co-exist in the same passband, dependent on how the DSP itself is programmed. It is also possible to deliberately over-notch or carry out other warnings on stations that are over-powerful. Because the DSP is programmable remotely from the earth, firmware may be upgraded to contend with new or unforeseen interference sources.

10. Conclusions

STELLA is a low power device that will provide equality to users of a multiple access linear satellite transponder. It can be implemented at a very reasonable cost using readily available devices. The primary benefit of the device is that it will finally resolve the problem of the 'alligator' uplink station, leaving well-behaved groundstations able to continue to conduct their QSOs.

```
// Constants
FFTLen=1024
SampleSize=512
FilterTaps=512
Headroom=100 // 20dB – this is power

// Arrays
Real,Imag,Power,Filter[0..FFTLen-1]
RealOverlap,ImagOverlap[0..SampleSize-1]

For each set of SampleSize samples…
        // Get samples
        Read in I,Q into Real,Imag[0..SampleSize-1]
        Real,Imag[SampleSize..FFTLen-1]=0 // Zero stuff

        // Filter
        Take in-place FFT of Real,Imag[0..FFTLen-1]
        Power[0..FFTLen-1]=(Real[0..FFTLen-1]+Imag[0..FFTLen-1])^2 // (i-jq)^2
        NoiseFloor=Median(Power[0..FFTLen])
        Filter[0..FFTLen-1]=1
        For Power[0..FFTLen-1] values>Headroom*NoiseFloor,
                Filter[0..FFTLen-1]=sqrt(1-(Power[]-Headroom*NoiseFloor)/Power[])
        Real,Imag[0..FFTLen-1]*=Filter[0..FFTLen]
        Real,Imag[0..FFTLen-1]=InvFFT(Real,Imag[0..FFTLen-1])

        // Overlap Add
        Real.Imag[0..FilterTaps-2-1]+=RealOverlap,ImagOverlap[0..FilterTaps-2-1]
        RealOA,ImagOverlap[0..FFTLen-FilterTaps-2-1]=Real,Imag[FilterTaps..FFTLen-2-1]

        // Write samples
        Write out Real,Imag[0..SampleSize-1] as I,Q
```

Figure 21Simplified pseudo code fragment showing the implementation of overlap-add and FFT auto notch filtering. In practice the filter has a fast attack, slow decay AGC on each bin.

---

[i] Gerald Youngblood AC5OG/K5SDR, "A software Defined Radio for the Masses - 1", QEX July/August 2003

[ii] Dan Tayloe N7VE, "A Low-noise, High-performance Zero IF Quadrature Detector/Preamplifier", http://rfdesign.com/mag/radio_lownoise_highperformance_zero

[iii] Richard Lyons, "Quadrature Signals: Complex, But Not Complicated", http://www.dspguru.com/info/tutor/QuadSignals.pdf

Towards a Software Defined Transponder for Future AMSAT Missions

Tom Clark (W3IWI), Frank Brickle (AB2KT), Bob McGwier (N4HY) and Rick Hambly (W2GPS)

Abstract

Heretofore, **AMSAT-NA** and **AMSAT-DL** have flown traditional linear transponders as the analog transponders for their linear orbiting repeaters. These have served us well so we wish to make the case for a departure from this traditional approach to one where the functions of the transponder are defined in software. The advent of modern microprocessors that can do real-time signal processing has already revolutionized modern communications radios – it is hard to find a transceiver that does not have some DSP widgets inside. What small increase in complexity that is incurred, is richly rewarded by the increased versatility of the radio. The same should be true for satellite transponders.

The linear transponders from Oscar 6's Mode A to AO-40's Mode US have been the staple resource for **AMSAT** satellites since the earliest years. These linear transponders are necessary to allow multiple users operate the satellite simultaneously in a frequency and power sharing arrangement. To make a linear transponder, one was faced with a design problem in which one had a fixed amount of DC power available, and a known set of antennas. The design goal was to produce the most efficient possible linear or near linear transponder. In his doctoral thesis, DJ4ZC, Dr. Karl Meinzer wrote about ***High Efficiency Linear Amplification by Parametric Synthesis*** (hereinafter HELAPS). This was adapted for and adopted by **AMSAT**'s Oscar-7 design team for the Mode B (435 MHz Up and 145 MHz down) transponder. HELAPS technology has flown on all the Phase-3 satellite projects since that time.

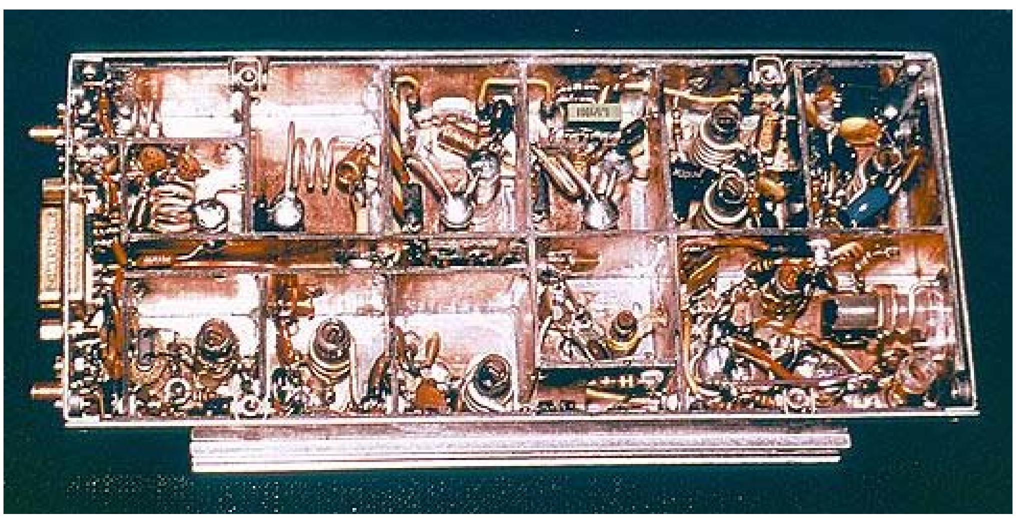


Figure1 – The HELAPS Mode B transponder for AO-7

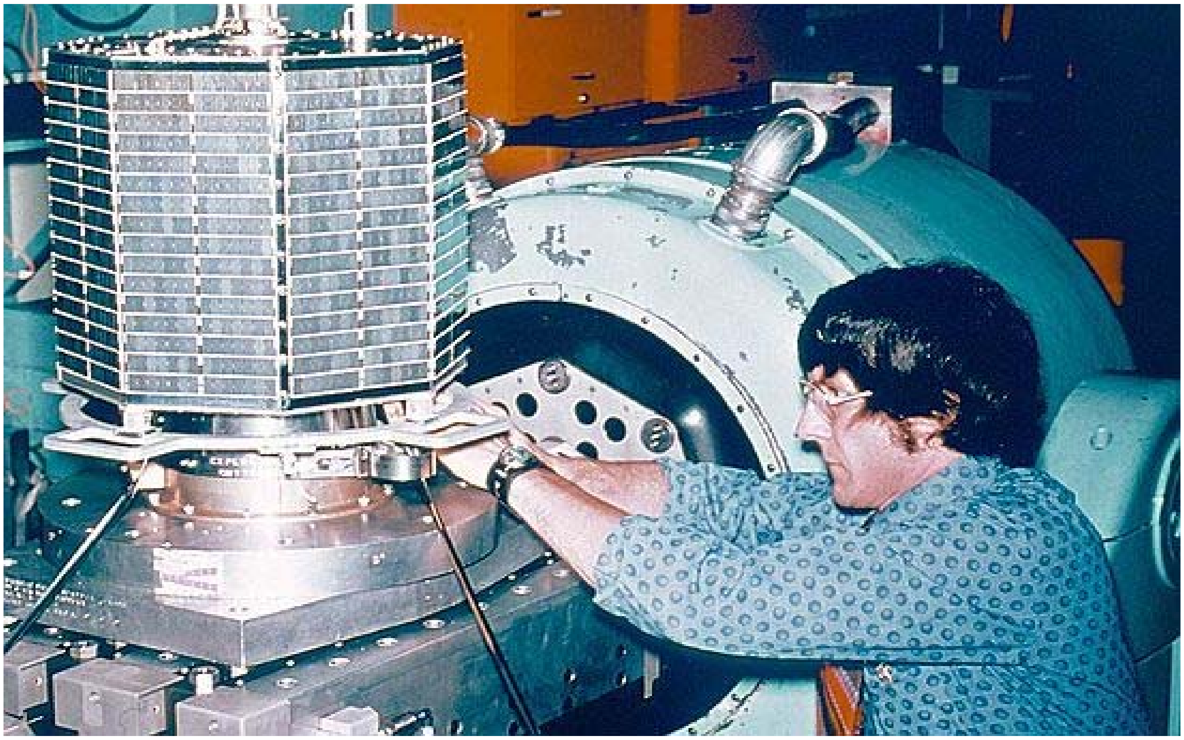


Figure 2: Jan King, W3GEY, mounts AO-7 for a shake test

For the microsats, we did digital and channelized transponders for the first few and then FM transponders have become increasingly popular for these Low Earth Orbit (LEO) satellites since packet radio has become the private domain of APRS .

There has been lots of discussions about linear, FM, digital, etc. and the relative merits, inherent evils, and general characteristics of each. There have been those who decry the cost of using a "Phase 3 bird" and those that deny an FM satellite even belongs in the ham bands. What would you say if you never had to make that decision again except to argue which mode we do tomorrow? Within reason, we are headed in exactly that direction.

Software Defined Radios

Software Defined Radio is a hot buzzword in amateur radio circles and has been in many technical circles for quite some time. The Department of Defense of the United States, would like nothing better than to have a one-size-fits-all radio. They have called it Joint Tactical Radio System or (JTRS, often dubbed "Jitters"). Recently the FCC approved the first SDR core for several applications by Vanu (http://www.vanu.com/). Why all of the excitement? DOD wants to be able to have its radios interoperate with any service it might encounter. Vanu wants to be the heart and soul of every cellular telephone irrespective of your brand of service, CDMA, GSM, DAMPS, AMPS, etc. How does one accomplish this technical magic?

Digital Signal Processing has been around for a while. Two of the authors started the TAPR and **AMSAT** digital signal-processing project in the early 1980's. One of the authors was a designer

Figure 3 – The AO-40 and its launch team

of the AEA DSP-1232 and -2232. One of the authors has been doing digital music composition, mixing, synthesis, and more since the early 1970's. Two of the authors spend much of their time doing GNU-licensed SDRs and invite you to visit our DSP web page at http://dttsp.sourceforge.net.

Why has digital signal processing transmogrified into software-defined radio? It would indeed be humorous if all we did were replace DSP with SDR and thereby turning a small CPU intensive block of code into the proverbial $50,000 hammer for DOD! That is not the case however. SDR is the marriage of DSP with newer hardware. This hardware allows much higher dynamic range analog to digital conversion and analog to digital conversion at IF frequencies which has pushed the digital domain much nearer to the antenna. We have much faster computers and some that can operate at low power with sufficient computational power to do the needed DSP jobs in small battery operated devices.

Recently amateur radio circles have seen a major insertion of SDR technology. GnuRadio, the DCP-1, and the SDR-1000 are major contributors of SDR technology and software for the amateur radio community. We have decided to use all of these pieces of technology in order to conduct serious experiments into the feasibility of applying SDR to **AMSAT-NA** needs.

The Flex Radio SDR-1000 receiver is based around the Quadrature Sampling Detector (QSD). The same circuit (with the signals flowing in the other direction) is used in the transmitter and is called the Quadrature Sampling Encoder (QSE).

Shown in figure 4, this simple idea has really helped SDR take off in a big way in the amateur radio community. Gerald, K5SDR, of Flex Radio is offering the first integrated software-defined HF radio transceiver. In practice, the usable bandwidth is set by resistor and capacitors in the sketch, with the bandwidth ~1/RC. This technology can be directly adapted to giving us several tens of KHz transponders. In the SDR-1000, the quadrature LO operates at a frequency within a few kHz of the desired center frequency, and the actual bandwidth is determined by the PC's sound card sampling rate. Using the QSD/QSE as the RX/TX mixers has much to recommend its use, including high Q, very good dynamic range, high IP3, and low power consumption. In our implementation, we would have a differential output for the I/Q outputs but the circuit would be very similar to the SDR-1000.

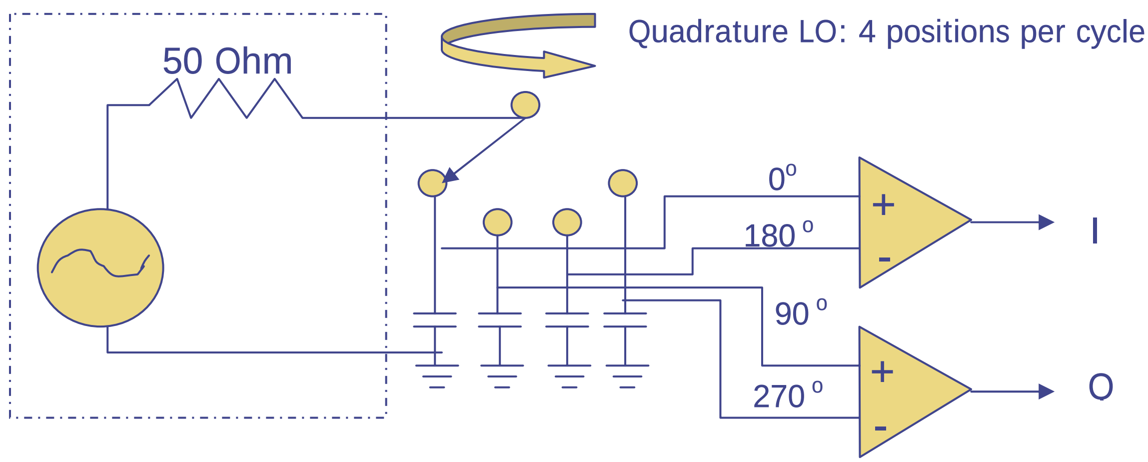


Figure 4 -- The Quadrature Sampling Detector as used in the SDR-1000

Recently, Howard Long, G6LVB, has adapted the QSD from the SDR-1000. Howard chose to use a DSP chip capable of peak rates of 150 MIPS and also low power consumption from Texas Instruments to process the signal from the QSD (200 mw). This series of chips has flown repeatedly on UoSAT's but to date has not flown in a Phase 3 orbit. Howard calls his QSD based transponder STELLA (Satellite Transponder with Equalizing Limiting Adapter). For more information on Howard's SDX activities, see http://www.g6lvb.com/Articles/STELLA/index.htm.

To illustrate how simple a QSD-based receiver can be, Tony Parks, KB9YIG has recently introduced his "SoftRock-40" QRP receiver and has made them available as kits in the $30-40 range. This receiver is a small circuit board with a USB plug on one end, and it is crystal controlled in the 40M QRP portion of the band (~7050 ± 20 kHz). One version of the receiver includes a USB-based CODEC chip that provides all the needed A/D conversion for the radio without needing to use a sound card. It is not a hard stretch of the imagination to think of a version of Tony's receiver tuned to the "standard" 10.7 MHz transponder IF. For information and photos of Tony's SoftRock, see http://www.n9vv.com/SoftRock-40.html.

We are also investigating the GnuRadio software project. It is led by K7GNU, Eric Blossom and Matt Ettus, N2JMI. Until recently, it has primarily been a computer science project that happened to provide a radio. Recently, with the introduction of daughter hardware by Matt, the project has taken on real significance to our experimentation. The heart of our experiments using GnuRadio software and the associated hardware will be done using the Universal Software Radio Peripheral, USRP.

The salient features of the USRP for our experimentation are the four input and output ports. These are clearly visible on the TX and RX daughter cards on this board. The engine is an Altera Cyclone FPGA. With this board we can easily do serious phased array tests with four

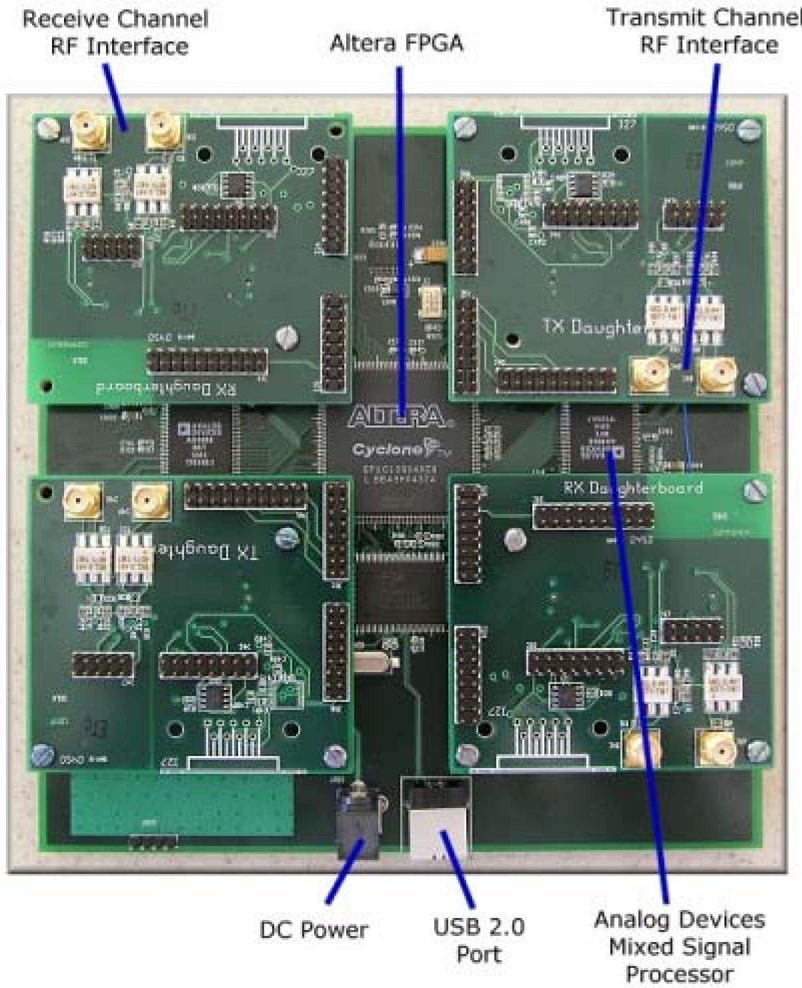


Figure 5. Matt Ettus GNU Radio USRP Boards

elements. This is made possible by the shared clock and coherence through the entire chain. We will get four digital streams that should allow us to beam steer in software. Since there are other daughter cards, this can be an experimental transponder on a single board with these receiver and transmitter daughter cards. .

<u>A Demonstration SDR Transponder (SDX)</u>

We have begun the Software Defined Transponder, SDX, development and we used two SDR-1000's with transverters. So far, we have been concentrating on writing the software and putting together a demonstration project using off-the-shelf hardware rather than delving directly into spaceflight capable hardware. On August 17, Rick Hambly, Tom Clark, and Bob McGwier conducted the first QSO through our breadboard SDR prototype.

In this hardware and software development system (see Figure 7), we demonstrate the power of the SDX concept. We can, with a simple command, change the nature of the transponder from a linear SDX, intended for SSB, CW, etc. in a frequency division multiplexed linear repeater to a channelized FM transponder. Even more impressive, we can change half the passband to a channelized FM transponder and leave the other half as a linear transponder. With another flick of the switch, we can make it a digital signal transponder. We have a standard 400 bps PSK beacon in the middle. And we have the same type of equalizing "AGC" system mentioned in the STELLA article by G6LVB. Expect this area of research and development for amateur radio in general, and **AMSAT** in particular, to really take off. You can hear the audio from the initial Mode-A test (Mode-A because we didn't have the 70cm-10M converter hooked up yet) at ftp://ftp.cnssys.com/pub/amsat/Eagle_SDT_1st_Contact.mp3.

Figure 6 -- W3IWI, W2GPS, and N4HY after the first QSO through our SDX!

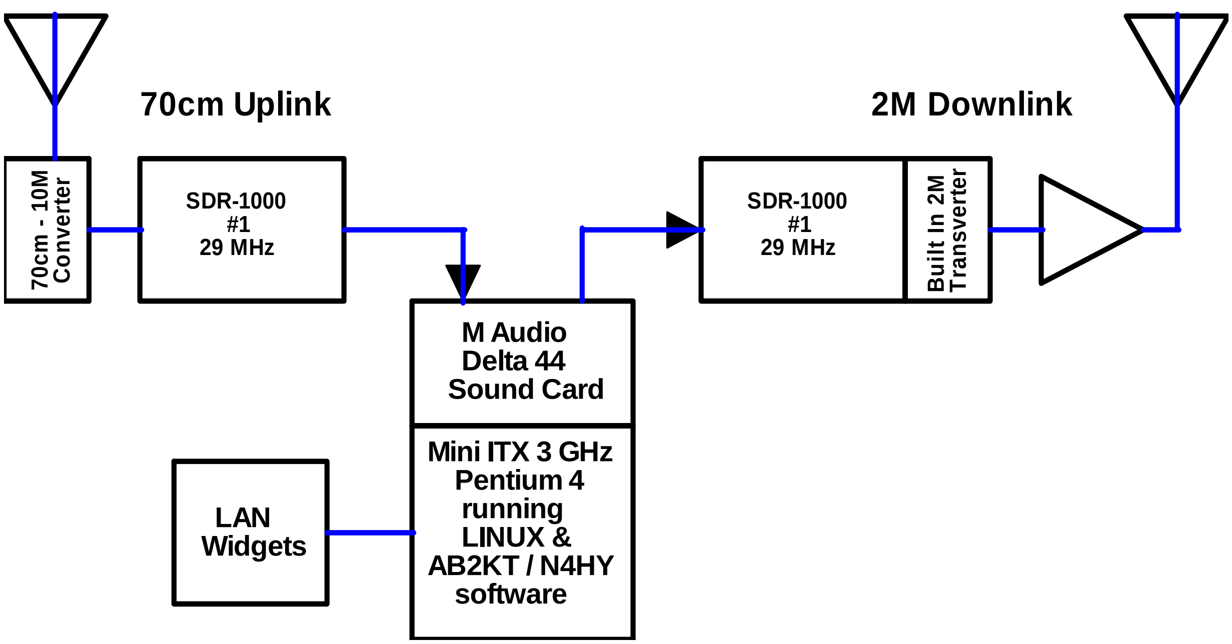


Figure 7 –Block Diagram of our Demonstration SDX

Adaptive Beam Steering for AMSAT's Proposed EAGLE Satellite

By Bob McGwier, N4HY and Tom Clark, W3IWI

The authors have proposed that AMSAT build and fly a transponder in a new band for us, C band [1,2]. In this band we have both an uplink segment and a downlink segment separated by sufficient space that we believe we can use them simultaneously. If we limit ourselves to a few hundred KHz, we can separate the uplink and downlink by almost 200 MHz. If we are to succeed with what is clearly a complex mission, we feel we must take on the most complex antenna system we have ever tried, a phased array.

The reasons for doing so are myriad. Let us give but a few. We can steer the beam "electrically" to allow keeping the antenna nadir pointing even when the spacecraft is tilted away for maximization of solar power production. It allows us to put smaller power devices right at the antenna since it is easier to derive 0.5 watt to 1 watt in a small device and to conduct the dissipated heat away than it is to make larger power efficiently and deliver it to a single feed point. In addition, the larger power to a single antenna would not allow us to steer the beam pattern at all except by changing the spacecraft attitude. The drawbacks to this approach are that we have no experience with such a system. It is our belief that we can only gain this experience by trying to do these experiments.

Let us consider some necessary assumptions we are going to make to greatly simplify our analysis and then argue these assumptions actually make sense. In our derivation of the beam steering mathematics, which we must do on an on board computer, we are going to be assuming:

1) The total bandwidth of the signal we are attempting to send or receive is thousands of times smaller than carrier frequency of the transmitter or receiver and this will allow us to approximate time delays as phase shifts.
2) We definitely need the antenna to be in space since we are going to assume a nondispersive, uniform transmission medium.
3) We are in the far field and the signals arrive as a planar wave front as a result.
4) The elements of our antenna are uniform in pattern and the signal amplitude is uniform across the antenna but only the phase differs.
5) The antenna patterns are all the same.

Since we are talking about transmitting a few hundred KHz at 5 GHz, the first assumption is obviously met since in the worst case the ratio of the bandwidth of the transponder to the carrier is greater than 10000. There is no medium less dispersive and uniform than the near vacuum of space. At perigee, the worst case has the emanations of a ground station "plane wave". Given this, consider for the sake of simplicity, we are talking about an array of elements aligned in a row and with the signal of interest moving through the same plane of interest. Mathematically, we can treat more complex cases, but for the sake of clarity of the exposition, we will not do so here.

Directional antennas are angle of arrival filters. Suppose we have N antennas is a linear array. Further assume that the angle of arrival of the plane wave of interest (say a beacon transmitter located on the earth for the purpose of aiding the steering of this array). Suppose further, for simplicity of analysis, that all the antennas a distance d apart. The beacon emitter, will be a complex Source carrier with frequency f or ω radians and as such will be denoted

Source signal: $S(t) = A_s e^{j\omega t}$.

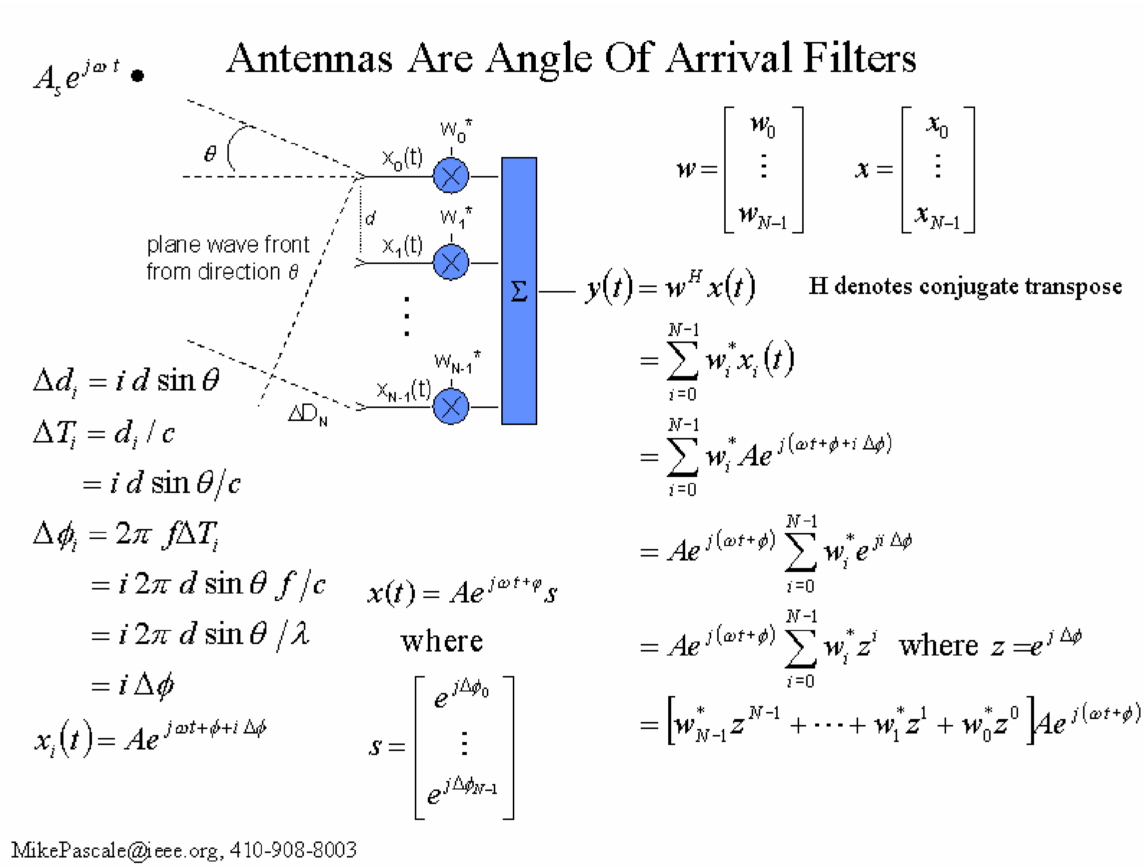


Figure 1

Our antennas each receive a signal from the source ***S(t)*** and we will denote the received signal by $x_i(t)$ if the signal is received on antenna ***i***. Our processing will be very simple indeed. Our simplifying assumptions allow us steer the antenna pattern by simply multiplying each of the incoming signals by a number (albeit complex) and summing the results over the array. The numbers are called “tap weights” and will be denoted as w_i where i ranges over the array.

Therefore, the received signal is, by design of our system:

Received Signal: $y(t) = \sum_{i=1}^{N} x_i(t) * w_i^*$.

Our job is to find the w_i's that steer the beam!

With just a little geometry and head scratching, this turns out to be really easy. The pictures, shamelessly stolen from Mike Pascale(3), will aid us considerably. What ***w***'s do I want to make “***y*** point at ***S(t)***”?

So suppose that the entire time of flight from the source to the “nearest antenna” is T. This will mean that the carrier frequency would have rotated through some angle before it gets to us[1]:

Total phase rotation before arrival: $\varphi = 2\square\omega T$.

A little trig will show you that as the wave front passes over the antennas, the distance of the extra travel from the 0-th to the ‘i-th’ is given by Δd_i in Figure 1 and the extra time is ΔT_i, the extra phase angle is then $\Delta\Phi_i$, yielding finally that the signal received on the antenna k is:

$$x_k(t) = A_s(t)e^{j\omega t+\phi+\Delta\phi k}$$

and the received vector ***x(t)*** given by

$$x(t) = A_s(t)\, e^{j\omega t+\phi}\, [e^{j\Delta\phi 0}, e^{j\Delta\phi 1}, \ldots, e^{j\Delta\phi(n-1)}]^T$$

where the superscript T means the transpose of the array. In this case, that means making a column vector out of a row vector. This is done for mathematical reasons only. What we have done is to separate the incoming signal into components of a vector. This vector is further broken down into the source signal ***S(t)*** times the angle rotations that correspond to the delays the elements will experience in the incoming signal. We are going to be dealing with a DSP based system. This means that we must sample the

---

[1] For the time being, this will be a static derivation. Nothing is moving so this number stays constant for this analysis

signal. The reason we get away with turning this delay into an angle rotation is straightforward. The interval between samples is so much longer than the delays across the entire array for all signals in our passband that we can effectively turn the delay into a simple rotation for our purposes.

So, what signal do we receive?

We are going to take up the individual element signals $x_i(t)$, multiply them by some weights and then and all of this signal up. Our received signal is $y(t)$ and this is given by

$$y(t) = w^H * x(t).$$

The superscript H means we take the column vector of weights, w_i and make it a row vector and take the complex conjugate of each of the numbers in the vector. This seems complicated but it is not. Taking the complex conjugate just means multiplying the imaginary part of the complex number by –1. We do this so that the equations we need to manipulate are very easily and naturally manipulated by the linear algebra mathematics we need to do. Given a set of these weighting numbers, what is our antenna pattern going to be? The pattern is the discrete fourier transform of the weighting and we see how to make it behave using the periodicity of a sinusoid (see Figure 2). With 16 elements in a linear array, we can get 12 dB gain with sidelobes down by 13 dB (see Figure 3). To steer the beam, we simply adjust phases in the weight array by a progression of phase angles across the array. The s vector in figure 1 will give the best vector. The steering angle is given by Theta and the best steering is accomplished by making the weight vector w the the "*matched filter*" for the steering vector s**,** this being the ultimate in simplicity $w=s$ (see Figure 4)..

One of the things we will not treat here is how to yield a little gain and decrease the side lobes by a much larger number. Suffice it to say for the purposes we have here, in this linear array, we could give up 0.5 dB of gain and get our side lobe suppression to improve from 13 dB to 20 dB. An analysis of this tapering will be done to decide if the extra complexity in the algorithm and added control of the individual antenna amplifiers gives sufficient gain to justify this extra work and complexity. In the beginning, it will be a much better use of time to derive the

Array Pattern is DFT of Weighting

array pattern: $\mathbf{w}^{\mathbf{H}}\mathbf{s} = \sum_{n=0}^{N-1} w_n^* e^{j2\pi nd\sin\theta/\lambda}$

DFT of $\mathbf{w}^*$: $W^*(k) = \sum_{n=0}^{N-1} w_n^* e^{-j2\pi n\left(\frac{k}{N}\right)}$ $\quad k = 0 .. (N-1)$ ← angle index

thus we have: $\mathbf{w}^{\mathbf{H}}\mathbf{s} = W^*(-Nd\sin\theta/\lambda)$

note DFT is periodic: $W^*(k+mN) = W^*(k)$ for any integer m

thus: $k + mN = -Nd\sin\theta/\lambda \quad k = 0 .. (N-1)$

$$\sin\theta = -\frac{k}{Nd/\lambda} - \frac{m}{d/\lambda}, \quad k = 0 .. (N-1)$$

use appropriate value of m to keep $\sin\theta$ in [-1, 1] as k goes from 0 to $(N-1)$

MikePascale@ieee.org, 410-908-8003

Figure 2

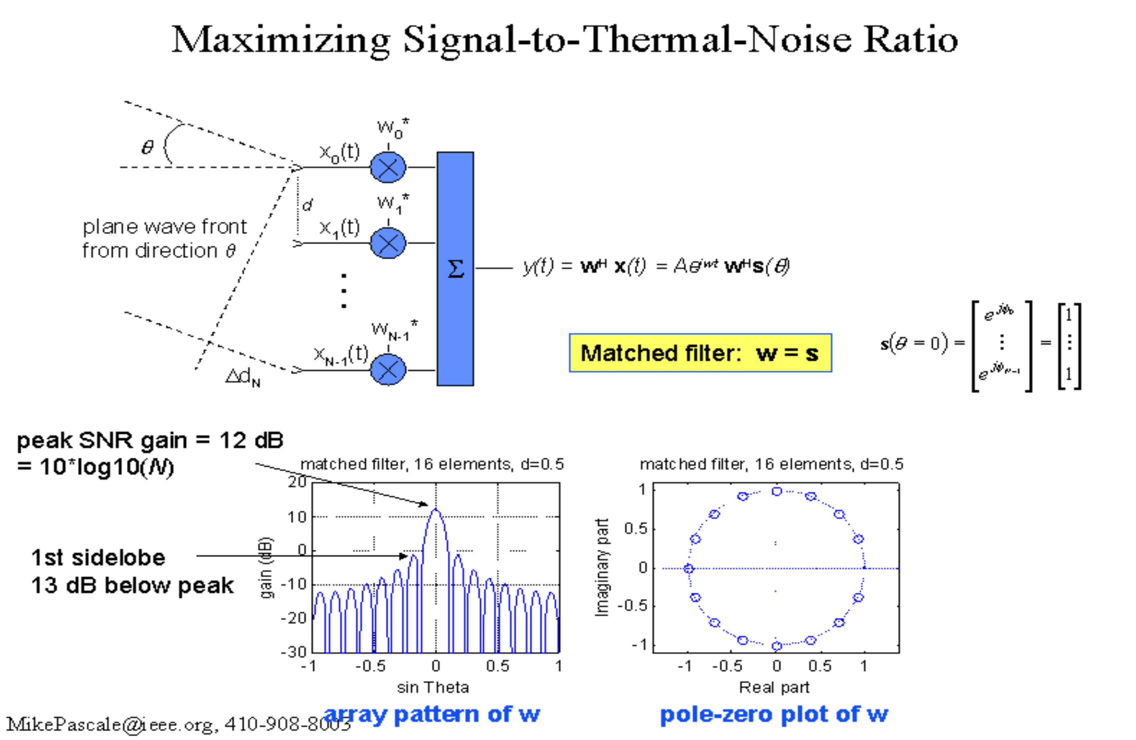
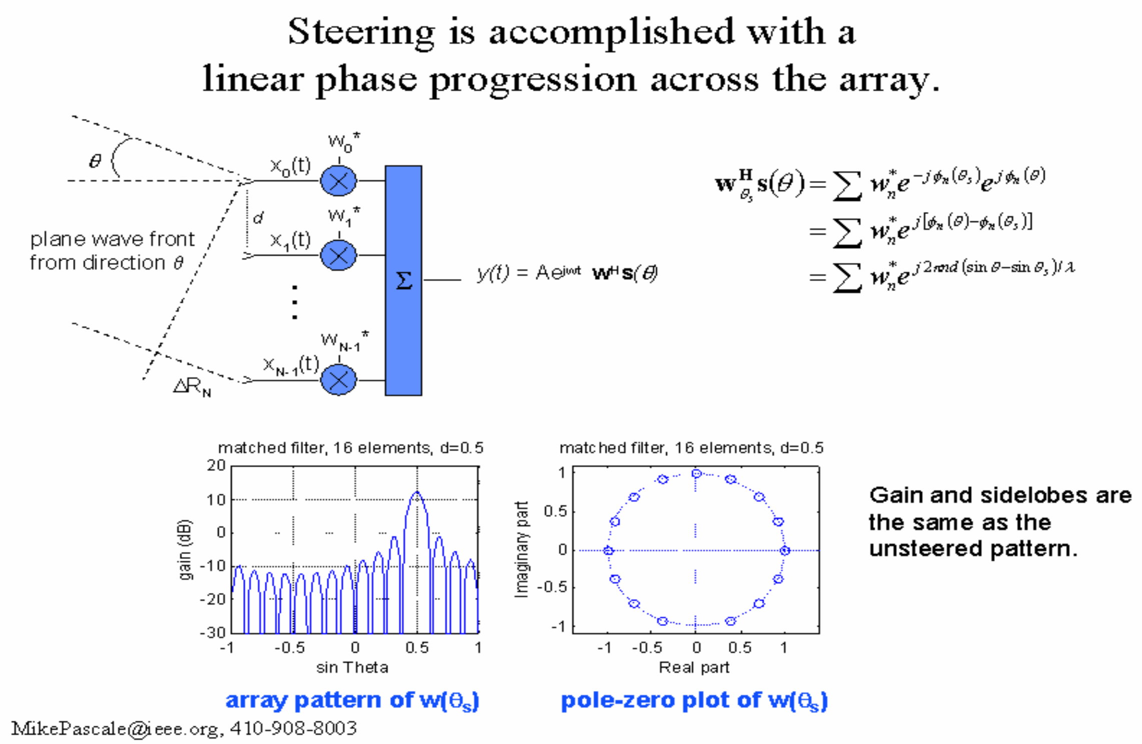


Figure 3 Optimum Weight vector is the matched filter w=s



$$\mathbf{w}_{\theta_s}^{\mathbf{H}}\mathbf{s}(\theta) = \sum w_n^* e^{-j\phi_n(\theta_s)} e^{j\phi_n(\theta)} = \sum w_n^* e^{j[\phi_n(\theta)-\phi_n(\theta_s)]} = \sum w_n^* e^{j2\pi nd(\sin\theta - \sin\theta_s)/\lambda}$$

Figure 4

So now that you have the idealized phased array basics, what does it have to do with us? Here is a block diagram from a previous paper:

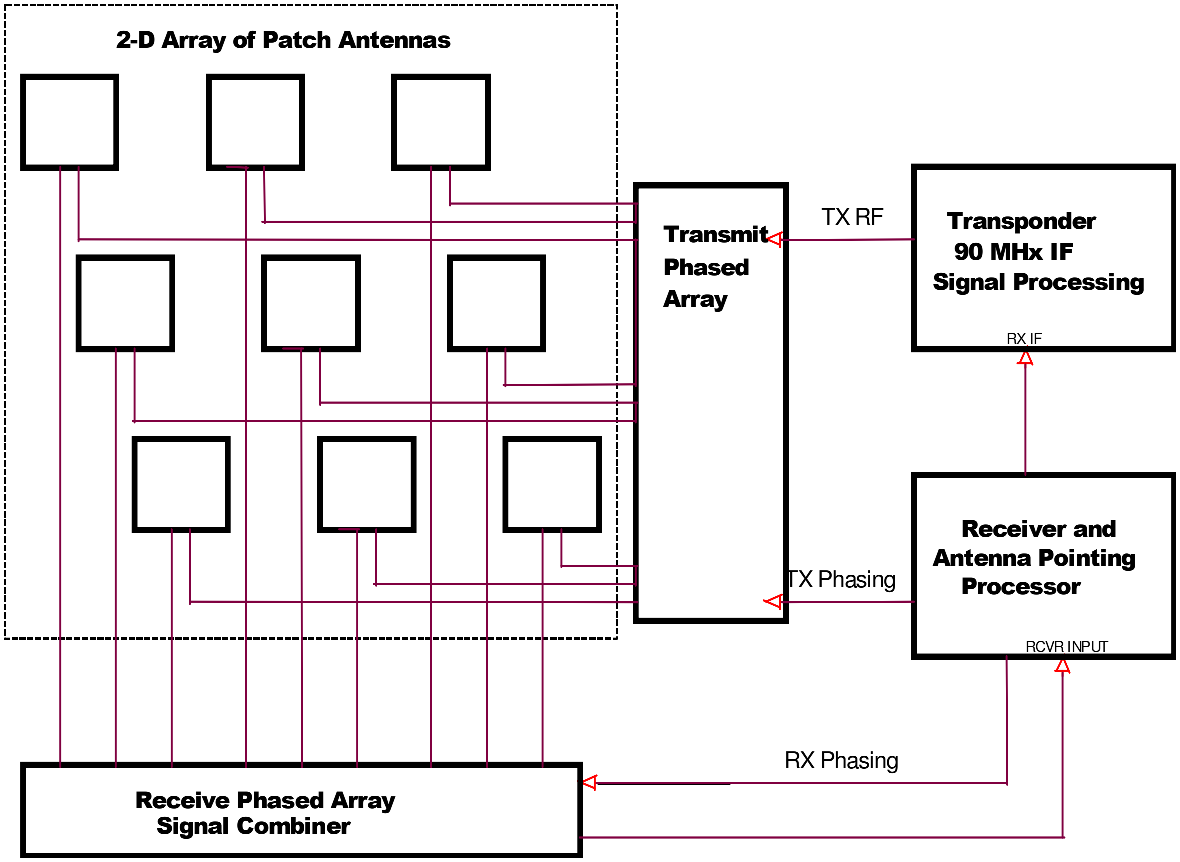


Figure 5: CC-Rider transponder phased array block diagram

The received phase array will have a signal combiner dsp process. The transmit phased array with have a signal splitting dsp process that takes the phase angles derived from computation plus observation of the received signal and points the beam back to earth. This will be done dynamically and will be made easier by taking the dynamics of the spacecraft into account.

Our array is quite a bit more complex than a linear array as you can see from this depiction of the spacecraft in Figure 5. The small circles in the upper right corner are meant to depict a 30+-element array of patch antennas. The block diagram above shows our basic concept for using this phased array.

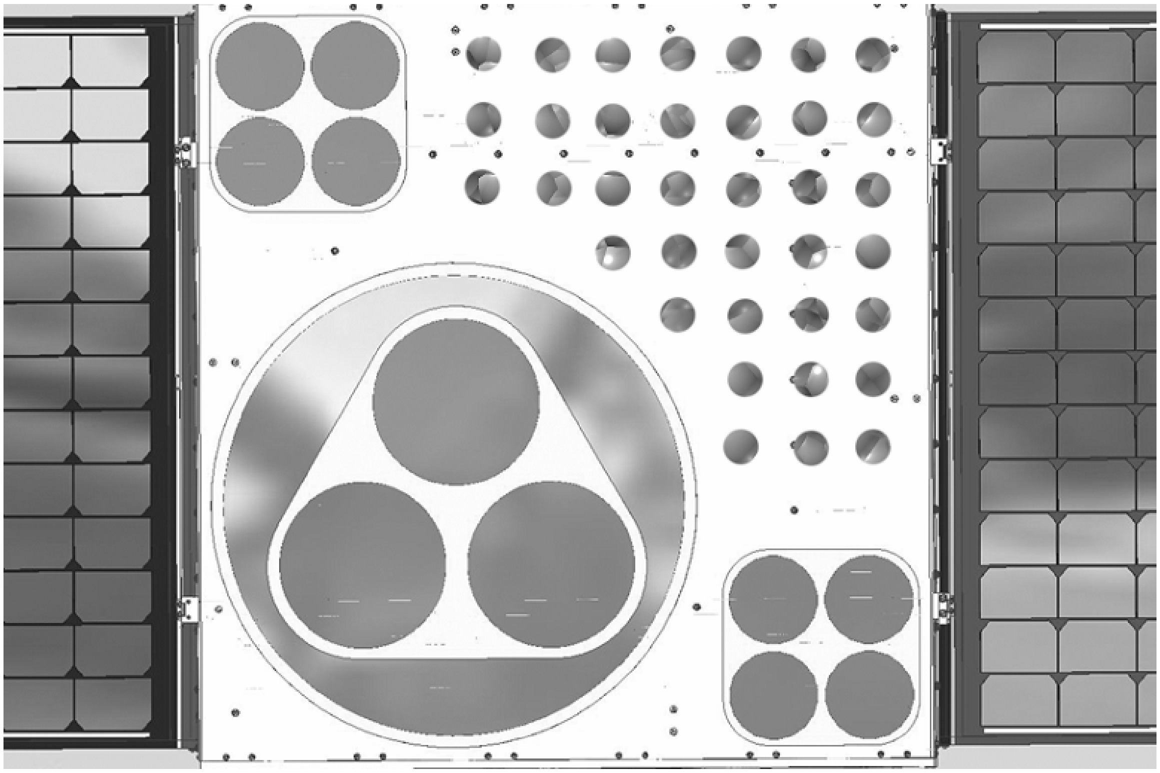


Figure 5: AMSAT Eagle potential mechanical design with antennas

We are beginning experimentation with control algorithms to do the adaptive and controlled beam steering. For our experiments we are using GnuRadio [4] and the USRP[5]. The USRP will be an SDR engine in many experiments because of its versatile and open design. The unit has just exactly what we need to develop algorithms for the phased array and to understand how we might scale this to a much larger array. The USRP has 4 receive antenna ports with which we can build a 4-element array easily. Since external clocking can drive the USRP, we can synchronize multiple USRP boards. The boards are hooked to a (primarily) Linux box by means of USB 2.0 connections for control and code upload. With 8 element arrays, we can easily do experiments with multiple configurations to learn how to control such an array with DSP processors. In the case of the USRP, the engine for DSP computation is the Altera Cyclone FPGA. We will need to control 4 software mixer frequencies and phases and return 4 narrow band signals from the USRP. This level of code is almost complete installed when the unit comes and we will need to do some minor modifications to allow us to control the phase angles of the incoming signals before we downsample and then add them for the final response. The nice thing is that the addition to get the combined gain occurs at the downsampled (transponder bandwidth) rates.

The rate of our experimentation has heated up considerably as we have settled on a series of tasks we would like to accomplish and most especially because of the hardware that has only recently (in the last 12 months) become available for our use in these experiments. The authors wish to thank Mike Pascale for allowing us to use his wonderful artwork for the basics of adapting beam forming and to Matt Ettus and Eric Blossom of GnuRadio for their work, which will help us to move forward at a more rapid pace.

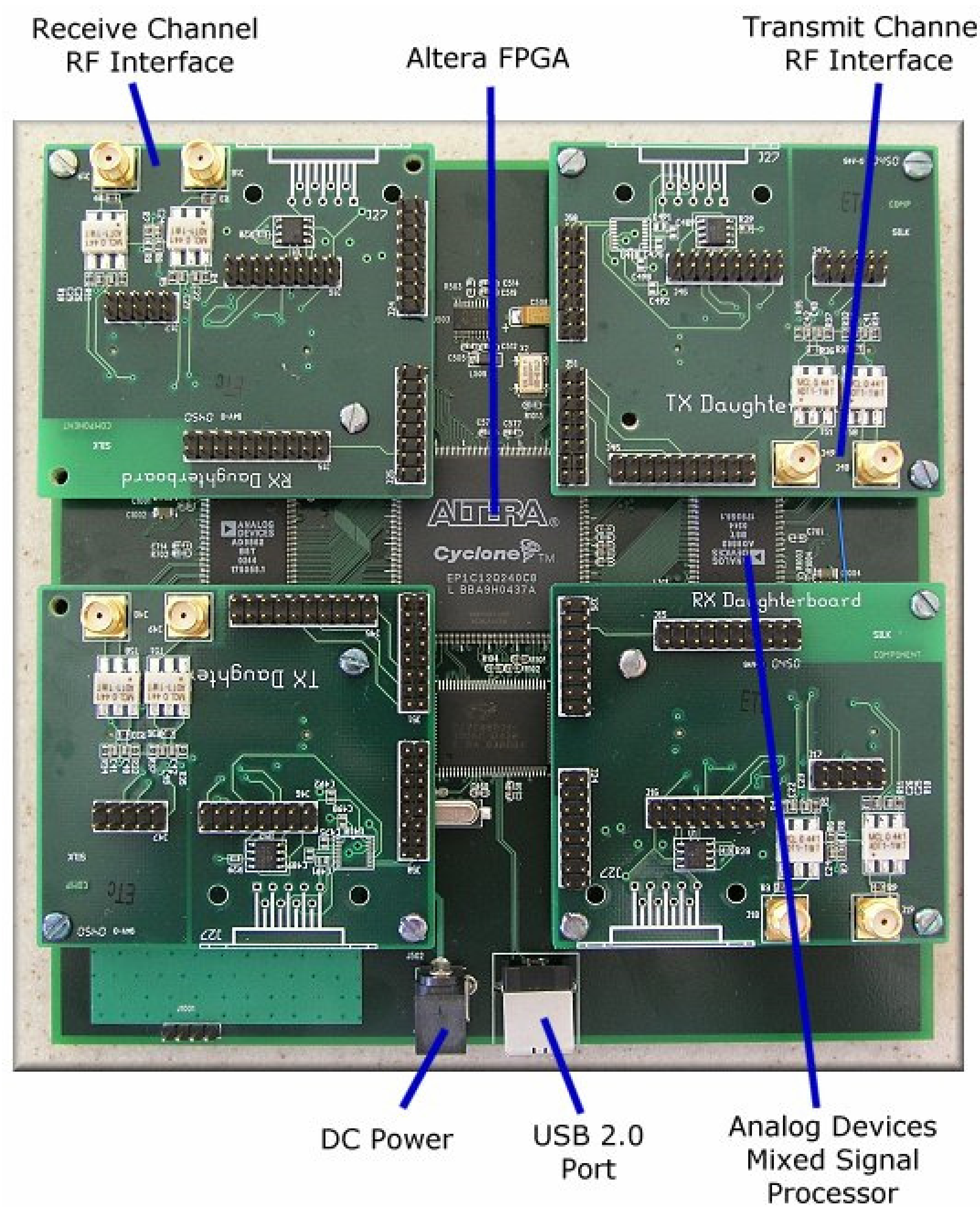


Figure 6. The Universal Software Radio Peripheral (USRP)

1) ***C-C RIDER Revisited, A New Concept for Amateur Satellites*** by Tom Clark, W3IWI as published in the Proceedings of the AMSAT-NA 21st Space Symposium, November 2003, Toronto, Ontario, Canada.

2) ***C-C RIDER Revisited*** by Tom Clark (W3IWI), Bob McGwier (N4HY), Phil Karn (KA9Q) and Rick Hambly (W2GPS) as published in the Proceedings of the AMSAT-NA 22nd Space Symposium, October 2004, Arlington, Virginia.

3) ***Adaptive Beam Forming,*** Mike Pascale, Engenium Technologies, Inc. http://www.ewh.ieee.org/r2/baltimore/Chapter/Comm/adapt/. Pictures reprinted with permission.

4) The GnuRadio project is describe on http://www.gnu.org/software/gnuradio/.

5) The Universal Software Radio Peripheral (USRP) is described on http://comsec.com/wiki?UniversalSoftwareRadioPeripheral and may be purchased from Matt Ettus, N2JMI. See http://www.ettus.com.

AMSAT IHU-3: Update and Status

Lyle Johnson, KK7P
Chuck Green, N0ADI
Bob McGwier, N4HY

BACKGROUND

AMSAT's next generation of high earth orbit (HEO) spacecraft require a flight computer for navigation and communication tasks. The original IHU, most recently flown on AO-40, has become impractical to produce. The prototype follow-on computer, IHU-2, also flown on AO-40, showed great promise but the primary components in its design have become obsolete.

IHU-3 builds on the IHU-2 and AO-40 experience in a simplified architecture.

DESIGN

IHU-3 is based on the ARM-7 processor core. This ubiquitous 32-bit processor has found its way into most cellular telephone handsets and has proven its reliability and miserly power consumption. In the IHU-3, it is running at a slow 26.2 MHz.

IHU-3 includes eight megabytes of unprotected memory, and one megabyte of error detecting and correcting (EDAC) memory. In addition, it has two Flash chips for basic program storage.

The use of Flash was demonstrated on AO-40, and has been used extensively in low earth orbit (LEO) missions.

A radical departure from AMSAT tradition is incorporated in IHU-3: control bus and command/telemetry interface.

CONTROL BUS

Earlier Phase 3 spacecraft have used an extensive, bulky and complex wiring harness. AO-40 required a second box just to hold the multiplexer electronics, along with over 150 pins of connectors to carry the control signals out and the telemetry signals back to the processor.

On AO-40, controller area network (CAN) was tested as an alternative. It worked flawlessly. CAN has been used for some time on low earth orbit missions, so after the AO-40 success in HEO, the decision was made to use CAN almost exclusively for control and telemetry. This is supported at the module end of the cable (transponder, power supply, etc.) by use of the CAN-Do! module, described in other AMSAT proceedings.

An additional feature is that use of CAN allows multiple masters, or redundant IHUs in a spacecraft. It is debatable whether or not this feature should be used, however!

COMMAND/TELEMETRY

In the past, uplink commands were decoded in hardware and loaded into the IHU a byte at a time. There was no Flash or other non-volatile memory, so this was necessary to load the computer memory in case of power failure or other reason.

However, a hardware solution is rigidly fixed in data rate and format.

With AO-40, experiments were run on the IHU-2 using encoded telemetry, which worked tremendously well. Partly as a result of that experience, and partly to allow extreme weak signal operation in case of failure (or interplanetary missions!), the IHU-3 performs all demodulation and decoding of the uplink in software.

A low-pass filter at the command receiver detector output limits bandwidth to something less than 3 kHz. This audio is sampled in the IHU-3 at 6400 Hz, and the ARM-7 CPU then performs digital signal processing for telecommand.

For the downlink (telemetry), a simple hardware interface is employed to allow the software to arbitrarily format the data, and set the downlink data rate over a wide range.

RESET

There are difficulties imposed on the design by the choice of processor implementation. In this case, an Atmel AT91M40800 series part is used. The internal architecture requires that certain information be kept in internal (unprotected) memory. To get around this problem, an elegant, progressive reset strategy was proposed by Karl Meinzer, DJ4ZC. This is incorporated in a combination of programmable logic and software in IHU-3. The result is expected to be a very reliable computer with graceful recovery from corrupted bits in the small amount of internal memory that must be used.

WHAT ABOUT THE AM1601?

The AM1601 is a proposed processor contained entirely in a programmable logic device, and intended for use in HEO and beyond. The design is not yet complete, and has been idle for more than two years. During this interval, Actel, a vendor of radiation-tolerant programmable logic, has made an arrangement with ARM to incorporate the ARM-7 as a core within the logic device, implemented in logic cells. This may open the door to use the ARM architecture in a very radiation tolerant device.

Alternately, the AM1601 may yet be developed, perhaps to fly as an alternative processor along side the IHU-3 in Eagle.

STATUS

In early August, the authors, along with Frank Brickle, AK2BT (and with telephone and email support from Stephen Moraco, KC0FTQ) gathered at the QTH of KK7P. The goal was to troubleshoot, repair, and prepare for radiation testing an IHU-3 with modifications resulting from an IHU-3 meeting in January.

The goals were accomplished, hardware repaired and software developed. An alternative for the analog-to-digital converter will be radiation tested, in an effort to get the best possible performance for the command link.

By the time these proceedings are published, we expect the radiation test to be well underway and for IPS to be running for the first time on the IHU-3. We hope to report on the results of that testing at the AMSAT Symposium in October.

Emerging Launch Opportunities for Small Satellites and Secondary Payloads

Lee J. McLamb, KU4OS
ku4os@amsat.org

Abstract

Finding opportunities to launch is a primary challenge faced by AMSAT and as well as the entire small satellite community. The European Space Agency's ARIANE Structure for Auxiliary Payloads (ASAP) ring and DNEPR launch vehicle are probably the best known carriers of small satellites to orbit and have been used successfully in the past. While these two opportunities will continue to exist for quite some time, additional capabilities are also emerging in the form of new launch vehicles, new launch sites as well as new multiple and secondary payload adapters for existing vehicles.

There has been a revolution building in the space community over the last few decades. Small satellites have proven to be useful tools for accomplishing real-world missions as well as serving educational, research and development missions. As a result an entire industry has now grown up around small satellites. Some studies[1] have identified hundreds to potentially thousands of small satellites that could be launched if inexpensive rockets were available and this market has proven to be fairly constant over the last several years. Because of this there are now new opportunities emerging to satisfy the increasing demand for small satellite access to space.

New Rockets

One means to satisfy the growing demand for access to orbit is with new rockets specifically tailored for that mission. Several companies are building entirely new rockets and others are adapting existing technology for new uses.

Table 1 shows the capabilities of some existing launch vehicles as well as those currently in development.

	Sun-synchronous (98 deg inclination)	
Existing Small Launch Vehicles	**Mass (kg)**	**Altitude (km)**
Athena I	320	600
Athena II	1080	600
Minotaur	380	600
Pegasus XL	250	600
Taurus	600	600
Future Small Launch Vehicles		
RASCAL	75	500
Scorpius Sprite Mini-Lift	150	741
Super Strypi	181	370
Falcon I Falcon V (Space X)	430 4780	700 700
Streaker	Not	Given
K-1	1750	600

Table 1 Existing and Future Small Launch Vehicles

One of the first questions asked is how likely is it that these future rockets will actually ever exist? Fortunately it appears that several have enough history behind them by being based on components from other vehicles or are already far enough along that they have a very good chance or existing as something more than a PowerPoint presentation.

Falcon – SpaceX

The Falcon I by Space Explorations Technologies Corporation[2] (SpaceX) was planning their first launch from Vandenberg AFB, CA for the summer of 2005. Because the Falcon flight path would over-fly the Titan IV launch pad, delays in launching the final Titan IV, have caused SpaceX to delay that mission until late in 2005 and pursue making their first launch from an entirely new Kwajelean Atoll launch site in the Pacific Ocean during September of 2005. Currently there are four flights contracted for the Falcon I launch vehicle in 2005 and 2006.

Figure 1: Falcon hotfire test at Vandenberg
Photo Credit: SpaceX

SpaceX is also developing a larger rocket called Falcon V. The Falcon V will feature over ten times the capacity to a Sun-synchronous LEO as well as being able to lift 1,900 kg to a Geo-Transfer Orbit (GTO). The Falcon V uses five engines on the first stage to provide the capability to still achieve orbit should an engine fail. With the Falcon V, SpaceX will also introduce their "half-bay" launch option to allow launch sharing for payloads that don't need the full 7.9m x 3m interior volume of the Falcon V payload fairing.

Super Strypi - Sandia National Laboratories

The Super Strypi[3] builds on the Strypi sub-orbital launch vehicle from Sandia National Laboratories. The Strypi vehicle has a history of 44 flights over the last 35 years. By developing a dedicated small satellite vehicle without requiring revolutionary new technologies it is hoped that significant reductions in developmental costs will be realized. The use of established sounding rocket technologies, methods and practices is expected to help reduce the recurring cost of placing small lightweight satellites into low earth orbit.

Streaker - SpaceDev

The SpaceDev Streaker[4] family of small, expendable launch vehicles is designed to affordably deliver small satellites to low earth orbit using hybrid engine technology. Hybrid engines use a combination of solid fuel with a liquid or gaseous oxidizer. Probably the best known example of hybrid engine technology being used was during the X-Prize Competition. SpaceShipOne utilized hybrid engines provided by SpaceDev to win the X-Prize. During the test flights leading up to the competition, the ability to throttle and perform an early commanded shutdown was also demonstrated. This capability greatly increases the safety and versatility of the engines. For fuel, either HTPB (rubber) or PMMA (Plexiglas) is chosen depending on the operating environment of the engine. Several oxidizers have been tested, including liquid oxygen, nitrous oxide, and hydrogen peroxide (LOX, N_2O, H_2O_2) for use in hybrid engines. Nitrous oxide is SpaceDev's oxidizer of choice because it is storable, and self-pressurizing to 700psi at room temperature. The combination of HTPB or PMMA and N_2O is completely benign and non-toxic. The hybrid engines developed in the Streaker booster stage will produce approximately 100,000 pounds of thrust, about six times the thrust of the SpaceShipOne motor. While this is a significant increase it remains less than one-half that of the 250,000 pound thrust hybrid rocket motors developed and tested several years ago by the American Rocket Company (AMROC).

Scorpius Sprite Mini-Lift - Microcosm

Microcosm is developing the Scorpius family of new of expendable launch vehicles. The sub-orbital SR-S and SR-XM-1 vehicles were launched in 1999 and 2001 respectively with the SR-M and SR-2 building on this development. The of smallest Microcosm's orbital vehicles, the Sprite Mini-Lift[3] adds a third stage to the SR-2. The Scorpius family of launchers are pressure-fed rockets which use liquid oxygen and kerosene. One goal of the program is to greatly simplify launch processing. All normal vehicle servicing on the pad is done at ground level so there is no need for a gantry or tower and the time from payload integration to launch is expected to be approximately 8 hours.

K-1 - Kistler

Kistler is taking a very different approach in the development of their K-1[5] launch vehicle. The K-1 is a two-stage, fully reusable vehicle. The K-1 first stage, or Launch Assist Platform (LAP), is 18.3 m long and 6.7 m in diameter. The second stage, or Orbital Vehicle (OV), is 18.6 m long and has a diameter of 4.3 m.

Three Aerojet engines power the K-1 LAP. These liquid oxygen (LOX)/kerosene engines provide 4,540 kN thrust at liftoff. Following separation of the OV, the middle engine is then restarted to return the LAP to the launch site. During the final stages of decent, parachutes are used to decelerate the LAP for a soft touchdown using four low-pressure airbags.

The OV uses a single engine for primary propulsion. After payload deployment, the engine fires again to place the OV into a phasing orbit with the correct period for re-entry. The OV may coast in this phasing orbit for up to 22 hours before a final de-orbit burn with the engine is performed causing the OV to reenter the earth's atmosphere. The OV flies a guided re-entry trajectory to the launch site and like the LAP also uses parachutes and airbags for landing.

Secondary Payload Adapters

In addition to new launch vehicles another area which is showing increased activity is developing new structures for mounting multiple secondary payloads on a single launch. Existing secondary payload adapters have also continued to grow and evolve over the years.

ASAP – Ariane

One of the best known secondary payload adapters is the Ariane Auxiliary Structure for Secondary Payloads[6] or ASAP. In fact the very first ASAP was used for the launch of OSCARs 14-19, in January 1990. As Ariane has transitioned to the larger Ariane V launch vehicle, the capabilities offered by ASAP have grown as well. When ASAP is positioned below the primary payload, the platform can carry up to eight small satellites, each weighing under than 120 kg. Another option is to mount the ASAP inside a dedicated Sylda structure. In this configuration it can carry either up to four satellites weighing up to 300 kg each, or a combination of two 300-kg and six 120 kg satellites.

ESPA - EELV

Figure 2: ESPA Ring
Photo Credit: CSA Engineering

In the United States two new rockets have recently been developed as part of the Department of Defense (DoD) Evolved Expendable Launch Vehicle (EELV) program. These two EELV launchers are more commonly known as the Delta IV by Boeing and the Atlas V by Lockheed-Martin. As these rockets were being developed it was noticed that there were large unused payload margins expected on most DoD missions. In almost every case this excess margin was greater than 1360 kg. To take advantage of this excess margin an EELV Secondary Payload Adapter (ESPA) has been developed. ESPA takes advantage of this unused payload margin by deploying up to six secondary payloads.

ESPA is an aluminum ring that is roughly 157 cm in diameter by 61 cm tall. Individual satellites can be mounted on one of six standardized secondary payload mounting locations on the perimeter of this ring. The secondary satellites mount on their side around the outside of the ESPA adapter using a separation system called Lightband, developed by Planetary Systems Corporation.

Figure 3: STP-1 Mission
Credit: CSA Engineering

Each satellite can have a maximum mass of 181kg and a dynamic envelope of 61 cm x 61 cm x 96 cm. ESPA is installed between the EELV payload attach fitting and the primary payload. Currently the first flight of and ESPA ring will be the STP-1 mission. STP-1 is currently scheduled to launch on an Atlas V late in 2006.

SAM – Delta IV

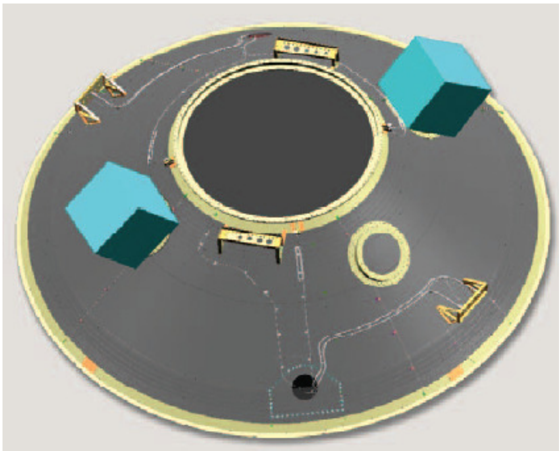


Figure 4: Delta IV SAM
Credit: Boeing

Boeing is also developing a new Secondary Attach Mounting[8] (SAM) specifically for the Delta IV launch vehicle. The SAM is an aluminum structure which is fastened to the outer shell of the conical Delta IV payload attach fitting. The SAM will accommodate payloads up to 136 kg and includes a standard volume envelope of 76.2 cm x 76.2 cm x 76.2 cm. Up to three SAMs could be attached to a payload adapter fitting for a mission if that mission had excess performance margin available for use. Boeing also adopted the same 15 in. bolted interface being used by ESPA.

Other Developments

The Defense Advanced Research Projects Agency (DARPA) and the Air Force are jointly sponsoring the Force Application and Launch from CONUS (FALCON) program to develop new technologies and capabilities. A significant part of this effort has been funding to develop a low-cost, operationally responsive, Small Launch Vehicle (SLV). The SLV is intended to provide a low-cost, responsive launch capability for placing small satellites into Sun Synchronous Orbit. This initiative has helped to fund some of the early work done on the launch vehicles above. It also serves as another indicator to those looking to market small launch vehicles that there is an evolving and growing customer base to support these new programs.

While this paper has focused mainly on activities within the United States, there is also significant activity in other parts of the world [9]. The changing of the old the Soviet space program to a commercial venture has opened some new launch opportunities to LEO, GTO as well as direct insertion into geosynchronous orbits as well. Commercial Space Technologies Ltd (CST) was begun with the objective of constructing a commercial consultancy providing launch brokerage services for Russian and Ukrainian rockets to the rest of the world including those who are looking for launches as a secondary payload. In some cases Russian launch costs have been near $12,000/kg. There is also the very active Indian rocket program which recently placed Hamsat, VO-52 into orbit. Plans for a new smaller launch vehicle to complement the Ariane V have also been announced by ESA.

AMSAT now has an active and on-going project to continually seek out, identify and evaluate new launch opportunities. Some may turn out to be suitable for HEO spacecraft such as Eagle while others are limited to LEO missions. Eagle is a small satellite by almost all measures. In fact, by some definitions, Eagle would be classified as a Nano-Sat. Which rocket will eventually carry Eagle to orbit is still unknown. What is clear is that there will be more options and opportunities in the future for all types of amateur radio satellites to be placed into orbit.

Reference::

1. Marco Carere, "Tracking nontraditional satellite customers", *Aerospace America Online*, October 2003

2. http://www.spacex.com

3. Access to Space web site, http://ats.gsfc.nasa.gov

4. "Products_Hybrid Rocket Propulsion Systems", http://www.spacedev.com/

5. "K-1 Vehicle", http://www.kistleraerospace.com/k1vehicle/k1vehicle.html

6. "The Ariane Structure for Auxiliary Payloads (ASAP)", http://www.arianespace.com/site/launcher/launcher_asap.html

7. "Small Satellite Technology", http://www.afrlhorizons.com/Briefs/Dec02/VS0202.html http://www.csaengineering.com/brochure/pdfs/ESPA.pdf

8. "Delta IV Secondary Attach Mounting", http://www.boeing.com/defense-space/space/delta/product_card/pc_d4_2ndary.pdf

9. Marcia S. Smith, "Space Launch Vehicles: Government Activities, Commercial Competition, and Satellite Exports", *Congressional Research Service*, February 3, 2003

The XP217 Experimental RADAR Transponder for the RAFT1 CubeSat

Anthony Monteiro, AA2TX (aa2tx@amsat.org)
Robert Bruninga, WB4APR (Bruninga@usna.edu)

Abstract

"…Now we have another great launch where eight microsat's were placed into orbit, and everyone is scrambling to come up with some Keps that reflect who is who up there. The tracking folks do a great job, but from what I remember from last years operation was that it will be a while before it is straighten out up there. I'm sure the trackers have no problem finding the large stuff, like the booster stage and shrouding. But when it comes to the microsat, well that's another issue. There small in size and probably close together right now. First they will have to find them, and then try to figure out who is what. I can recall from last years launch that it took the better part of a MONTH before it was settled…"
- From the AMSAT-Bulletin Board[1], 29-JUN-2004.

The US Air Force Space Surveillance System (AFSSS) RADAR[2] provides critical orbiting object data to NORAD[3] which generates the Keplerian elements needed to track satellites orbiting the earth. The advent of CubeSats, MicroSats, PicoSats and other small satellites launched in clusters, has caused a difficulty in identifying specific satellites in orbit since the number and very small size of these satellites is beyond the tracking ability of the AFSSS RADAR.

This paper describes the XP217 RADAR transponder, developed by a team of AMSAT members, which will be part of an experiment to determine if small satellites can help identify themselves. This experiment is the primary mission of the RAFT1 CubeSat. RAFT1 is being developed by midshipmen at the US Naval Academy Satellite Lab under the leadership of AMSAT member, Robert Bruninga, WB4APR. RAFT1 is scheduled to be launched on Space Shuttle mission STS-116 in 2006.

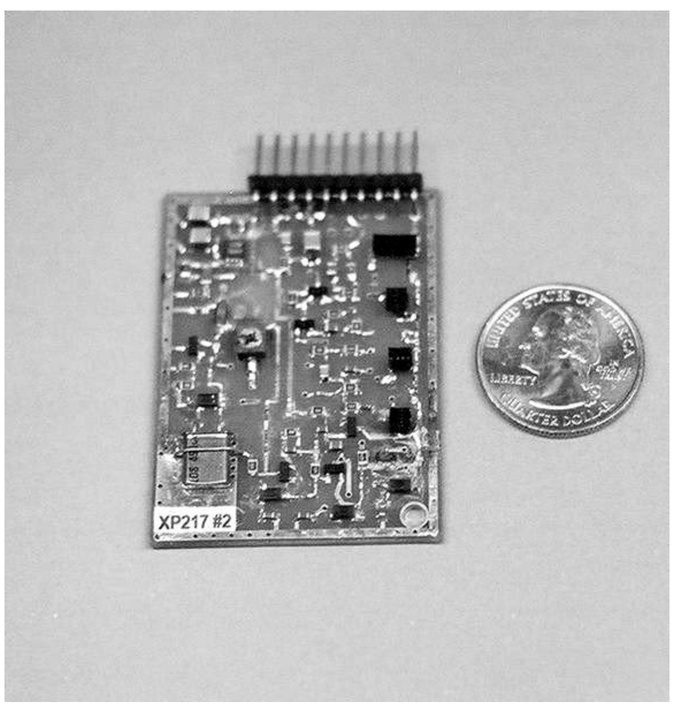


Figure 1. XP217 RADAR Transponder with US quarter coin

Introduction

The US Air Force Space Surveillance System (AFSSS) RADAR provides critical orbiting object data to NORAD to generate the Keplerian elements needed to track satellites orbiting the earth. The advent of CubeSats, MicroSats, PicoSats and other small satellites launched in clusters, has caused a difficulty in identifying specific satellites in orbit since the number and very small size of these satellites is beyond the ability of the AFSSS RADAR to distinguish them.

The RAFT1 CubeSat project was developed as a response to these issues and was approved by the Department of Defense, Space Experiments Review Board in 2002. This satellite will conduct experimental interactions with the AFSSS RADAR to determine if an active transponder could assist in tracking and identifying very small satellites. The RAFT1 CubeSat, shown in Figure 2, is a 5-inch cube covered with solar cells and includes antennas for 217 MHz, 146 MHz, and 29 MHz. The AFSSS Radar experiment is the primary mission and the satellite carries an amateur radio payload as a secondary mission. RAFT1 is being developed by midshipmen at the US Naval Academy Satellite Lab under the leadership of AMSAT member, Robert Bruninga, WB4APR, and is scheduled for launch on Space Shuttle mission STS-116 in 2006.

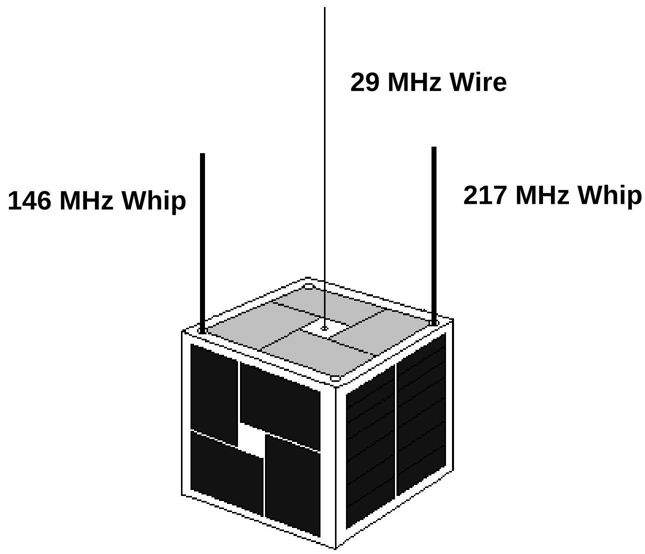


Figure 2. RAFT1 CubeSat

A block diagram of the satellite can be found in Figure 3. The RADAR experiment, shown in the dashed lines, includes a direct-conversion receiver and a beacon transmitter operating at 217 MHz. The output of the 217 MHz receiver is fed into an FM downlink transmitter operating on the 2-meter amateur radio band at 146 MHz. This will allow the RADAR signal to be monitored by ham radio ground stations as the satellite passes through the beam. The 217 MHz beacon transmitter provides a signal to help the AFSSS RADAR receivers to positively identify the satellite.

RAFT1 has a VHF FM receiver, also operating in the 2-meter ham band, and it feeds a customized AX.25 Terminal Node Controller (TNC.) This TNC provides the Telemetry, Command and Control functions for the satellite and provides a digital transponder for use in the Amateur Satellite Service. The output of the TNC is fed to the VHF FM transmitter for the downlink. The VHF transmitter and receiver operate on the same frequency using half-duplex mode. The transmitter and receiver share the same whip antenna through a pin-diode based electronic switch.

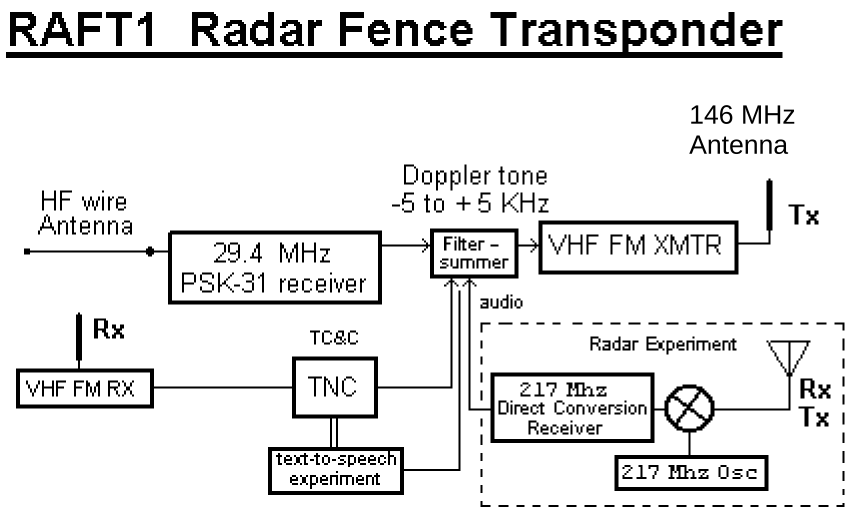


Figure 3. RAFT1 Satellite block diagram

RAFT1 also includes a PSK-31 receiver operating on 29.4 MHz. The PSK-31 signals are combined with the audio output of the TNC and fed into the VHF FM transmitter. The TNC and PSK-31 transponder can operate simultaneously as they use different parts of the audio spectrum. For more details of the RAFT1 satellite program, please see the RAFT web site[4].

While most of the electronic subsystems needed for the satellite are available off-the-shelf, no current manufacturers provide the equipment needed to interact with the AFSSS RADAR system. A team of three AMSAT members from the Boston area, Joe Fitzgerald KM1P, David Goncalves W1EUJ and Anthony Monteiro AA2TX, volunteered to help by designing and building the XP217 RADAR Transponder Unit. Additionally, Tom Kneisel, K4GFG, volunteered to assist the development team in understanding technical aspects of the AFSSS RADAR.

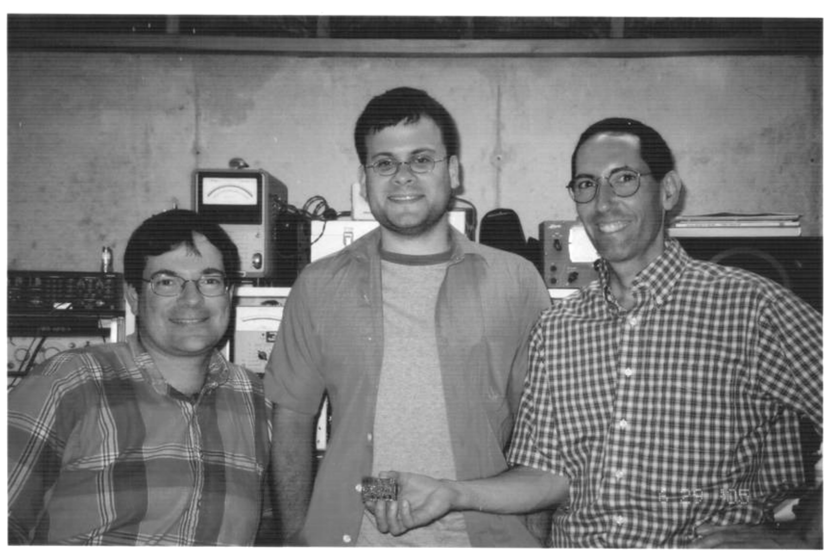


Figure 4. XP217 Development Team L-R: Joe KM1P, Dave W1EUG, Tony AA2TX

AFSSS RADAR Fence

The Air Force Space Surveillance System (AFSSS) is a network of RADAR transmitting and receiving stations that all operate at around 217 MHz. The transmitting sites generate a continuous-wave fan beam, called the *Fence* that is very narrow in the North/South direction but extends straight up, from East to West across the entire southern United States.. Any object that crosses the *Fence* will generate an echo that will be detected by the receiving stations. The AFSSS includes three transmitting stations and six receiving stations as shown in Figure 5.

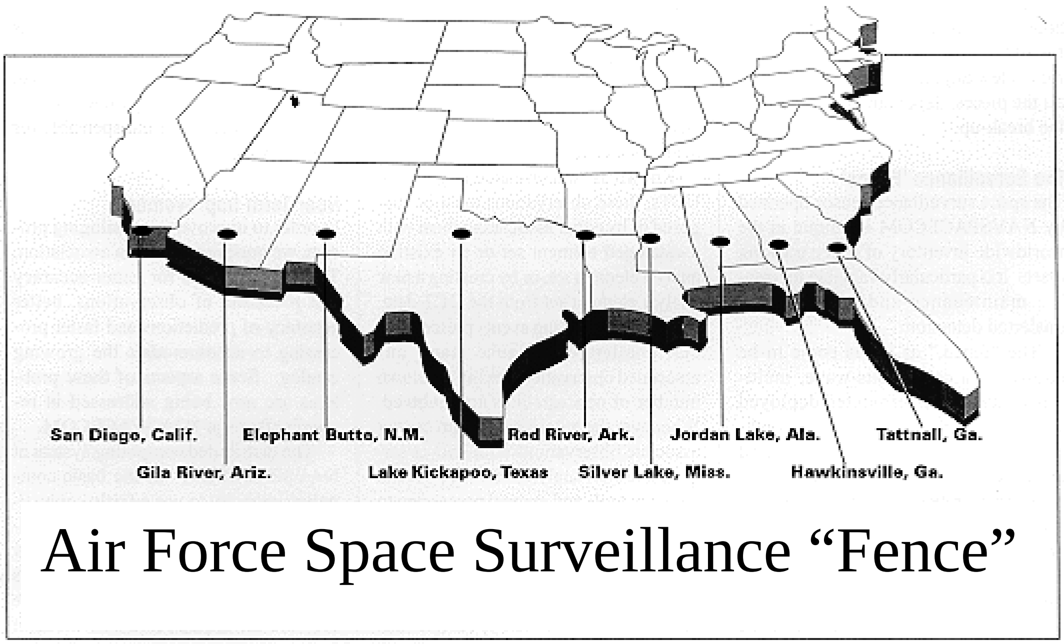


Figure 5. AFSSS Transmitting and Receiving Stations[5]

The main transmitting station is in Lake Kickapoo, Texas. It consists of a linear array of 2,556 inverted-V antenna elements over a reflector screen, each with its own 300 watt power amplifier. It generates a total effective isotropic radiated power (EIRP) of over 6,000 megawatts. A photo of part of the antenna is shown in Figure 6.

The Lake Kickapoo transmitter operates at 216.980 MHz. The other transmitting sites are lower power but help to fill in the east and west edges of the *Fence*. They are at Gila River, Arizona on 216.970 MHz and at Jordan Lake, Alabama on 216.990 MHz.

The six receiving stations are at San Diego, CA, Elephant Butte, NM, Red River, AR, Silver Lake, MS, Hawkinsville, GA and Tattnall, GA. The AFSSS receiving stations each have an interferometer antenna array and use a variety of signal processing techniques, including measuring the Doppler-shift, to extract the orbital vectors from the received echo. For more information about the AFSSS RADAR, please see the web site by Tom Kneisel.[6]

Figure 6. Photo of Lake Kickapoo Transmitting Antenna[7]

The AFSSS RADAR Experiment

The RADAR transponder on the RAFT1 satellite will provide a receiver and a transmitter on the Lake Kickapoo frequency of 216.980 MHz. The receiver is a direct-conversion type and the recovered audio tone is the difference between the receiver local oscillator and the Doppler-shifted, Lake Kickapoo transmitter frequency seen at the satellite. When enabled, the receiver audio output will be fed into the 146 MHz VHF FM transmitter so that ground stations can actually listen to the RADAR signal as the satellite flies through the fence.

The transponder transmitter is an un-modulated CW beacon that the RADAR ground stations will be able to detect along with the received echo of the RADAR transmitter. The idea is to provide a strong beacon signal to help positively identify the satellite.

Key Transponder Design Issues

Simultaneous Transmit and Receive

An interesting requirement of the transponder is that it needs to transmit and receive *simultaneously* on 216.980 MHz. This is to allow both the receive and transmit experiments to be conducted at the same time. While the needed transmit level is only around 4 milli-watts, this is much more local oscillator leakage than any typical modern mixer circuit would provide. The transponder circuit needs to provide a way to accommodate this requirement.

RAFT1 Antenna System

The antenna system of the RAFT1 satellite includes a 217 MHz whip dedicated for the XP217 RADAR transponder. The whip is expected to have a gain of 0 dBi.

Low Cost

The circuit was designed to keep costs low so that the completed transponder could be reasonably replicated for use in other satellite projects. The development team has been strictly adhering to the KISS[8] principle and has attempted to minimize complexity.

Expected Received Signal Level

The planned orbit of RAFT1 is approximately circular and will have an altitude of about 360 Km. The AFSSS RADAR System transmits a continuous-wave (CW) signal, with a power density of $-7.5 dBm_0/m^2$ at this altitude[9]. An isotropic antenna at this frequency has an effective aperture of .152 m^2 so the maximum signal power available at the satellite on an overhead pass would be -16 $dBm_{0.}$. At night when the Faraday rotation is expected to be close to 0 degrees[10], there would be a significant antenna polarization loss and the expected signal level would be around -30 dBm_0.

For night passes when RAFT1 crosses the RADAR fence within range of the Naval Academy at Annapolis, MD, the nominal received signal level would be about -43 dBm_0. During the daytime, when the Faraday rotation is least predictable, the maximum signal level could be as high as -22 dBm_0 or as low as -52 dBm_0.

Note that the IARU[11] specification for an “S9” signal at 217 MHz is -93 $dBm_{\mathbf{0}}$ so the absolute maximum signal level is greater than 70 dB over “S9.” For night passes within range of Annapolis MD, the signal would be around 50 dB over S9. It is clear that the receiver does not need to be terribly sensitive but it does need to be able to tolerate a high RF level. The XP217 receiver will be designed to provide its nominal output at -30 dBm_0 and will work down to at least -50 dBm_0.

Receiver Local Oscillator Frequency Tolerance

The XP217 receiver will use a direct-conversion, approach so the local-oscillator operates at the same 216.980 MHz frequency as the AFSSS RADAR System transmitter. The recovered audio output of the XP217 receiver will be re-transmitted by RAFT1’s 2-meter FM transmitter and this transmitter has a bandwidth of at least 3 KHz. For passes that are within range of Annapolis, MD, the Doppler-shift will be from -1 KHz to about -4 KHz[12] In order to guarantee that at least some passes will be audible, the XP217 local oscillator will be designed for a tolerance of around ±10 ppm.

Additionally a temperature sensor will be provided on the XP217 board and the designers will provide the frequency versus temperature curve in order to allow the XP217 local oscillator frequency error to be predicted while in orbit.

Transmitter Frequency Tolerance

The AFSSS RADAR System receivers have a bandwidth of several tens of kilohertz and this represents a much wider tolerance than the requirements on the XP217 receiver local oscillator. Since this oscillator will be shared between the receiver and the transmitter, no additional requirements are placed on the XP217 transmitter frequency tolerance.

146 MHz Transmitter Signal Rejection

The recovered audio signal from the XP217 receiver will be re-transmitted by a downlink transmitter operating in the amateur 2-meter band. This transmitter has an output power of 1 watt (+30 dBm_0) operating into a whip.

An EZNEC[13] model of the RAFT1 satellite antennas indicated that the worst case power transfer between the 146 MHz antenna and the 217 MHz antenna should be no more than -30 dB. But, this means that the downlink signal at 146 MHz could be +30 dB to +50 dB higher at the XP217 receiver input than the desired 216.980 MHz RADAR signal. The XP217 receiver must reject the 146 MHz signal and operate normally under these conditions.

Transmitter Radiated Signal Characteristics

In order to provide a solid link margin to the AFSSS RADAR System receivers, the RAFT1 satellite will have an effective isotropic radiated power (EIRP) of around +6 dBm_0 (4 milli-watts.) The RAFT1 antenna is expected to have a gain of 0 dBi so the XP217 transmitter must be able to provide about +6 dBm_0 output. Based on publicly available information, this is expected to be more than 10 dB greater than what is needed to detect the beacon.[14]

The XP217 transmitter will be operated under authority of the Department of Defense (i.e. National Telecommunications and Information Administration.) The typical specified limit on spurious and harmonic emissions under this authority would generally be -50 dB. But note that the beacon transmitter runs at a very low power level and any spurious emissions would already be far below a typical VHF transmitter.

XP217 Technical Specifications

General

Service	Radiolocation
Operating Frequency	216.980 MHz
RF input/output impedance	50 Ohms
Frequency Tolerance	± 10 ppm
Operating Temperature	-20 to +40 °C
Power Supply Voltage	+7.0 to +9.6 VDC
Power Supply Current	< 15mA

Transmitter

Power Output	+6 dBm_0 (nominal)
Emission mode	N0N (CW)

Receiver

Type	Direct conversion
Sensitivity	> 10 dB S/N at -50 dBm_0 input
Dynamic Range	-50 dBm_0 to -16 Bm_0
Out-of-band rejection	> 50 dB at 146 MHz
Audio output bandwidth	15 KHz
Audio output impedance	2K Ohms nominal load
Audio output level	30 mV p-p nominal (adjustable)

Temperature Sensor

Resistance	10 K Ohms (nominal)
Temperature coefficient	negative
Manufacturer	Vishay/BC Components
Manufacturer part#	2322 640 64103

The temperature sensor signals will be isolated (i.e. floating) from the other XP217 signals including any common/ground signals. The specified component is available from *Digikey Corporation* as part# 2322 640 64103-ND.

Physical Construction

The project goal is to make the XP217 “matchbook” size. The XP217 will employ a double-sided, printed circuit board and use primarily surface-mount components.

I/O Connections

All XP217 input and output connections must be on a single edge of the printed circuit board. All connections shall be made with gold-plated, dual-row, Molex male header pins with .1” x .1” spacing. The signal leads are as follows:

Signal Name	**Function**
PWR-POS	+DC power
PWR-COM	-DC Supply (Common)
TEMP-A	Temperature Sensor Lead A
TEMP-B	Temperature Sensor Lead B
RF-IO	RF input/output
RF-GND	RF ground
RX-OUT	Received audio output
RX-GND	Received audio ground

XP217 Architecture

The XP217 circuit architecture is shown in Figure 7. The diagram provides the nominal transmit (TX) and maximum receive (RX) signal levels. The XP217 circuit consists of an Infinite-Z Mixer, an Audio Amplifier, an RF Filter, a Local Oscillator, and a Voltage Regulator.

This architecture solves the problem of how to transmit and receive at the same time. The key component is the Infinite-Z Mixer, which provides a very high input impedance. It is connected in parallel with the local oscillator output and does not load down either the transmit or receive signals. The Infinite-Z Mixer works in a manner similar to the "infinite impedance detector" circuits that were commonly used in old vacuum tube TRF[15] receivers and it can handle very large input signals. This circuit block mixes the received RADAR signal with the local oscillator signal and produces an audio tone that is equal to the frequency of the Doppler-shift of the AFSSS RADAR signal as seen by the satellite.

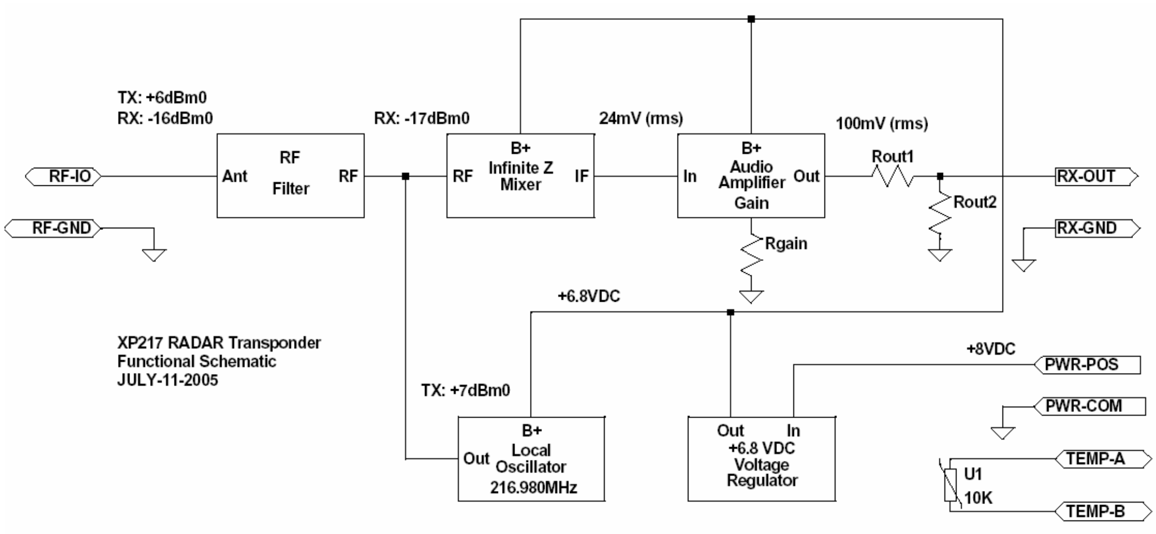


Figure 7. XP217 Architecture

The Audio Amplifier stage amplifies the recovered audio tone from the Infinite-Z Mixer. It is a low noise amplifier that provides an adjustable amount of gain and an adjustable output level. The voltage gain can be set by changing the value of *Rgain*. With *Rgain* open, the Audio Amplifier voltage gain is about 4.2 providing about 100 mV rms output into a 2 K-ohm load at the maximum receive signal level. The output voltage divider, *Rout1* and *Rout2*, provides an adjustable attenuator to set the output level to as required by the downlink transmitter.

The RF Filter is bi-directional and provides significant rejection at 146 MHz to keep the downlink transmit signal from interfering with the operation of the XP217 receiver. The RF Filter has 50 ohm input and output impedances and provides over 30 dB of rejection at 146 MHz. The insertion loss is about 1 dB.

The Local Oscillator block provides a 216.980 MHz signal at approximately +7 dBm_0. This is enough power for the beacon transmit signal and also provides the local oscillator injection for the receiver mixer.

The Voltage Regulator block provides a steady 6.8 VDC for the entire transponder. It can maintain regulation down to the minimum specified power supply voltage of +7 VDC and up to 10 VDC.

The temperature sensor (U1) will be fed into a satellite telemetry channel and provides the temperature of the XP217 transponder.

XP217 Transponder Circuit

The XP217 Transponder circuit schematic is shown in Figure 8.

A voltage regulator circuit using U1, a Linear Technologies LT3010, provides +6.8 VDC for the other transponder circuits. The LT3010 is a low-drop-out linear voltage regulator and will maintain regulation with as little as +7 VDC on its input. The entire transponder only draws about 12 mA so the power dissipation is low.

The crystal oscillator consists of Q7, a J309 FET, and uses a 108.49 MHz crystal operating in a fifth-overtone mode. The circuit is a Butler oscillator using the FET in a grounded-gate configuration. Inductor L8 cancels the crystal holder capacitance so that the frequency of the maximum amplitude of the feedback is the same as where the phase is 0-degrees (i.e. the crystal will oscillate at the correct frequency.) Trimmer capacitor C22 is used to fine-tune the oscillator. Inductor L9 resonates with the capacitors at the output to 108.490 MHz.

The crystal oscillator drives the frequency doubler stage consisting of Q6, a J309 FET. The output of this stage is tuned to 216.980 MHz using L7, C16 and the output capacitance of the FET. This forms an L-network and provides an impedance match to the input of the driver stage FET, Q5.

The driver and power output stages consist of J309 FETs Q5 and Q4 respectively. They increase the level of the local oscillator signal up to about +7 dBm_0. L1 along with C19 and the output capacitance of Q4 form an L-network and match the output impedance of Q4 to the 50 ohm impedance of the RF filter.

The RF Filter consisting of capacitors C1,2,3, and 27 and inductors L2,,3, 4 and 5 form a high-pass filter and provides significant rejection of the 146 MHz downlink signal but allows the received 217 MHz RADAR signal to pass through with only around 1 dB loss.

The received RADAR and the local oscillator signals appear at the gate of Q1, another J309 type transistor, which operates as a high-impedance mixer. This transistor is biased nearly to cut-off by the source resistor R1. When the input signal on the gate goes negative, the transistor remains nearly cut-off and there is very little change in the current through the transistor. When the input signal goes positive, the transistor turns on and conducts a current from source to drain creating an output voltage across R1 which follows the envelope of the combined RADAR signal and local oscillator injection. The output signal is low-pass filtered by R2, C4, and C5 to remove the high-frequency components leaving just the recovered audio signal.

The audio output of the mixer is coupled to Q2, a low-noise, 2N5088 type, bipolar transistor. This transistor amplifies the received signal with a voltage gain of about 4.5. The resistor, R17, (*Rgain* on the Functional Schematic) controls the degree of negative feedback which sets the overall voltage gain. Transistor Q2 is directly coupled to Q3, another 2N5088 type transistor, operating as an emitter-follower buffer. The audio output can easily drive a 1K ohm load. The output voltage divider consisting of R8 and R9 (*Rout1* and *Rout2*, on the Functional Schematic) allows the output level to be adjusted to that needed by the downlink transmitter. These are set to provide about 30mV p-p when the receiver input signal is at -30 dBm_0

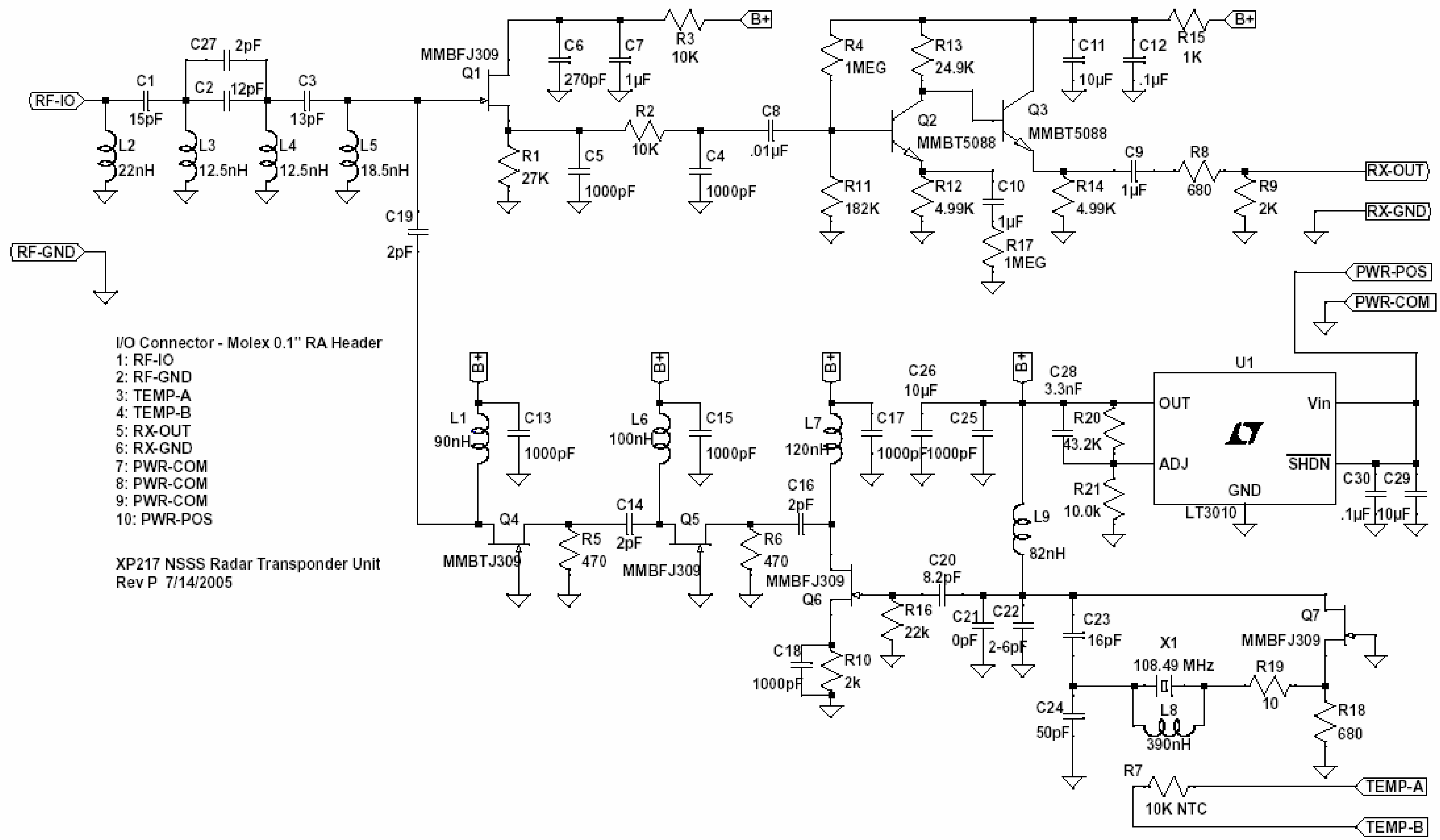


Figure 8. XP217 Circuit Schematic Diagram

Construction

In order to meet the "matchbox" size goal, the XP217 uses all surface mount components. A two-layer printed circuit (PC) board was designed with the bottom layer being primarily a ground plane. The PC board layout was developed using free software from ExpressPCB[16] and ordered through their web site. The actual-size pc layout is shown in Figure 9.

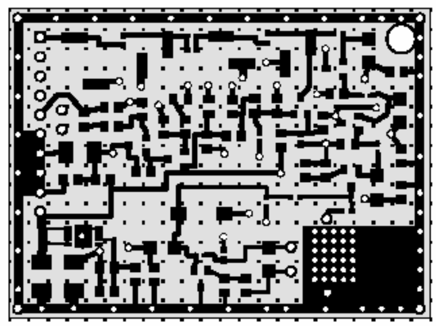


Figure 9. Actual-size printed circuit board layout (top view)

Two flight models (serial numbers XP217-#2 and XP217-#3) have been constructed Since only two models were needed, they were constructed by hand-soldering the components to the pc board. This was a significant chore given the tiny size of most of the components!

Testing

The two flight models were subject to an intensive set of functional tests. The units were tested in the basement lab of AA2TX. A GPS-based frequency standard was used to verify the calibration of the frequency counter used to measure the XP217 local oscillator frequency. Highlights of the results of these tests is shown in the table below.

Functional Test Summary		
Parameter	**Unit #2**	**Unit #3**
Power supply current	11.19 mA	12.06 mA
Oscillator Frequency	216.9798 MHz	216.9804 MHz
Transmitter Power Output	+6.4 dBm_0	+6.2 dBm_0
Receiver signal to noise ratio @-50dBm_0	37 dB	35 dB
Receiver frequency response	15.1 KHz	15.3 KHz

The XP217 flight models were also tested to verify their performance over the operating temperature and voltage ranges. All four corners were tested. The selected parameters tested included transmitter power output, receiver sensitivity, and frequency stability. The kitchen freezer at the Monteiro (AA2TX) residence was used for some of temperature testing as shown in the photograph of Figure 10. The XP217 was placed in the freezer and the cables were run through the door seals to the test equipment. The freezer was able to provide a minimum temperature of -13C versus the specified minimum operating temperature of -20C. However the units worked fine over the range tested and the developers are confident that they will operate correctly when final testing is done at -20C.

Figure 10. Dave (left) and Joe (holding meter) test the XP217 in the freezer

The high temperature testing at +40C was done using the apparatus shown in the photograph of Figure 11. This consisted of a 100 watt light bulb in a fixture to provide the heat and a Styrofoam cooler to provide temperature stability. A thermocouple was used to measure the temperature. Both flight units worked properly at +40C.

Figure 11. Testing the XP217 models at +40C

Project Status as of 8/1/2005

At the time this article was written, two flight models had been constructed and tested. After the testing was completed, the models were provided with a MIL-Spec (as per NASA-STD-8739.1) conformal coating using HumiSeal® type 1A33 polyurethane protective coating. This coating includes a fluorescent dye tracer and a short-wave ultra-violet lamp was used to inspect and verify the coating quality.

Because the 1A33 conformal coating has a relative dielectric constant of around 3.7, some de-tuning of the circuitry was expected. The two flight models were re-tested for critical parameters and though some reduction in transmit power output and receiver sensitivity were noted, the flight units continued to operate acceptably. One of the units will be selected for integration with the RAFT1 satellite and the other will remain as a spare.

Figure 12. Veronica Monteiro shows off an XP217 model in the lab at AA2TX

Summary

The XP217 RADAR Transponder unit for the RAFT1 CubeSat was developed by a team of AMSAT volunteers in the Boston area consisting of David Goncalves W1EUJ, Joe Fitzgerald KM1P, and Anthony Monteiro AA2TX. The complete transponder circuit uses only seven transistors and an integrated-circuit, voltage regulator keeping it simple and inexpensive. Two flight models have been constructed, tested and coated with a MIL-spec polyurethane conformal coating. One of these units will be integrated with the RAFT1 satellite and the other will be kept as a spare. The current RAFT1 schedule calls for launch in 2006 via Space Shuttle mission STS-116.

The development team would like to thank Tom Kneisel for his invaluable assistance in understanding the technical aspects of the AFSSS RADAR system and for reviewing this document.

Development team member David Goncalves, W1EUJ, has created a web site[17] with the current design documents and status as well as interesting links. For the latest XP217 information please visit the web site.

---

[1] For information about the AMSAT Bulletin-Board, please see www.amsat.org
[2] AFSSS formerly know as the Naval Space Surveillance System or NSSS before handoff to the Air Force as described in "Military Role in Space Control: A Primer" by Adolfo J. Fernandez, National Defense Fellow. Published by the Congressional Research Service September 23. 2004.
[3] NORAD: North American Aerospace Defense Command
[4] RAFT Satellite web site: http://web.usna.navy.mil/%7Ebruninga/raft.html
[5] AFSSS Fence Image from National Space Security Road Map (NSSRM) unclassified photo list, http://www.wslfweb.org/docs/roadmap/irm/photo.htm
[6] Tom Kneisel 's NAVSPASUR web site at http://www.k4gfg.us/navspasur/index.html
[7] Lake Kickapoo Antenna photo courtesy of Tom Kneisel
[8] KISS Principle: "*Keep it Simple…*"
[9] "Theoretical Radiation Patterns of NAVSPASUR Transmitter Antennas," by Dr. Steven L. Berg, Interferometrics, Inc. November 30, 1988.
[10] Faraday rotation information was provided by Tom Kneisel
[11] IARU: *International Amateur Radio Union*
[12] Doppler-shift estimate was provided by Tom Kneisel
[13] EZNEC antenna modeling software available from: www.eznec.com
[14] AFSSS Receive system sensitivity estimate was provided by Tom Kneisel
[15] TRF: *Tuned Radio Frequency*, a type of receiver circuit using an RF amplifier, a detector, and audio amplifier.
[16] ExpressPCB printed circuit boards are available at www.expresspcb.com
[17] The RAFT Tracking Device Development website is at http://www1.coe.neu.edu/~dpg/rx217.html

INTERNATIONAL SATELLITE FREQUENCY COORDINATION BENEFITS ALL RADIO AMATEURS

Hans van de Groenendaal ZS6AKV
IARU Satellite Adviser

Presentation at the 2005 AMSAT Space Symposium

Background

Following the increase in the number of organisations building and launching satellites operating on frequencies allocated to the amateur-satellite service, various attempts were made to introduce a coordination system. This led to the appointment of the IARU Satellite Adviser who is responsible to the IARU Administrative Council and charged with the task to work closely with AMSAT organisations to provide a coordination facility and a link to the IARU.

Various processes were followed, including the appointment of a Satellite Frequency Coordinator who reported to the IARU Satellite Adviser. This did not work too well as a single person was not always able to take a world view. In addition, the volume of work has grown well beyond the ability of two volunteers to handle it.

Some years back, following recommendations by the IARU Satellite Adviser to the IARU AMSAT International Forum, held in alternate years in conjunction with the AMSAT UK Colloquium and the AMSAT NA Space Symposium, an Advisory Panel was introduced. Over the past three years this panel has developed a transparent process that has greatly enhanced the coordination of frequencies for satellites that operate on frequencies allocated to the amateur satellite service. Credit is due to the unstinting amount of time and effort the Panel has put into it.

Currently the panel is as follows:

Convener
Hans van de Groenendaal ZS6AKV

Region 1

Graham Shirville	G3VZV
Norbert Notthoff	DF5DP

Region 2

Ray Soifer	W2RS
Art Feller	W4ART

Region 3

Jan King	VK4GEY

Region 3 has been invited to appoint an additional person.

Panel members were chosen for their expertise and experience on recommendation from the regional IARU organisations and AMSAT groups.

Changing Environment

For some time satellites to operate on frequencies allocated by the ITU to the amateur-satellite service were designed, built and launched by AMSAT groups in various countries. Other institutions such as Universities, Technical Colleges and National Space Agencies are now showing a great interest in small satellites as educational and development projects. Many of these satellites are "scientific birds" used for research into scientific principles that have little or nothing to do with amateur radio, or are "educational birds" primarily intended to train students in satellite engineering, yet they will operate on frequencies allocated to the amateur-satellite service.

Different countries have different views on how amateur frequencies may be used and many encourage educational institutions to do so. In some areas of the world, even projects that border on commercialisation are licensed to operate on amateur frequencies.

Holistic Coordination Approach

In conjunction with advice from the IARU Administrative Council, the Satellite Frequency Advisory Panel have adopted a holistic approach and will coordinate frequencies for the "non amateur" satellites to ensure the least possible impact on amateur satellite operation.

Creating understanding of what an amateur satellite is

A document setting out what an amateur radio satellite is, and giving details of various ITU Radio Regulations pertaining to operating a satellite on amateur frequencies has been produced and is available on the IARU web pages (www.iaru.org/satellite).

In the panel's interaction with non-amateur organisations building small satellites that operate on amateur frequencies, it became apparent that many had little or no idea of amateur radio's involvement in satellite communication and the level of technological expertise that had been developed since the launch of OSCAR 1 in 1959.

Individual panel members have done a great job interfacing with Universities and the small satellite industry and other interest groups to carry out the AMSAT message. Amateurs pioneered the small satellites, industry followed.

The frequency coordination process

Prospective builders complete a form with as much detail as possible. This is studied by the Panel. Copies of the requests are sent, for comment, to the

National Society and the AMSAT organisation in the country where the request originated.

The panel will discuss the validity of the request and interact with the various role-players to achieve a common understanding. Where a satellite is strictly non-amateur every effort is made to convince the requester to seek alternative frequencies.

Ultimately the panel selects the best possible frequencies and proposes these to the requester.

The process is transparent and regular updates are posted on a website hosted by AMSAT UK. (Linked from www.iaru.org/satellite)

The panel monitors the progress of the project and, where appropriate, offers advice.

National Society Support is needed

Even considering the potential opportunities which educational satellite projects can provide for legitimate amateur satellite activities as well as the role of educational institutions in training and motivating new generations of amateur radio space enthusiasts, the danger of overcrowding amateur frequencies exists.

IARU member Societies have an important role to play:

> First, Member Societies should work with those in their country who are responsible for satellite projects intended for operation in the amateur bands to educate them about how good and appropriate frequency planning will benefit their projects.
>
> Second, Member Societies should work with their national administration to promote the proper use of amateur frequencies in accordance with the Radio Regulations.
>
> Third, engage with educational institutions to create an understanding of the amateur service and to encourage prospective satellite project teams to study the IARU paper on “What is an Amateur Satellite”.

Communication with the Panel may be directed to satcoord@iaru.org

A $5 Mode V/S Adapter Using a Sub-Harmonic Mixer

Anthony Monteiro, AA2TX (aa2tx@amsat.org)

Abstract

The recently launched AMSAT Echo Satellite, AO-51, introduced the use of transponder mode V/S. Mode V/S uses the 144 MHz (VHF) band for the uplink and 2.4 GHz (S-band) for the downlink. Equipment for this new mode is a challenge because most commonly available S-band down-converters use VHF for the intermediate frequency but the currently available transceivers cannot use VHF for both the uplink and downlink at the same time. Operating on this new mode has required using a second radio or buying a special down-converter that can use the UHF band for the intermediate frequency.

This paper presents an alternative solution that is simple and inexpensive: an adapter that will convert the output of an S-band down-converter to the 6-meter band. This device enables most satellite and many non-satellite transceivers to work mode V/S since they can receive the downlink on the 6-meter band while using the VHF transmitter for the uplink. The adapter employs a sub-harmonic mixer circuit along with a standard TTL clock oscillator and can be easily constructed for about $5 in parts.

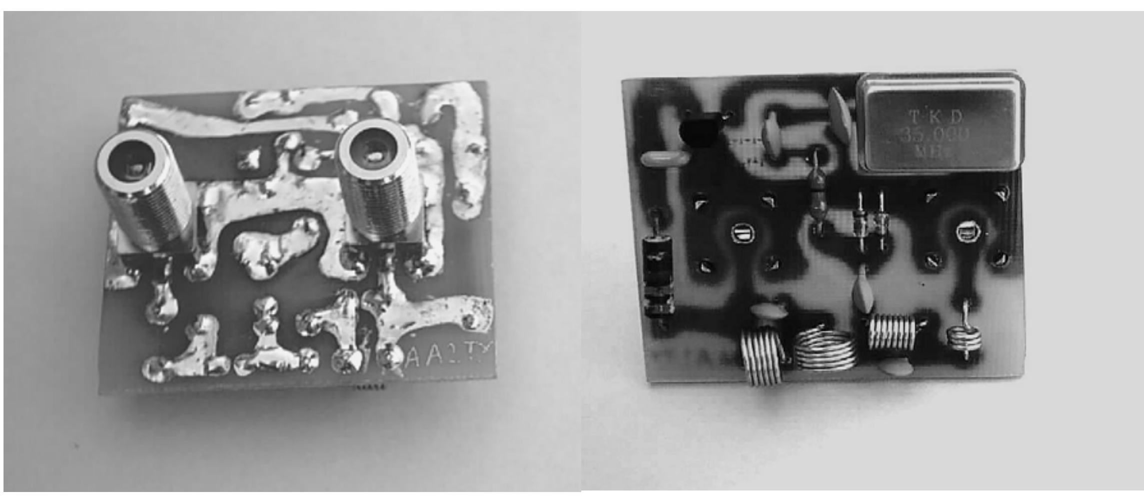


Figure 1. Top and bottom views of the $5 Mode V/S Adapter

Introduction

The AMSAT *Echo* Satellite, AO-51, introduced the use of transponder mode V/S. Mode V/S has a VHF (144 MHz) band uplink and an S-band (2.4 GHz) downlink. Since S-band was the primary downlink used on the AO-40 satellite, there are large numbers of amateur satellite stations world-wide that are equipped to receive S-band and which could easily receive the downlink from AO-51.

However, most S-band receive converters have their output intermediate frequency in the VHF band. This worked well for OSCAR-40 since it had an uplink in the UHF band. But mode V/S presents a problem because the currently available amateur satellite transceivers cannot operate with the same (VHF) band for both the uplink and downlink. Operating on this new mode has required using separate radios for the up and down links or buying a special down-converter that uses the UHF (70 cm) band for the intermediate frequency.

This paper introduces an alternative solution that is simple and inexpensive. It presents an adapter that will convert the VHF output of an S-band down-converter to the 6-meter band (30-60 MHz.) This device enables most satellite and many non-satellite radios to operate mode V/S since they can use the 6-meter band for receiving the downlink while using the VHF transmitter for the uplink. The 6-meter band is not authorized for use in the Amateur Satellite Service so there is no potential conflict with a future satellite transponder mode. In addition, use of 6-meters for receiving the downlink solves a similar problem when using L-band up-converters as they typically also use VHF as their intermediate (IF) frequency.

The adapter employs a sub-harmonic mixer circuit. A sub-harmonic mixer effectively doubles the applied local oscillator frequency before mixing it with the RF input signal. At VHF, a pair of ordinary 1N914 diodes can be used to make one and doing so allows a commonly available TTL clock oscillator to be used to generate the local oscillator signal. This dramatically reduces the overall complexity and cost of the adapter and it can be easily constructed for about $5 in parts. Photographs of a prototype are shown in Figure 1.

Sub-Harmonic Mixers

A sub-harmonic mixer is designed to mix the input Radio Frequency (RF) signal with the second harmonic of the applied local oscillator (LO) signal. Sub-harmonic mixers are typically used only at very high microwave frequencies where it is difficult to generate the needed local oscillator signal because they have a higher conversion loss than fundamental mode mixers. But the ability to double the local oscillator signal can be easily worth the tradeoff in reduced circuit complexity at the higher microwave frequencies.

In theory, all mixers can be used this way as all have high-order product terms in their outputs. However, for most mixer circuits, the output signal would be very low and the conversion loss would be intolerably high. Sub-harmonic mixers are specifically designed to provide a reasonably high output when using the second harmonic of the local oscillator signal.

Figure 2. Diode mixer

To understand how a sub-harmonic mixer works, let us first examine the operation of a diode mixer as shown in Figure 2. The mixer operation depends on the fact that the diode has an approximately *square-law* response. This means that the current in the diode (while it is forward-biased) is proportional to the square of the applied voltage. Mathematically, this is written as:

$$\mathbf{I}_{\boldsymbol{diode}} \; \mu \; (\mathbf{V}_{\boldsymbol{diode}})^2$$

If we apply a local oscillator signal, $\mathbf{V}_{lo}\mathbf{sin(}\mathrm{w}_{lo}\mathbf{t)}$ and an RF signal, $\mathbf{V}_{rf}\mathbf{sin(}\mathrm{w}_{rf}\mathbf{t)}$ to the diode, the current through the diode becomes:

$$\mathbf{I}_{\boldsymbol{diode}} \; \mu \; (\, \mathbf{V}_{lo}\mathbf{sin(}\mathrm{w}_{lo}\mathbf{t)} + \mathbf{V}_{rf}\mathbf{sin(}\mathrm{w}_{rf}\mathbf{t)} \,)^2$$

Squaring the terms, we get:

$$\mathbf{I}_{\boldsymbol{diode}} \; \mu \; \mathbf{V}^2_{lo}\mathbf{sin}^2\,(\mathrm{w}_{lo}\mathbf{t)} + \underline{\mathbf{2V}_{lo}\mathbf{V}_{rf}\mathbf{sin(}\mathrm{w}_{lo}\mathbf{t)}\;\mathbf{sin(}\mathrm{w}_{rf}\mathbf{t)}} + \mathbf{V}^2_{rf}\mathbf{sin}^2\,(\mathrm{w}_{rf}\mathbf{t)}$$

But, remembering from trigonometry:

$$\mathbf{sin}^2(\mathrm{w}\mathbf{t)} = \tfrac{1}{2}\,(\,1 - \mathbf{cos(2}\mathrm{w}\mathbf{t)}\,)$$

So, the first and last terms are just the phase-shifted, second harmonics of the local oscillator and RF signals along with some DC components. In an actual mixer circuit, these would be filtered out of the mixer output. The interesting term is the middle term that is underlined above. This term is the product (i.e. multiplication) of the applied local oscillator and RF signals.

The product of two sin-waves can be expanded from the trigonometry identity:

$$\mathbf{sin(w_a t)\ sin(w_b t) = ½\ [\ sin((w_a{+}w_b)t) + sin((w_a{-}w_b)t)\ ]}$$

Assuming we will filter out the second harmonic and DC terms, the diode current is then:

$$\mathbf{I_{diode}\ µ\ \ V_{lo}V_{rf}\ [\ sin((w_{lo}{+}w_{rf})t) + sin((w_{lo}{-}w_{rf})t)\ ]}$$

This is the familiar sum and difference frequencies that we expect from a mixer. Usually one or the other is selected via a filter leaving just the desired *intermediate frequency* output. Thus a single diode, or any *square-law* device (i.e. bipolar transistors, FETs, triodes etc.) can be used as a fundamental-mode mixer.

To make a *sub-harmonic* mixer, a pair of diodes is connected *anti-parallel* or back-to-back as shown in Figure 3.

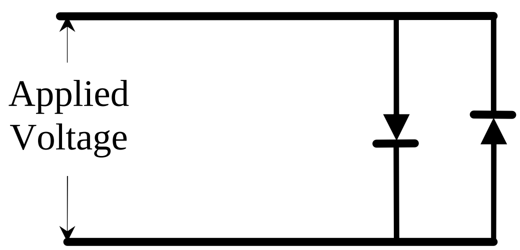


Figure 3. Anti-parallel diode connection

Each diode is still assumed to have an approximate *square-law* response, but now there are two of them and so the current into the pair of diodes is:

$$\mathbf{I_{diodes}\ µ\ \ (V_{diodes})^2 \quad when\ V\ ^3 0}$$
$$\mathbf{-\ (V_{diodes})^2 \quad when\ V<0}$$

Each diode only conducts when it is forward biased. When we apply the local oscillator signal $\mathbf{V_{lo}sin(w_{lo}t)}$ and RF signal $\mathbf{V_{rf}sin(w_{rf}t)}$, the current will flow in *both* directions depending upon the polarity of the applied voltage seen by the diodes.

Since the local oscillator signal is much larger than the RF signal, the diode current direction is really just dependent on the phase of the local oscillator signal. Therefore, we can combine the two terms with a square-wave function that is in phase with the local oscillator signal:

$$\mathbf{SQRW}(\omega_{lo}t) = \begin{cases} +1 \text{ when } \sin(\omega_{lo}t) \geq 0 \\ -1 \text{ when } \sin(\omega_{lo}t) < 0 \end{cases}$$

Combining the terms, we get:

$$I_{diodes} \propto \mathbf{SQRW}(\omega_{lo}t)\ (V_{lo}\sin(\omega_{lo}t) + V_{rf}\sin(\omega_{rf}t))^2$$

Now recalling Fourier analysis, we can replace the square-wave function with its sinusoidal components which are the fundamental wave and all odd harmonics:

$$\mathbf{SQRW}(\omega_{lo}t) = \sum_{n=1,3,5...} \sin(n\omega_{lo}t)/n$$

This leaves us with:

$$I_{diodes} \propto \sum_{n=1,3,5...} \sin(n\omega_{lo}t)/n\ (V_{lo}\sin(\omega_{lo}t) + V_{rf}\sin(\omega_{rf}t))^2$$

To find the first-order response, we take n=1 leaving:

$$I_{diodes} \propto \sin(\omega_{lo}t)\ (V_{lo}\sin(\omega_{lo}t) + V_{rf}\sin(\omega_{rf}t))^2$$

which is the same as the single diode response we derived before but it is now multiplied by the local oscillator signal. Expanding the squared terms as before:

$$I_{diodes} \propto \sin(\omega_{lo}t)\ [V^2_{lo}\sin^2(\omega_{lo}t) + 2V_{lo}V_{rf}\sin(\omega_{lo}t)\sin(\omega_{rf}t) + V^2_{rf}\sin^2(\omega_{rf}t)]$$

But as before, the first and last terms are just the second harmonics of the local oscillator and RF signals. The product of these terms with the local oscillator signal yields the original local oscillator signal, the third harmonic of the local oscillator signal and the sum and difference of the local oscillator signal with the second harmonic of the RF signal.

If we choose our frequencies carefully enough, it will be easy to filter these out of the mixer output. This leaves the interesting middle term again but this time it is multiplied by the local oscillator signal:

$$\mathbf{I}_{\boldsymbol{diodes}}\ \mu\ \ \mathbf{sin(}\mathrm{w}_{\boldsymbol{lo}}\mathbf{t)}\quad \mathbf{2V}_{\boldsymbol{lo}}\mathbf{V}_{\boldsymbol{rf}}\mathbf{sin(}\mathrm{w}_{\boldsymbol{lo}}\mathbf{t)\ sin(}\mathrm{w}_{\boldsymbol{rf}}\mathbf{t)}$$

Combining the two local oscillator terms:

$$\mathbf{I}_{\boldsymbol{diodes}}\ \mu\ \ \mathbf{2V}_{\boldsymbol{lo}}\mathbf{V}_{\boldsymbol{rf}}\mathbf{sin^2(}\mathrm{w}_{\boldsymbol{lo}}\mathbf{t)\ sin(}\mathrm{w}_{\boldsymbol{rf}}\mathbf{t)}$$

Using the previously introduced trigonometry identity for the square of a sin(), we can substitute and simplify as follows:

$$\mathbf{I}_{\boldsymbol{diodes}}\ \mu\ \ \mathbf{V}_{\boldsymbol{lo}}\mathbf{V}_{\boldsymbol{rf}}\ [\ \mathbf{sin(}\mathrm{w}_{\boldsymbol{rf}}\mathbf{t)\ –\ (\ cos(2}\mathrm{w}_{\boldsymbol{lo}}\mathbf{t)\ )\ sin(}\mathrm{w}_{\boldsymbol{rf}}\mathbf{t)\ )}\ ]$$

The term $\mathbf{sin(}\mathrm{w}_{\boldsymbol{rf}}\mathbf{t)}$ is the input RF frequency. Examining the remaining term, we see that it is the product of the input RF signal with the second harmonic of the local oscillator signal. Recall that the product (i.e. multiplication) gives us the sum and difference frequencies. However, the first-order response of the sub-harmonic mixer does not include the products of the input RF and local oscillator signals like the familiar fundamental mode mixer. Instead, it includes the products of the input RF and the *second harmonic* of the local oscillator signal:

$$\mathbf{I}_{\boldsymbol{diode}}\ \mu\ \ \mathbf{½}\ \mathbf{V}_{\boldsymbol{lo}}\mathbf{V}_{\boldsymbol{rf}}\ [\ \mathbf{sin((2}\mathrm{w}_{\boldsymbol{lo}}\mathbf{+}\mathrm{w}_{\boldsymbol{rf}}\mathbf{)t)\ -\ sin((2}\mathrm{w}_{\boldsymbol{lo}}\mathbf{-}\mathrm{w}_{\boldsymbol{rf}}\mathbf{)t)}\ ]$$

In fact, if the diodes are well-matched, the fundamental and all odd mixer products cancel each other out.

A well designed, high-performance sub-harmonic mixer may have only a few dB higher conversion loss than a fundamental-mode diode mixer[1] and may be as low as around -10 dB. In situations where the local oscillator signal is difficult to generate, this small penalty in conversion efficiency can be well worth the tradeoff in reduced circuit complexity.

Typical sub-harmonic mixers for microwave frequencies employ matched Schottky diode pairs and several manufacturers make units specifically for this application. However, there is nothing that prevents us from using a pair of ordinary 1N914 silicon switching diodes to make one for use in the VHF range as long as we do not need absolute best performance.

Design Considerations

There are several important considerations that went into the design of the Mode V/S Adapter. They concern the output frequencies and overall gain of common down-converters, the wide availability of TTL clock oscillators, and the desire for low cost and ease of construction.

S-band down-converters are available in two basic types. There are those originally designed for MMDS[2] and those specifically designed for amateur radio service. The units designed for amateur radio use generally provide the IF output at around 145 MHz. The MMDS units will provide the IF at around 123 MHz although some vendors will modify these by changing a crystal so the output is at 145 MHz. In any case, the two common intermediate frequencies are at 123 MHz and 145 MHz.

A typical S-band down-converter has a large amount of overall gain. Usually, an external attenuator is needed to bring the signal levels down to more reasonable levels. Without an attenuator, the receiver S-meter will provide a high reading even if there are no input signals. As an example, the popular TransSystem AIDC-3731AA has 37 dB of gain. To properly use this down-converter, the receiver RF preamp must usually be turned off and in addition, an attenuator of 10 to 15 dB is usually needed to bring the S-meter reading back down to S-0 with no signal applied. This means that a Mode V/S adapter can have a significant amount of conversion loss without impacting the overall receive system performance.

TTL Clock oscillators are widely available and very inexpensive (~$1) at certain standard frequencies up to around 66 MHz. Unfortunately, the standard frequencies that are widely available are not quite what is needed to convert from VHF to the 6-meter band. The required local oscillator signal needs to be in the 70 – 100 MHz range. Some manufacturers will make custom clock oscillators at these higher frequencies but they are much more expensive. But, standard TTL clock oscillators at half the required local oscillator frequencies are readily available.

With the above considerations in mind, the main benefit of using a sub-harmonic mixer becomes clear; a cheap standard TTL clock oscillator can be used at ½ the desired local oscillator frequency. This dramatically reduces the circuit cost and complexity over using a typical crystal oscillator chain. For the sub-harmonic mixer, we can use a pair of common 1N914 switching diodes since we do not require high performance and can tolerate a fairly high conversion loss. In fact, the high conversion loss could even be considered a benefit as it may eliminate the need for an attenuator.

The Mode V/S Adapter was specifically designed to be inexpensive and easy to build with no tuning and no test equipment needed to make it work.

High-Level Design

Please see the block diagram in Figure 4. The Mode V/S Adapter is actually quite a simple design. It consists of an input filter, an output filter, a sub-harmonic mixer, an oscillator and a power supply.

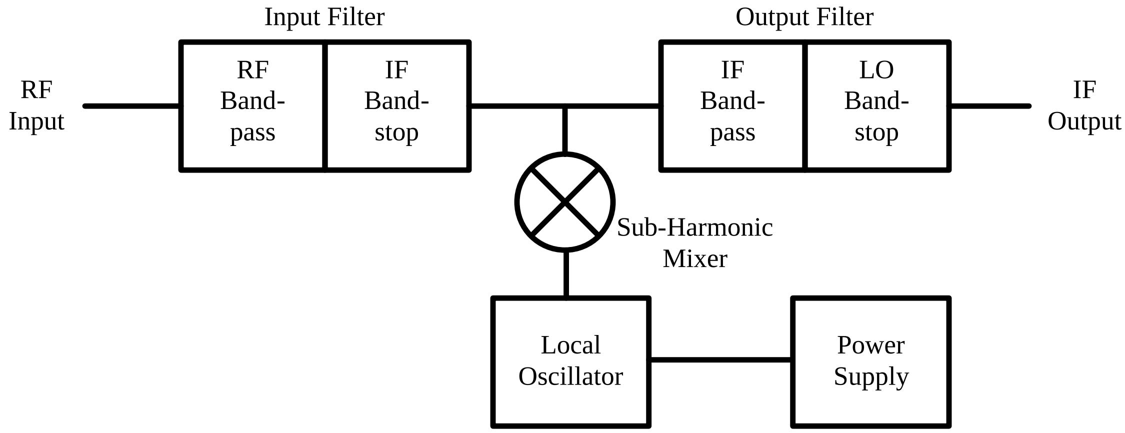


Figure 4. Block Diagram

The power supply provides a regulated, stable voltage for the local oscillator which oscillates at half of the desired mixer injection frequency. The input filter passes the RF input signal but blocks the IF output signal. The sub-harmonic mixer mixes the RF input signal with the second-harmonic of the local oscillator and produces the IF output signal. The output filter passes the desired IF signal and blocks the fundamental local oscillator frequency.

Circuit Description

There are two versions of the Mode V/S Adapter circuit, one is for use with down-converters with 123 MHz outputs and the other is for down-converters with 145 MHz outputs. The basic circuit is the same but the inductors and TTL clock oscillators are unique for each one and C2 is not needed in the 123 MHz version. The schematic diagrams are shown in Figures 5 and 6. The 123 MHz version will be described in detail.

The S-Band down-converter output is connected to the Mode V/S Adapter ***RF-Input*** port and the down-converter's power inserter is connected to its ***IF-Output*** port. The ***IF-Output*** port provides the 6-meter signal to the station transceiver.

Inductors L1 through L4 provide DC conductivity through the adapter so the power inserter's DC voltage appears at the *RF-Input* port to power the S-band down-converter. This DC voltage is also fed through resistor R1 to a 5-volt, linear, voltage-regulator, U1. U1, a 78L05, along with filter caps C6 and C7, provide +5 VDC for the TTL clock oscillator, X1.

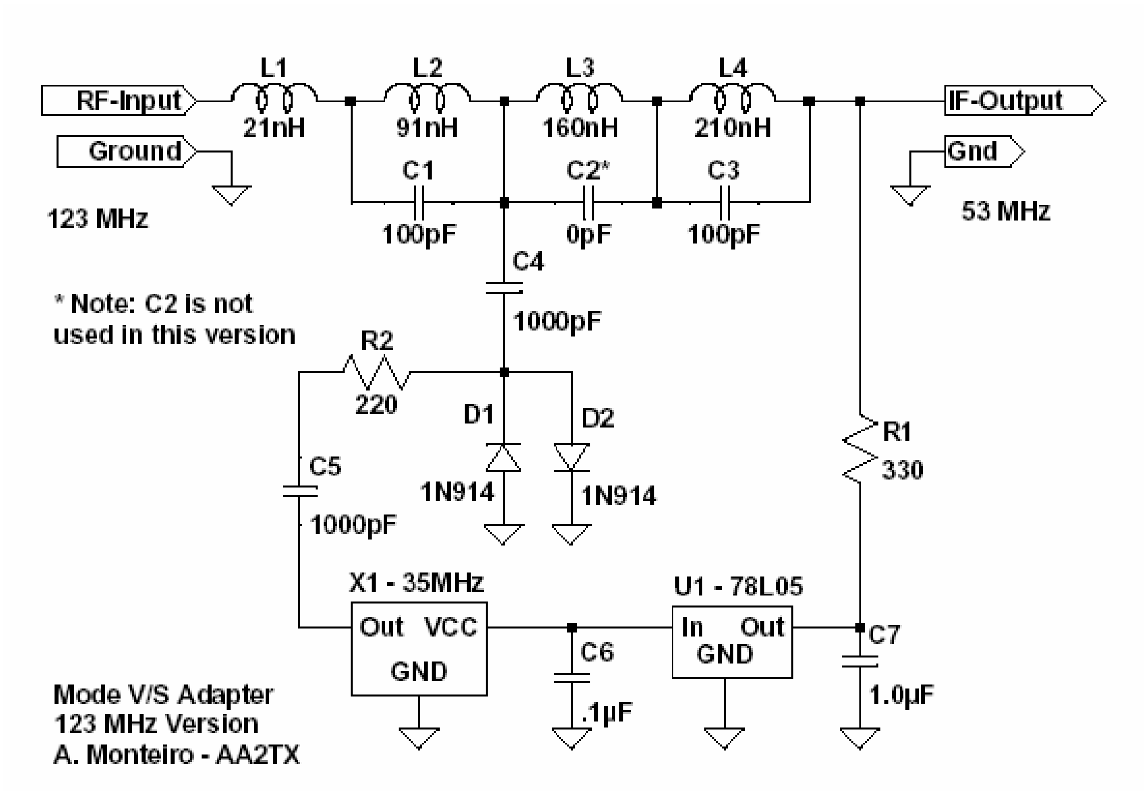


Figure 5. Mode V/S Adapter circuit, 123 MHz version

The TTL clock oscillator generates a signal at 35 MHz and this signal is fed through a DC blocking capacitor, C5, and load resistor, R2, to the 1N914 mixer diodes. The diodes are connected *anti-parallel* and so conduct on both the positive and negative swings of the oscillator signal. This action effectively doubles the frequency from the TTL clock oscillator to 70 MHz.

The parallel tank circuit of L2 and C1 is resonant at the IF output frequency of 53 MHz. This tank circuit presents a very high impedance at the IF frequency and effectively isolates the RF input port from the IF output port. At the 123 MHz RF input frequency, the C1/L2 tank circuit has capacitive reactance (i.e. it "looks" like a capacitor.) Inductor L1 resonates with this capacitance to form a series resonant circuit so the input RF signal sees a low impedance path directly to the mixer diodes through capacitor C4 which provides DC isolation.

The mixer diodes D1 and D2 mix the RF input signal at 123 MHz with twice the TTL clock frequency and create the usual sum (193 MHz) and difference (53 MHz) frequencies. The tank circuit consisting of C3 and L4 are resonant at the local oscillator frequency of 35 MHz and so provide rejection of the local oscillator fundamental signal at the IF output port. At the IF output frequency of 53 MHz, the C2/L4 tank circuit provides a capacitive reactance (i.e. it "looks" like a capacitor) and inductor L3 resonates

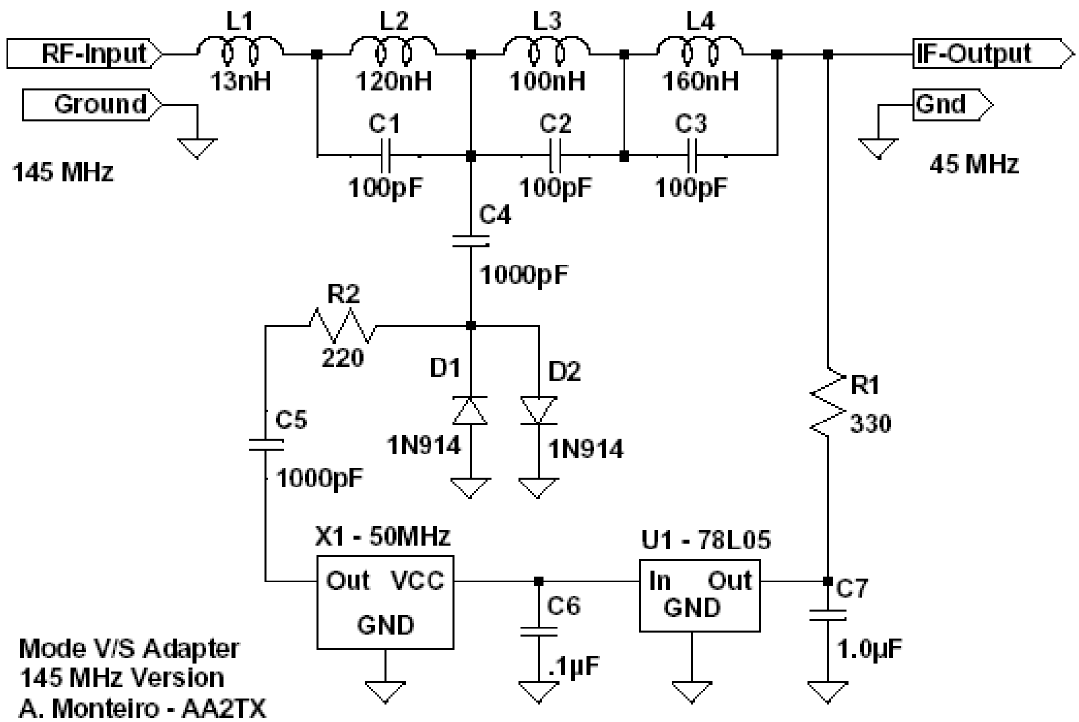


Figure 6. Mode V/S Adapter circuit, 145 MHz version

with this capacitance to form a series resonant circuit. Thus, the desired IF output signal at 53 MHz sees a low-impedance path from the mixer diodes to the IF output port.

The 145 MHz version works in basically the same way. The TTL clock oscillator is at 50 MHz to provide an output intermediate frequency at 45 MHz. The parallel combination of L3 and C2 are resonant at the local oscillator frequency of 50 MHz and block this signal from the IF output port. At the IF output frequency of 45 MHz, they provide an inductive reactance and the parallel combination of L4 and C3 provide a capacitive reactance to cancel this and so form a series resonant circuit at the desired IF output frequency.

Construction

The prototypes were constructed on single-sided printed circuit (PC) boards. The full-size, PC board layout and parts placement guide can be found in Figures 7 and 8. The dots on the drawings represent 0.1" centers.

The following is a simple process for making the pc boards. First, the full-size PC layout is printed on paper. The layout is cut out and glued to a piece of single-sided, copper-clad pc board stock using rubber cement. The piece of copper-clad stock is cut to the right size with a hacksaw using the paper layout as a cutting template. Next, using the paper layout as a guide, all of the holes are drilled through the paper and board stock using a small drill. After the holes are drilled, the paper layout is peeled off and the board is cleaned with steel wool and alcohol. Then, the pads and traces are drawn between the holes using a *Sharpie* permanent magic marker.

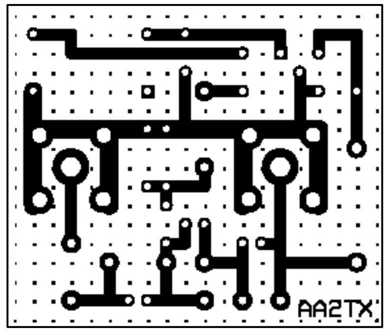


Figure 7. Full-size PC board layout

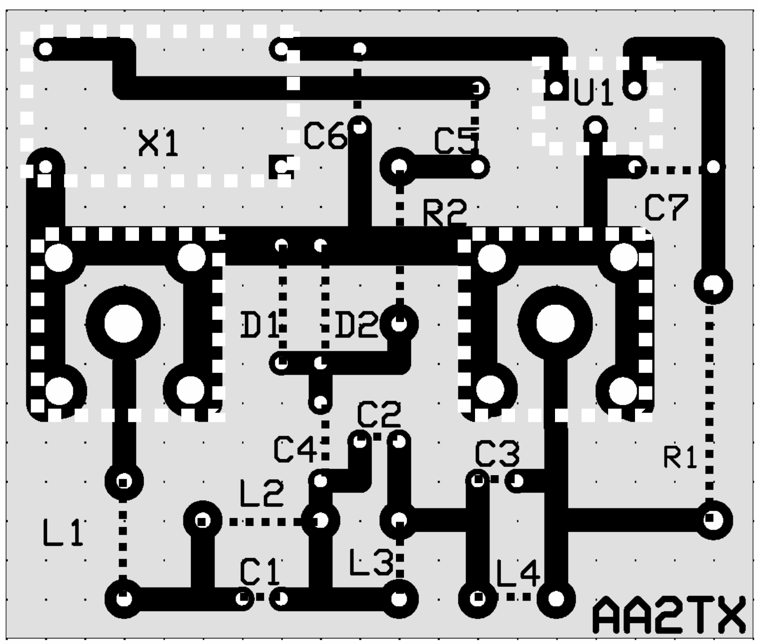


Figure 8. Parts placement guide

After the board is etched, it should be cleaned again with steel wool and alcohol. It is now ready to assemble. The prototypes have the F-connectors mounted on the bottom (copper) side of the PC board so the entire unit can be mounted in a small enclosure using 3/8” nuts on the connectors.

Note that the circuit is not very critical and as long as the lead lengths are kept short, perf board, “dead-bug” or terminal-strip construction could also be used.

Coils

The four coils are made by winding #22 gauge, enameled magnet-wire on a drill bit. The wire should be wound as tightly as possible with no space between turns. The tables below provide the coil winding information. Note that #22 gauge enameled magnet wire is available in a magnet wire kit at *Radio Shack* stores as well as from many other vendors

145 MHz Version				
Coil	**L1**	**L2**	**L3**	**L4**
Inductance	13nH	120nH	100nH	160nH
Drill bit size	1/16”	1/4”	7/32”	1/4”
Turns	4	4	4	5

123 MHz Version				
Coil	**L1**	**L2**	**L3**	**L4**
Inductance	21nH	91nH	160nH	210nH
Drill bit size	7/64”	1/8”	1/4”	1/4”
Turns	3	8	5	6

Components

The parts list is provided in the table below. These components were specifically selected for their wide availability and low cost. Many of these can be found in even the most meager of "junk-boxes."

For reference, the estimated costs are included and are believed to be representative for small purchase quantities. But, note that some parts, especially resistors, are generally not available in unit quantities. Fortunately, the TTL clock oscillator and 78L05 voltage regulator are available from *Jameco*[3] in single quantities and the input and output F-connectors are available from *All Electronics*[4] in single quantities. Many other vendors carry these parts as well.

Mode V/S Adapter - Parts List				
Component	**Description**	**Cost each**	**QTY**	**Total Cost**
C1,2,3	100pF 50V ceramic disc	$0.05	3	$0.15
C4,5	1000pF 50V ceramic disc	$0.06	2	$0.12
C6	0.1uF 25V ceramic disc	$0.14	1	$0.14
C7	1.0uF 50V monolithic ceramic	$0.53	1	$0.53
D1,2	1N914B silicon diode	$0.02	2	$0.04
R1	330 Ohms, ½ Watt	$0.01	1	$0.01
R2	220 Ohms, ¼ Watt	$0.01	1	$0.01
U1	78L05 5V, 100mA (TO-92)	$0.27	1	$0.27
X1	35/50 MHz TTL Oscillator	$1.19	1	$1.19
Connectors	F-connector, PC mount	$0.50	2	$1.00
Total Parts Cost				$3.46

Performance Tests

The conversion loss of the 123 MHz version was measured and was found to be -15 dB. The 145 MHz version measured -14 dB. This is well within the expected range for these circuits and is ideal for this application. The attenuator normally required for use with an S-band down-converter should not be needed when using the Mode V/S Adapter.

As a further performance check, the RF input of the 145 MHz version was connected to an omni-directional antenna and several local 2-meter repeaters were tuned in using a 6-meter IF receiver. The audio quality of the stations heard through the adapter was indistinguishable from directly listening on 2-meters.

Operation

The Mode V/S Adapter is connected in-between the power inserter and the S-band down-converter as shown in Figure 9. The adapter will work with most satellite radios and many non-satellite radios that have 6-meter band coverage (30-60 MHz) including the FT-847, TS-2000, IC-706, IC-746, FT-817, FT-857, FT-897, FT-100 and probably a few others. It will not work most notably with the IC-910 since that radio does not include the 6-meter band.

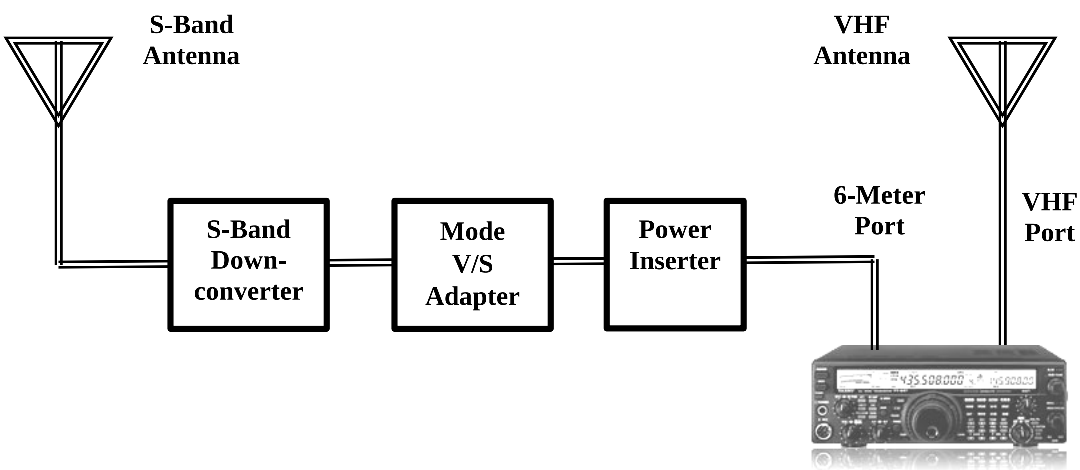


Figure 9. Connecting the Mode V/S Adapter

The AO-51 S-band downlink is at 2401.200 MHz. When using the 123 MHz version, the downlink will appear at around 53.200 MHz and when using the 145 MHz version, it will appear at around 45.200 MHz but remember to include the Doppler-shift when looking for the satellite signal.

When using computer control, it will be necessary to change the receiver converter parameter in your software's configuration file. For most automatic tuning programs, this parameter would represent the down-converter local oscillator frequency and would be around 2278 MHz for a 123 MHz converter or 2256 MHz for a 145 MHz unit. The Mode V/S Adapter adds a second level of conversion that acts like the local oscillator is 70 MHz higher for the 123 MHz version or 100 MHz higher for the 145 MHz version so add this to the original parameters. The new parameters would be around 2348 MHz for the 123 MHz version and 2356 MHz for the 145 MHz version.

The Mode V/S Adapter was tested *on-the-air* using a 2'x 3' grid dish, an AIDC-3731AA down-converter and an FT-847 transceiver. The radio S-meter read S-0 with no signal tuned in. The downlink signal level received from AO-51 exceeded S-9 for much of the pass and was quite impressive for one accustomed to AO-40 signal levels.

For transmitting, an omni-directional 2-meter antenna was used. *Instant*Track with *Instant*Tune[5] software was used for satellite tracking and automatic Doppler-tuning of the FT-847. With this setup, it was quite easy to make several leisurely, albeit short, contacts on an AO-51 satellite pass.

Alternative Frequencies

The Mode V/S Adapter circuit is fairly robust and could be easily modified to operate on other RF or IF frequencies. For example, the 12-meter (HF) band could readily be used as an alternative IF frequency. With a 50 MHz oscillator, the 123 MHz version would convert to 23 MHz and the 145 MHz version with a 60 MHz oscillator would convert to 25 MHz. This might be preferably for some operators. The input and output filters would need to be changed to operate on the new frequencies but would follow the same design principles as the 6-meter IF output versions.

Summary

This paper has presented a simple and inexpensive adapter that enables most satellite and many non-satellite radio transceivers to be used to operate the Mode V/S transponder on the AMSAT OSCAR-51 satellite. This Mode V/S Adapter works by converting the VHF output of an S-band down-converter to the 6-meter band making the VHF band available for transmitting to the satellite.

The adapter employs a sub-harmonic mixer circuit, typically used only at very high microwave frequencies. In this application it allows a commonly available and inexpensive TTL clock oscillator to generate the local oscillator signal. This adapter was tested *on-the-air* via several AO-51 contacts and it performed well.

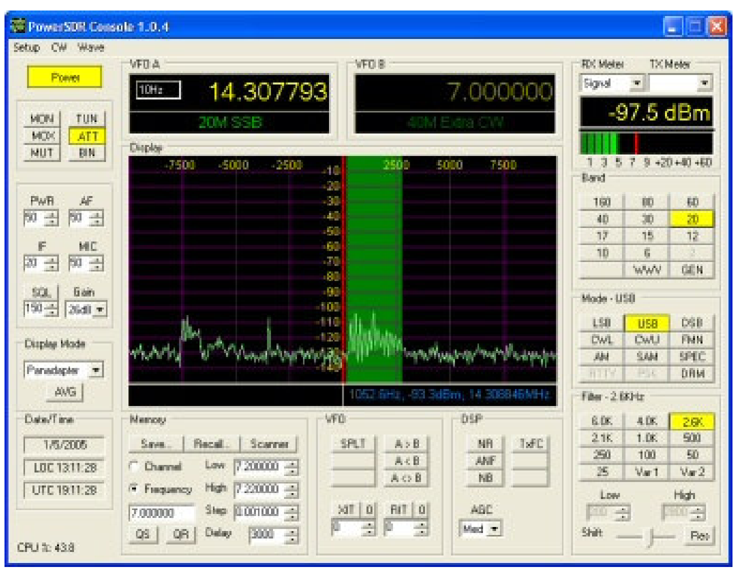
---

[1] "Mixers" by Liam Devlin, see: http://www.plextek.co.uk/papers/mixers2.pdf
[2] MMDS: *Multipoint Microwave Distribution System*, a type of wireless "cable" TV service
[3] Jameco Electronics: www.jameco.com
[4] All Electronics: www.allelectronics.com
[5] *Instant*Track and *Instant*Tune software are available from AMSAT at www.amsat.org

Software Defined Radios for VHF Through SHF
By
Gerald Youngblood
FlexRadio Systems

The FlexRadio Systems' SDR-1000 is the first commercially available Software Defined Radio (SDR) transceiver for the amateur radio market. The SDR-1000 began shipping in April of 2003 with GPL open source software, a first for a commercial transceiver. This has created a groundswell of support for the radio from contributors worldwide. This is evidenced by the constant improvement available through free software downloads on almost a weekly basis. These enhancements are well documented in the October 2005 *QST* product review, "FlexRadio Systems SDR-1000 HF+VHF Software Defined Radio *Redux.*" The current SDR-1000 now boasts dynamic range performance that meets or exceeds that of radios costing ten times its cost.

Frank Brickle, AB2KT, Bob McGwier, N4HY, and Eric Wachsmann, KE5DTO, have collaborated for almost two years on the latest open source version of the PowerSDR software that runs the SDR-1000. The figure below shows a screen shot of the software in the real time pan adapter mode that allows signal location and instant click tuning with a mouse.



The SDR-1000 Moves to VHF and Beyond

While the SDR-1000 has been thought of as a HF radio, many prominent amateurs are moving to the SDR-1000 as their IF radio of choice for VHF, UHF and microwave. Key features that are available on the SDR-1000 for VHF+ enthusiasts are:

- Real time click to tune pan adapter spotting
- No ring filters to 25Hz
- SDROM impulse noise removal
- 10 or 20MHz LO reference input option
- Extremely high dynamic range IF (99dB IMD DR3)
- 2m DEMI IF option
- Integrated transverter and antenna software control with UCB
- 44KHz Bandwidth IF Record/Playback

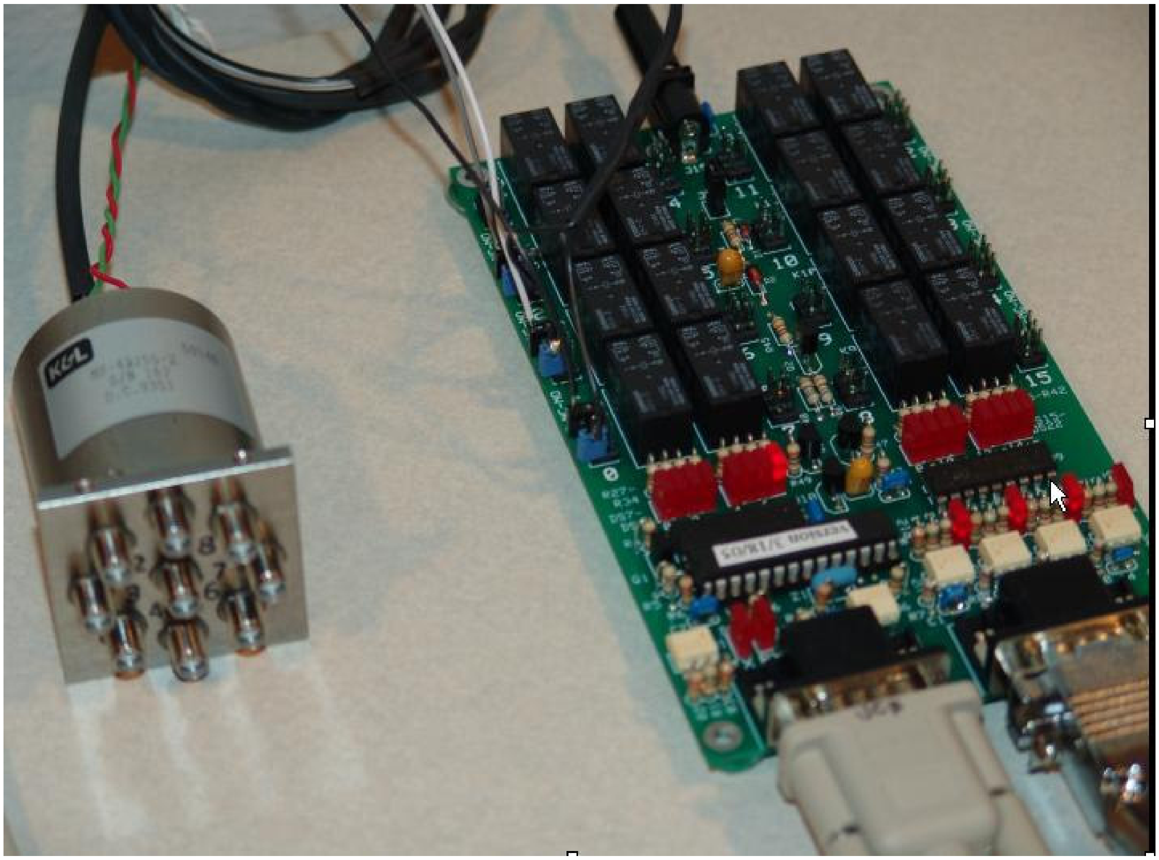
Through collaboration between Mike King, KM0T, Tony Parks, KB9YIG, Terry van Benschoten, W0VB, and FlexRadio Systems, a Universal Controller Board (UCB) has been developed and integrated with the SDR-1000 to allow transparent software control of up to 16 external transverters and/or antennas. In fact, there are also 16 possible combinations of those 16 devices that may be controlled under the software. It allows for full control of band switching, sequencing, and PTT by simply changing the frequency on the PowerSDR console. By the time this paper is in print, the software will provide direct frequency readout in GHz with transverter-offset correction. That means that one could within seconds QSY from 144MHz to 24GHz with a single click, find the signal on the real time spectrum and click to tune on frequency.

This paper will describe the integration and operation of the UCB with the SDR-1000 IF for microwave operation at the KM0T location. A special thanks goes to KM0T and W0VB for allowing FlexRadio to use their materials to show a real world user application of the SDR-1000.

The UCB hardware was designed and has been produced by W9YIG. While the UCB is currently available only through W9YIG, FlexRadio Systems is considering its addition to the standard product line.

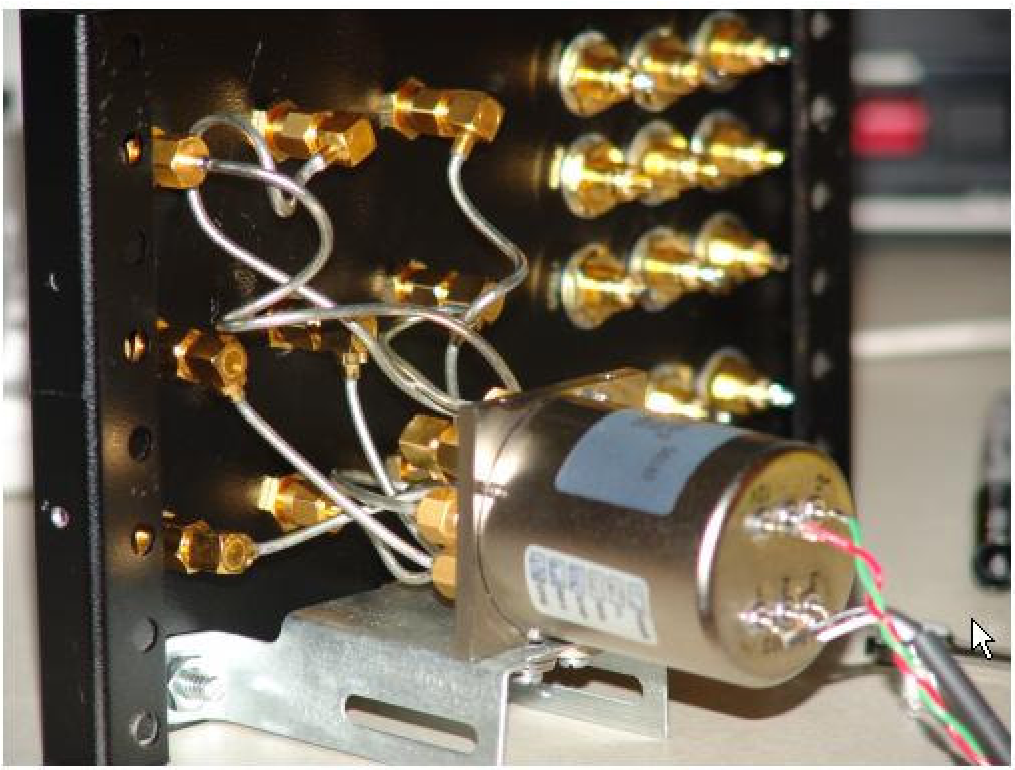
The UCB is a single PCB with a 15-pin connection to the External Control (X2) connector on the back panel of the SDR-1000. The X2 connector provides PTT input and output as well as six spare open collector switched outputs. These six outputs can be set under software control for simple external control by band with no other external hardware. However, with the addition of the UCB, very sophisticated control options are available including separate antenna, transverter and PTT control. It even allows the choice of binary or BCD control of antenna switching relays as seen in the KM0T installation.

The photo below shows the UCB on the right with an 8-position SMA coaxial relay on the left. The coax relay uses BCD encoding for control so the UCB must provide the necessary codes to select each band. Headers are provided for the normally open and normally closed contacts on each of the 16 relays. LEDs provide status indication for each relay as well as other control and data lines. The board is powered by an external __V supply. A 15-pin loop through connector allows dedicated control signals from the X2 connector to be passed through the UCB.

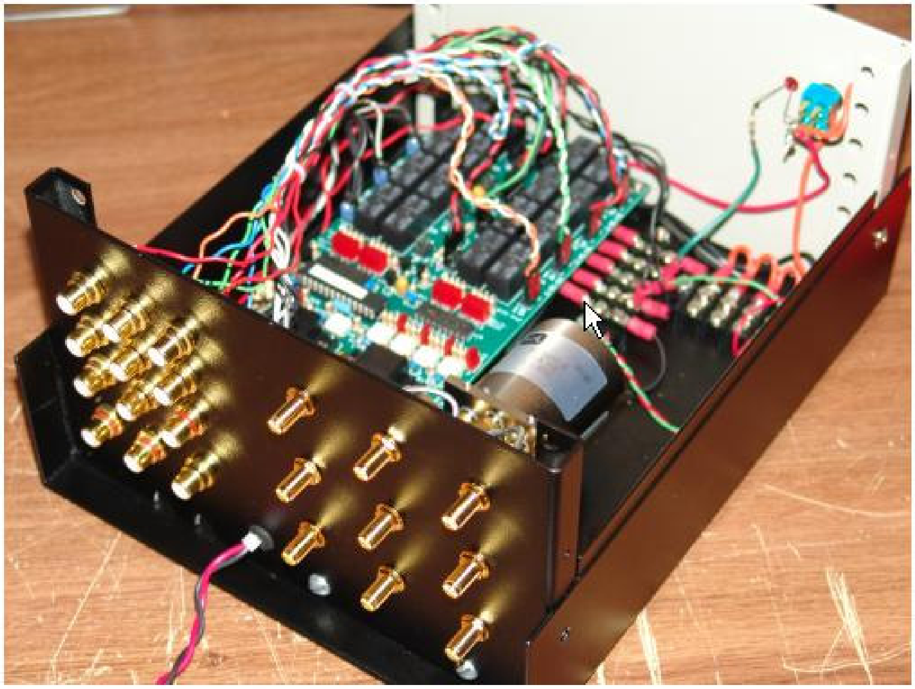


KM0T has designed his new station for operation on all microwave bands from 50MHz to 47GHz, with room to grow. He decided to integrate the UCB, 8-position coax relay, and all PTT connections in a single enclosure for a clean installation in the shack. The following two photos show the rear panel layout in progress. The coax relay is mounted on a bracket on the left with semi rigid coax connections to the panel mounted SMA connectors. A bank of 12 gold plated RCA connectors are mounted on the right hand side for PTT control outputs.

Rear Panel Showing PTT and Control RCA Jacks



Closeup of SMA Jumpers to Rear Panel Bulkheads



Rear Panel View

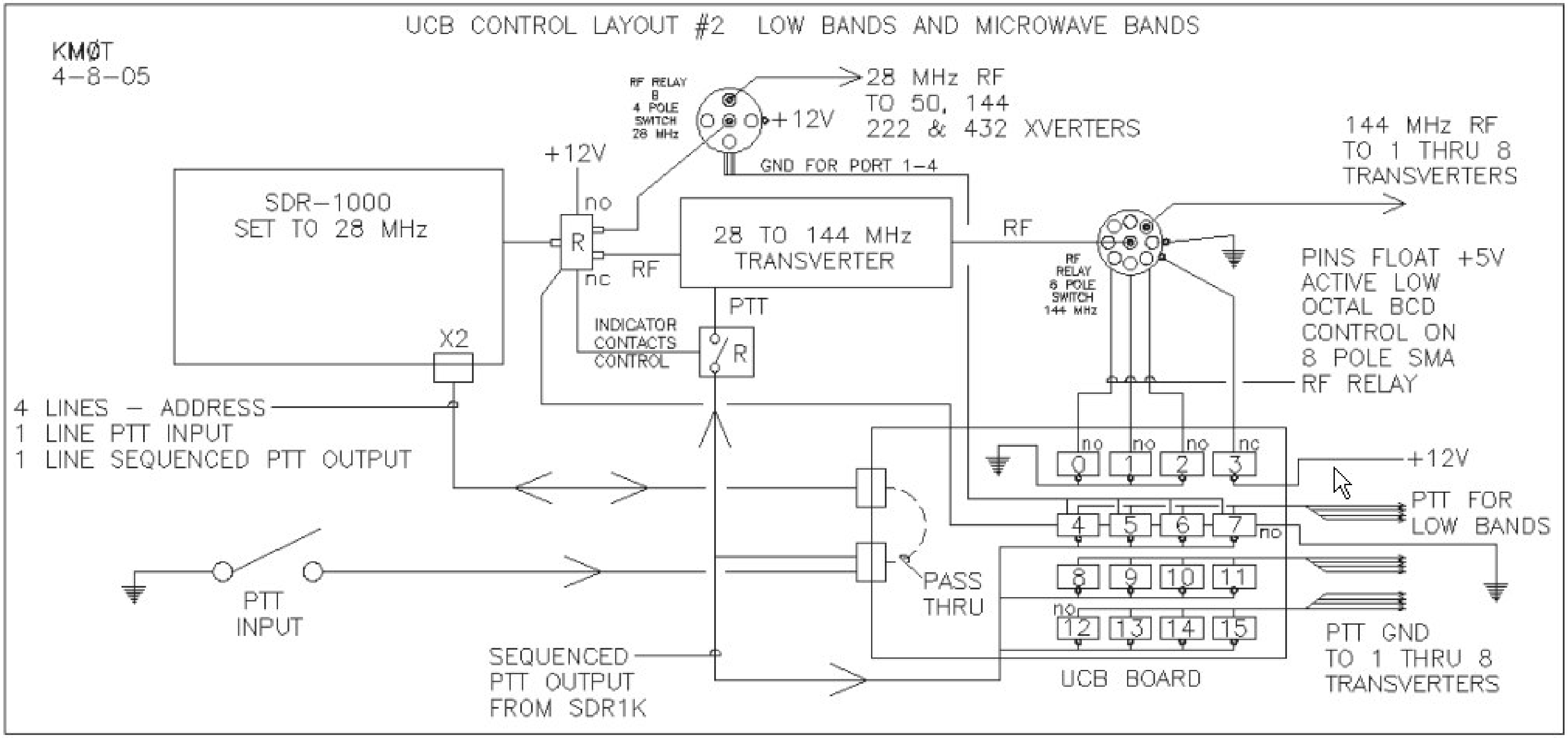
The photo above shows the completed controller module with all interface wiring installed. The single red and black wiring pair protruding from the grommet at the bottom center of the back panel is the DC power supply input. The final station installation may be seen in the following two photos. Note the neatness of the installation for coverage of all bands from 50MHz through 24GHz!

KM0T QTH

Integration of the SDR-1000 with UCB in the station requires a careful planning. The key steps are as follows:

1. Draw a wiring diagram of the station with all accessories to be controlled. Include all relays, PTT, power wiring, and other control logic required for the installation.
2. Create a spreadsheet matrix for the control logic by band and map each band to a UCB control register address.
3. Wire the station according to the schematic and control logic matrix.
4. Program the PowerSDR software by band according the control logic matrix.
5. Turn on the SDR-1000 and have fun.

The schematic on the next page provides the final wiring configuration at the KM0T location. Note the UCB at the bottom left of the drawing shows each relay and how it is connected to the other major components. The BCD control signals for the 8-position coax relay are clearly indicated. The SDR-1000 is used as a 28MHz IF for all bands. Note the two relays to the right and above the 28-144MHz transverter provide for low band selection. The SDR-1000 allows a sequenced PTT output with a user programmable delay time in milliseconds.



KM0T STATION WIRING DIAGRAM

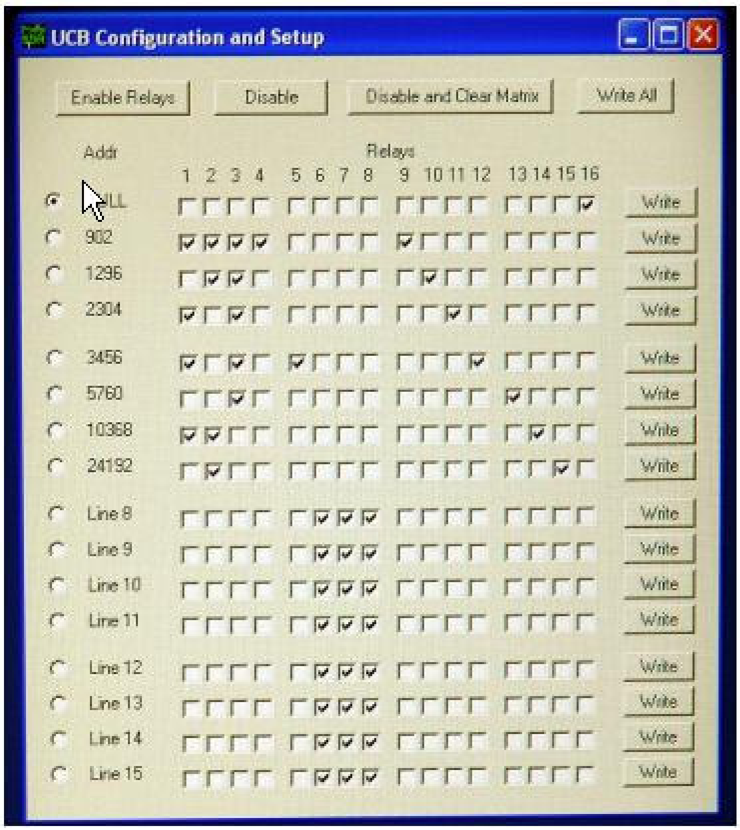
		RELAY CNTRL BITS: O = OPEN RELAY 1 = CLOSE RELAY												RELAY	BIT OF 1 INDICATES			
UCB	SDR-1000													PWR	RELAY CLOSE TO GND			ASSOC
REGISTER	ASSOCIATED				PTT RELAYS					PTT RELAYS - LOW BANDS				ENABLE	RF RELAY ADDRESS			RELAY
ADDRESS	BAND BUTTON	BIT-15	BIT-14	BIT-13	BIT-12	BIT-11	BIT-10	BIT-9	BIT-8	BIT-7	BIT-6	BIT-5	BIT-4	BIT-3	BIT-2	BIT-1	BIT-0	PORT
0	NULL BAND	0	0	0	0	0	0	0	0					1	0	0	0	N.O.
1	902	0	0	0	0	0	0	0	**1**					0	**1**	**1**	**1**	1
2	1296	0	0	0	0	0	0	**1**	0		RESTRICTED AREA			0	**1**	**1**	0	2
3	2304	0	0	0	0	0	**1**	0	0		ALL ZEROS			0	**1**	0	**1**	3
4	3456	0	0	0	0	**1**	0	0	0					0	**1**	0	0	4
5	5760	0	0	0	**1**	0	0	0	0					0	0	**1**	**1**	5
6	10368	0	0	**1**	0	0	0	0	0					0	0	**1**	0	6
7	24192	0	**1**	0	0	0	0	0	0					0	0	0	**1**	7
8	SPARE - 47 GHZ?	**1**	0	0	0	0	0	0	0					0	0	0	0	8
9	50									1				1	X	X	X	1B
10	144		RESTRICTED AREA								1			1	X	X	X	2B
11	222		ALL ZEROS									1		1	X	X	X	3B
12	432												1	1	X	X	X	4B
13	NA		RESTRICTED AREA								RESTRICTED AREA							
14	NA		ALL ZEROS								ALL ZEROS							
15	NA																	
NOTE 1:	BIT-3 - RELAY POWER ENABLE - ON 1 - POWER BROKEN TO MICROWAVE RELAY - ADDRESS DOESENT MATTER - "X"																	
NOTE 2:	1 IN BIT 4, 5, 6 & 7 ROUTES PTT TO CORRECT LOW BAND XVERTER - AND SELECTS CORRECT LOW BAND 4 POLE RELAY PORT																	

KM0T CONTROL MATRIX TABLE

Note how the UCB registers control multiple functions on each address. Application of the control bits is as follows:

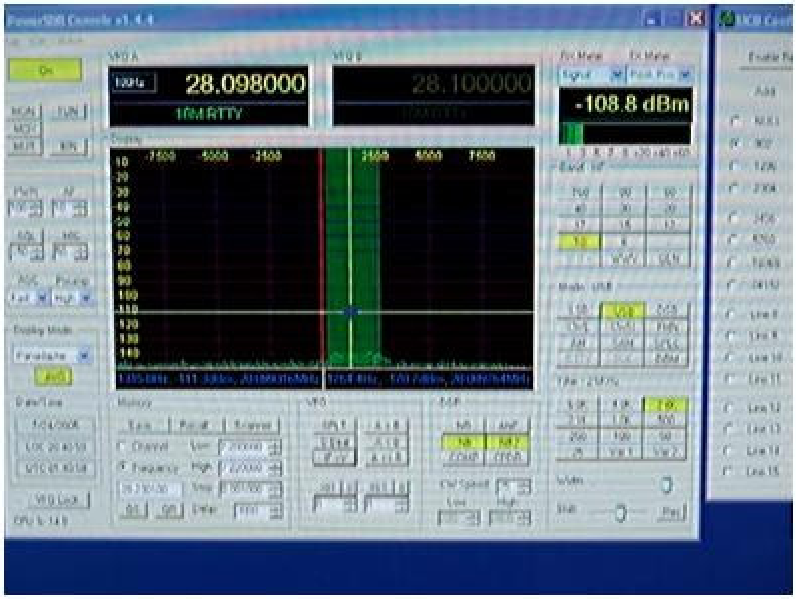
1. B0-B2 – BCD control of 8-position coax relay
2. B3 – Low/High band selection relay
3. B4-B7 – Binary control of low band PTT relays
4. B8-B15 – Binary control for high band PTT relays

Once the hardware is installed it is time to program the PowerSDR software to properly control the station. At the time of writing, the UCB Configuration and Setup form is shown below. Note how the previous spreadsheet data is directly programmed into the form's matrix. Testing of each band is accomplished by clicking on the respective radio button on the left.



Now that setup is done, the moment of truth is to make contacts on all the microwave bands in just minutes with N0DQS. The presentation will include a video recording of the sequence of contacts from 902MHz through 24GHZ!

The Moment of Truth – Running the Bands with NØDQS.



Coming Soon to a SDR-1000 Near You

PowerSDR software plans include instant band switching and direct frequency readout. Using the VHF+ button on the front console the band buttons will convert to VHF+ bands three band-stacking registers per band. The setup form will allow programming of offsets for each transverter so that direct frequency readout is possible that corrects for oscillator-offset error in each transverter. With the SDR-1000, UCB, and PowerSDR software, QSY to any of the VHF+ bands becomes as easy as switching HF bands. Now “DC to light” operation is possible from a single operating position.

LVB Tracker 2 – An autonomous, portable satellite tracking device and rotator interface

Howard Long, G6LVB

1. Abstract

Based on the design criteria of the original LVB Tracker rotator interface, this upgraded version provides integrated full satellite prediction and handheld battery powered operation by means of a simple chip and firmware upgrade still using the original PCB of the first LVB Tracker interface.

2. Introduction

The original LVB Tracker[i] presented at the AMSAT Colloquium in 2003 has proved to be very popular, with 150 PCBs sold. Originally based on a PIC 16F876 microcontroller, more recently newer devices with more memory have been introduced, and it is now possible to provide integrated prediction without the need for a host computer, although this new version will also function as before with a host computer issuing rotator movements.

Figure 1 Two prototype LVB Tracker 2's

3. Design Considerations

The original design considerations remain, primarily these are:

- No need to solder surface mount components
- Inexpensive
- Additional optional components
- User upgradeable firmware
- Many host interface possibilities, including RS-232, Ethernet, USB, WiFi
- Open source/GPL
- Cross platform host compatibility
- Standard host interface – GS-232 and EasyComm I

Further considerations for prediction:

- Upgraded but pin compatible PIC, allowing use of existing PCB
- More program memory – size of firmware risen from 2000 to 7500 lines
- More RAM – prediction needs a lot of variable memory
- Increased EEPROM storage required for Keps
- Faster speed to predict quickly
- Simple to use
- Still backwards compatible
- Further optional modules, for example GPS and radio interfacing
- Handheld device
- Low power
- Audible and vibrating alerts

Future considerations

- Digital recording capability
- MP3 player

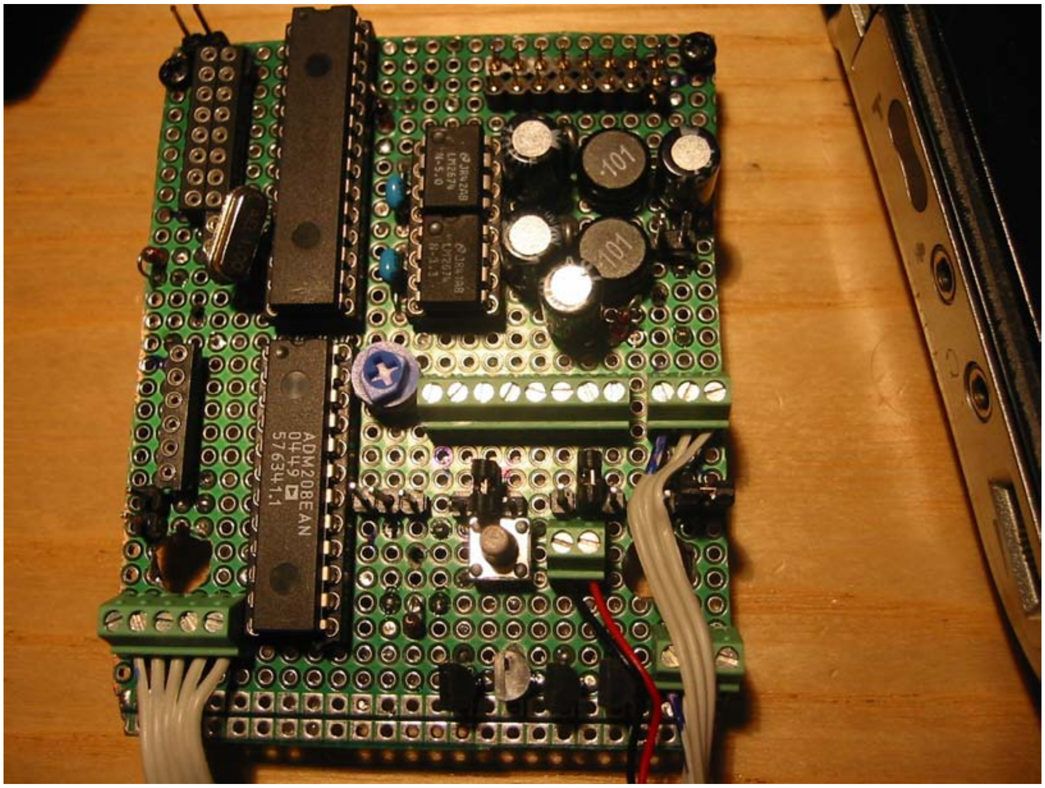


Figure 2 The first LVB Tracker 2 prototype

The PIC device chosen for compatibility with the original LVB Tracker PCB is the 18F2620. This is directly pin compatible with the original 16F876, although the firmware is different. It is envisaged that many existing and new users will take this option, although it is also possible to take advantage of even larger devices that will support additional program overhead, allowing automatic Doppler correction with support multiple radio interfaces.

This new tracker also requires completely new host programming software, and again this is made freely available.

To support future automatic Doppler correction, the firmware has already been ported to the larger 18F8720 and 18F8722 devices, using an identical source code base as that used for the 18F2620. Although the 18F8720 and 18F8722 are surface mount devices, they are both available pre-assembled on a PCB from Microchip, the manufacturer of PIC devices.

Figure 3 The first attempt at a portable LVB Traker 2

The software is written in C, with the prediction software based on James Miller's G3RUH PLAN13[ii] algorithm. Plan13 was originally written in BASIC, but Edson Pereira, N1VTN, has ported the software into C[iii]. The LVB Tracker 2 firmware is essentially based on the Pereira C port of Miller's PLAN13 as the prediction engine.

Not included in the original PLAN13 code is the ability to find the next AOS or LOS of a given satellite. The AOS/LOS algorithms used in the LVB Tracker 2 are based on code from the Predict program[iv] written by John Magliacane, KD2BD. These algorithms use an iterative process to calculate AOS and LOS.
Although the newer PIC devices have sufficient memory for prediction, at first it was not clear whether there would be enough speed available to make such an application viable. After writing the prototype software and running it in an emulator, it became clear that at full speed a PIC is indeed capable of running 140 predictions per second – certainly more than adequate for prediction needs as well as AOS and LOS prediction.

Key to the design was the simplicity of the user interface. Although only having four buttons and a small LCD screen, the implementation is intended to be highly intuitive, using an uncomplicated menu style.

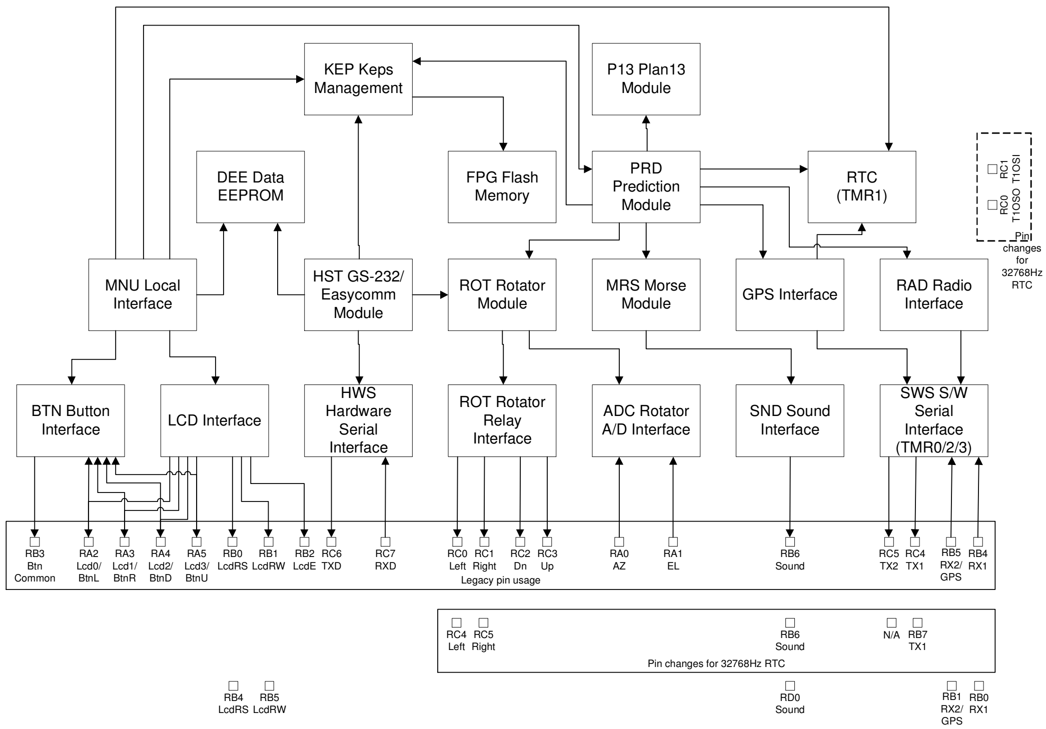


Figure 4 The software modules of the LVB Tracker

There are two non-volatile memory areas in the PIC. The EEPROM area is 1K bytes in size and is used for storing the user's location and rotator calibration information. Due to the size required by the Keplerian elements, the EEPROM is not sufficiently large, and so the flash program memory is used to store this data.

New Keplerian elements are uploaded in the standard two-line element (TLE) NASA format from a host computer as a text file using a terminal emulator. Checksum calculations are implemented to ensure that the data is valid. If a new satellite appears in the TLE file (identified by the catalogue number), it is added to the end of the existing data in the PIC. If the satellite already exists in the PIC, then the data is overwritten irrespective of whether the elements are newer or not.

4. Portable Operation

With its prediction capabilities, the use of the LVB Tracker is now not limited to use purely with a rotator: it is a highly useful device in its own right operating autonomously.

Although the 18F2620 on the original LVB Tracker PCB could easily be used, to keep the device small, the SMD 18F8720 and 18F8722 devices were chosen for use in two example portable prototypes.

One of the key issues when operating portable is that of being able to rapidly and accurately make satellite predictions with both a very straightforward user interface and useful additional functionality. With this in mind, an additional software serial interface has been implemented that connects directly to a GPS device. Standard

NMEA sentences are interpreted and used to set the device's real time clock and location. To further simplify operations, the current locator is also displayed on the LCD display.

An essential consideration to portable operation is battery life. Switching regulators were used at the outset, initially using a PP3 style battery and switching down. More recently, two AAA cells have been used in conjunction with a step up regulator, providing a longer life. Even without any power management, typically eight hours of prediction time is available on a single pair of rechargeable NiMh AAA batteries.

In addition, there is a user selectable audible and/or vibrating Morse indication of AOS of forthcoming passes.

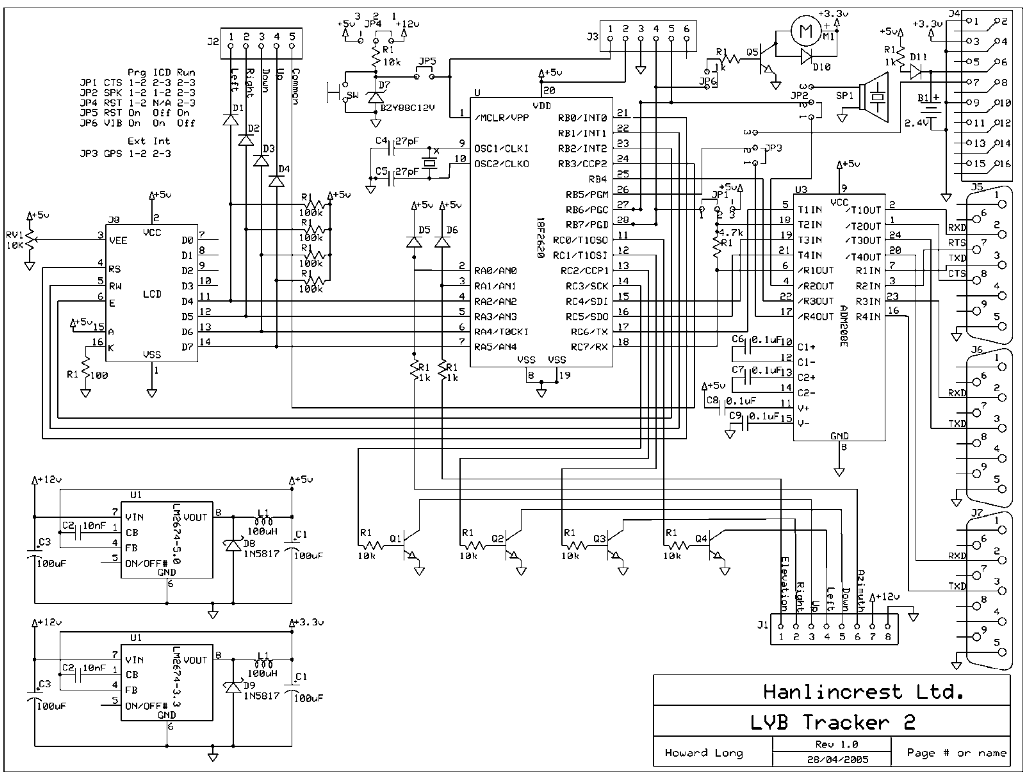


Figure 5 Schematic of an enhanced version of the LVB Tracker 2 with a total of three serial interfaces. The original LVB Tracker design and PCB can also still be used, substituting the PIC for and upgraded 18F2620 device and new firmware.

5. Programming

One of the features of the original LVB Tracker was that the firmware is in-circuit user upgradeable without the need for a specialist programming device. Although the new 18F devices are significantly different in their firmware programming protocol, the hardware interface remains the same as the 16F87X devices used in the original tracker.

The different protocol demands new host programming software that has been developed for the Windows platform allowing end-user programming in the same way as the original LVB Tracker. This includes both comprehensive device identification and code verification.

6. Acknowledgements

The LVB Tracker 2's raison d'être is the prediction engine. The program code of the prediction engine is based exclusively on code developed by the following authors, I am indebted to them all for the permission to use their code in the LVB Tracker 2 design:

James Miller, G3RUH
Edson Pereira, N1VTN
John Magliacane, KD2BD

Although the LVB Tracker source code has always been in the public domain, at John Magliacane's suggestion it is now released under the GNU Public Licence.

---

[i] The Las Vegas Boulevard Tracker Interface, Howard Long, G6LVB, Proceedings of the AMSAT-UK Colloquium 2003, also http://www.g6lvb.com/Articles/LVBTracker
[ii] PLAN-13 Satellite Position Calculation Program, James R. Miller, G3RUH, Oscar News No. 85, Oct 1990 p.15-25, also ftp://ftp.amsat.org/amsat/articles/g3ruh/a111.zip
[iii] A partial C port of G3RUH's Plan13 Keplerian Propagator, Edson Pereira, N1VTN, http://www.qsl.net/n1vtn/plan13-0.1.tar.gz
[iv] PREDICT - A Satellite Tracking/Orbital Prediction Program, John A. Magliacane, KD2BD, http://www.qsl.net/kd2bd/predict.html

The State of Amateur Satellite Telemetry

Gould Smith, WA4SXM

Telemetry on amateur satellite goes back to the first amateur satellite OSCAR 1, launched in 1961. It transmitted the greeting HI in CW with the transmission rate proportional to the temperature of the satellite.

Where are we forty-four years later? Well, we have at least nine satellites transmitting telemetry on the amateur satellites bands using a variety of modes, including CW. A number of satellites are being developed that will experiment with new modes. For a more in depth description of the current telemetry data, reception equipment and decoding see the 2005 AMSAT publication *Digital Satellite & Telemetry Guide*.

Why should I capture telemetry?

There are 100's of thousands of amateur radio operators, 1000's of satellite operators, 100's of digital satellite operators and few telemetry operators. It is imperative that we maintain a group of individuals that understand, maintain and improve amateur satellite telemetry. Without this dedicated group, the lifetime of future satellites will be drastically shortened. I have found that telemetry reception and decoding offers an excellent path to optimizing my satellite ground station. If you can reliably copy satellite telemetry, you have a good satellite station. Back in January 2005 I requested station information from the digital satellite users. In addition I also asked, "Why do you do digital satellite operations?" Almost to the person, the answer was, "I like the technical challenge." In addition to telemetry reception, satellite telemetry offers an interesting challenge for experimentation. Like providing a new soundcard software demodulator /display like Douglas Quagliana, KA2UPW, or better error detecting and correcting algorithms like Phil Karn, KA9Q or experimenting to find the minimal station requirements for good, consistent copy.

Where have we been?

Amateur satellite telemetry started with CW and this mode is still in use. Over the years we have also seen the data sent as digital voice, RTTY, 7 and 8 bit ASCII, 8 bit hex hexadecimal used. In addition to the data types, there have been a number of modulation schemes – CW, RTTY, FSK, AFSK, PSK, BPSK, QPSK. There have also been various types of checksums used – none, parity, channel checksums, entire packet CRC, XOR packet checksums. AMSAT has ventured into FEC (Forward Error Correction) schemes, to detect and correct errors.

Telemetry tradeoffs

The purpose of telemetry is to monitor the status of satellite. When things are going well a great deal of data seems unnecessary, but when problems arise there never seems to be enough data. You want enough data to be able to identify developing problems, but no so much that you are overwhelmed by the data. How much data is this? A difficult question. Telemetry transmissions require power, and power is the most valuable resource on the satellite. So deciding how much telemetry, how often and how much power is a constant

item of discussion during development and during command. Each telemetry channel requires and sensor and wiring, each of these adds weight and additional wiring harness and connectors. Weight is a primary concern for launch and each connector is a potential problem source. The operating system must allocate time to sample the various data channels, store the data, form it into packets and transmit it. The data transmission rate type and rate must be determined. The faster the data is transmitted the more data that can be transmitted, but also the greater the chance that a noise source or fade can interfere with the data burst. The modulation type chosen can enhance the ability of the earth station to recover the data, but new hardware requirements may drastically decrease the number of stations able to receive the data. Data reliability, more bits used to detect errors means more reliable data, but less data. Unreliable data is useless. Do you put error detection on each channel, each packet or an entire frame? Who actually designs the telemetry hardware? Who tests the hardware? Who provides the demodulating hardware? Who provides the decoding and display software? Who collects and uploads the telemetry data? Who combines and evaluates the telemetry data?
You do!

Telemetry Goals

- Get a significant amount of data to the ground
- Make it as reliable as possible
- Send the data at a fast enough rate to be able to identify anomalies
- Use a format that allows affordable hardware for a wide network of ground stations
- Use a modulation mode that allows good reception without exotic station requirements

CW telemetry

Four of the active satellites (AO-7, LO-19, FO-29 and VO-52) still use CW, transmitting data at 10-20 WPM. These have the advantage that very common equipment is needed to copy them. The main disadvantage is the skill of the receiving operator. With graphic CW decoding software available today it is much easier to copy reliable CW telemetry. All CW decoding software I have tried to use for many years proved very unreliable in decoding CW signals. This was mainly due to the frequency induced by Doppler shift and trying blindly to keep the signal centered. CW decoding software like Hamscope and MixW now give you a graphical display of the signal and the audio frequency around which the software is attempting to decode. Today it is a simple matter of keeping the signal on top of the decoding frequency to get a fairly reliable copy.

Although the CW transmissions are standard Morse characters, they may be shorthand for other data. LO-19 uses this method to save energy. Since the numeric characters are all 5 sounds long, and many of the sounds are Dahs, it is more efficient to equate the numbers to short Morse characters like A, E, T, D, N, etc… and convert.

Table 1. LO-19 CW to numeric telemetry conversion formula

A = 1 or .-	**T = 0 or -**	**O is O or - - -**	**E = 5 or .**	**B = 7 or -…**	**U = 2 or ..-**
D = 8 or -..	**V = 3 or …-**	**4 = 4 or ….-**	**N = 9 or -.**	**6 = 6 or -….**	

Figure 1. LO-19 TLM format and a received LO-19 telemetry frame

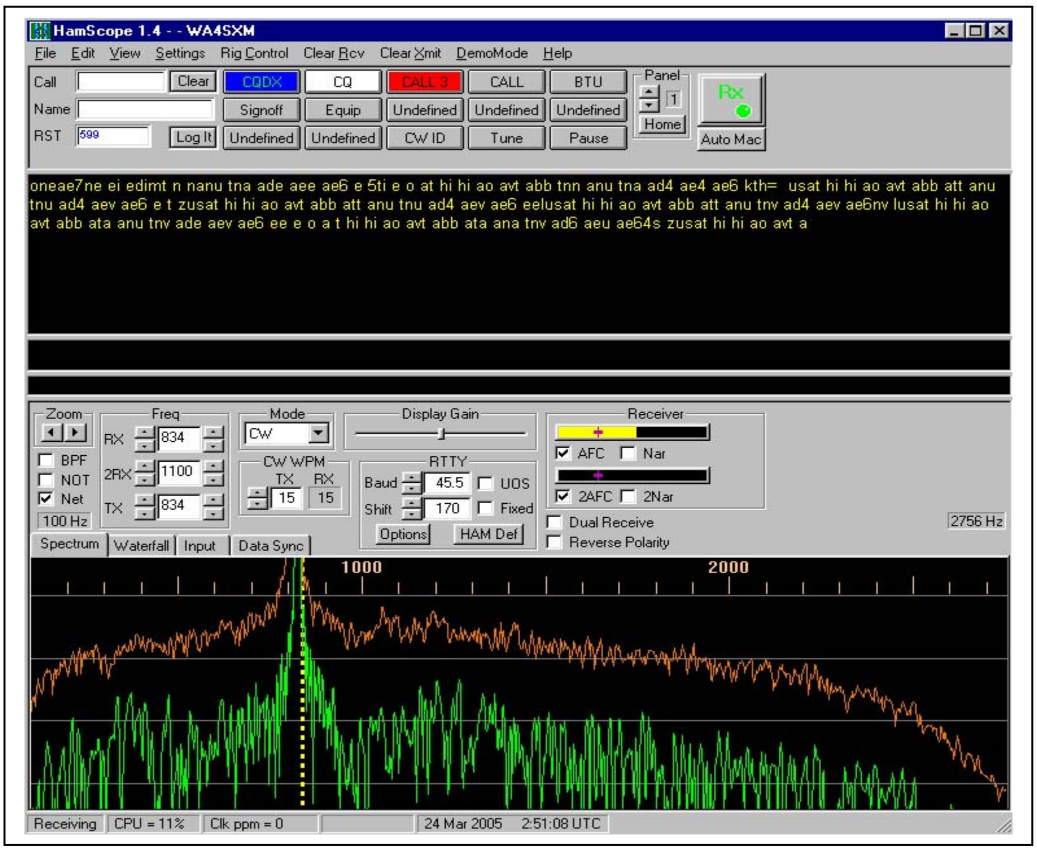
E LUSAT HI HI NL ch1 ch2 ch3 ch4 ch5 ch6 ch7 ch8

+-------------------- 35 second transmission --------------------------------+- 25 sec NO XMT -¦

E LUSAT HI HI AO AVT ABB ATT ANU TNU AD4 AEV AE6

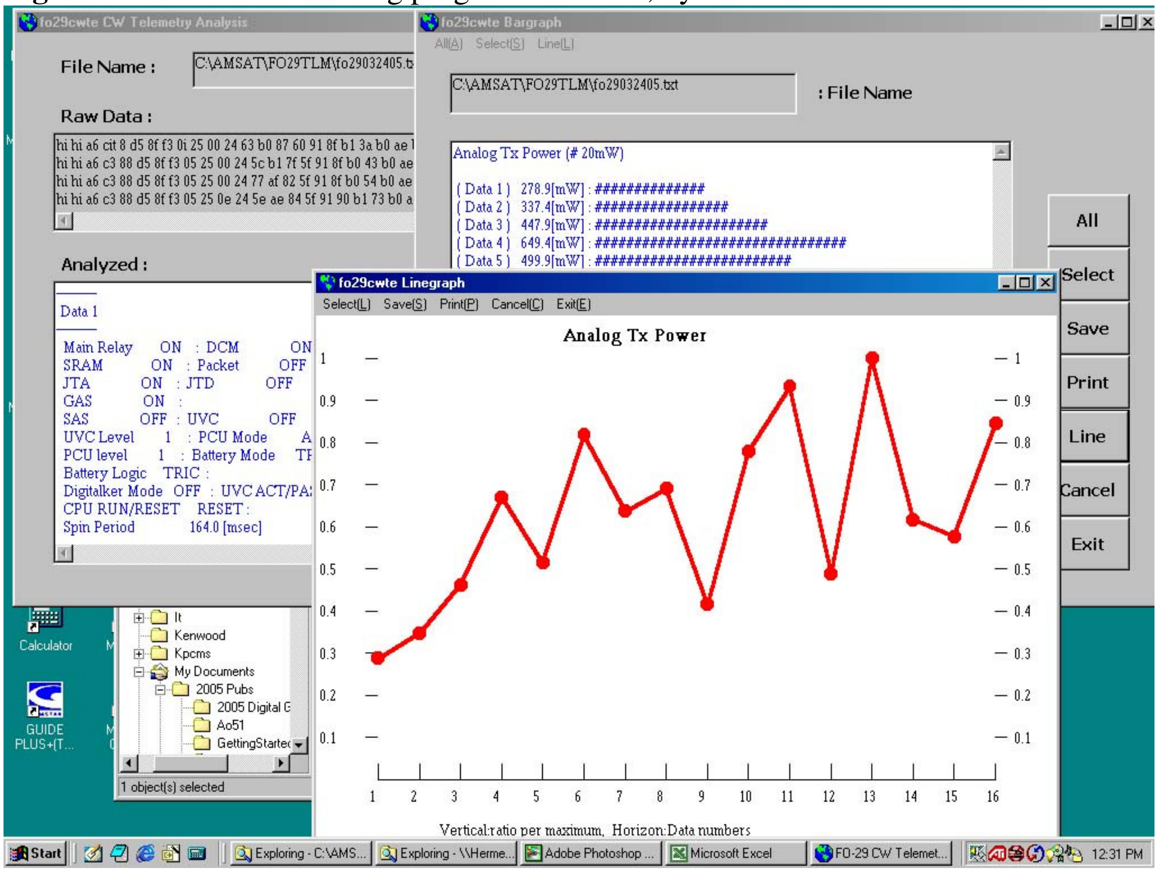
```
↑ ↑          ↑      ↑   ↑
| |          |      |   ⌊Beginning of 8 analog data values
| |          |      ⌊Status byte
| |          ⌊Historical HI message (no data)
| ⌊Satellite identifier
⌊Attention character (no data)
```

Figure 2. Hamscope reception of LO-19 (LUSAT) CW telemetry



An additional benefit of software decoding is that the data can be stored as a text file to be evaluated after reception. Mineo Wakita, JE9PEL has provided us with a program to interpret the FO-29 CW telemetry, fo29xwte.exe.

Figure 3. FO-29 CW decoding program fo29cwte, by JE9PEL



AO-7 sometimes sends 24 channels of CW telemetry data. The value of the final channel tells you whether the data sent was valid or not. This doesn't take into account the accuracy of the receiving station.

Figure 4. Sample AO-7 CW telemetry

good data

```
HI HI
100 176 164 178
280 262 200 254
375 358 331 354
453 454 461 459
541 501 552 529
600 600 601 651
HI HI
```

bad data

```
HI HI
180 180 180 180
252 252 252 252
324 324 324 324
496 496 496 496
568 568 568 568
696 696 696 696
HI HI
```

These data are valid when channel 6D is one of these values: 649, 650 or 651.

CW telemetry Positives – Easy to generate, simple, inexpensive, easy to receive, low transmit power, multiple receive stations
CW telemetry Negatives – no checksum, low data rate, low number of samples per pass, manually record date/time, post process, few channels of data

1200 bps ASCII Telemetry

UO-11 sent telemetry data in a number of different formats. Today only the 7-bit AFSK, ASCII data is functional and lately only part of that. UO-11 did improve upon the data reliability by 1) using Even parity on each character and 2) using an XOR checksum for each data channel.

Figure 5. Sample UO-11 1200 bps ASCII telemetry

```
UOSAT-2            0503306230954
002435010436020000203000304003705013706009F070272080293090229
0050041100001200031305341400051500041600071737751836 3F19423D
20492D210254226547230001240006210000n26082E27372328367829394 5
302302310112322762330000340007352105362698373465383 75A394097
40736641014042653643057544157345000446000247395C48410949375C
5057525b170242642753647354069E55`00056000357406058398F594080
60800E615FC16201416333416444026 51E0C6627EB67000168000E69000F
```

Channel 37 is the 145 MHz beacon temp, using Figure 4, channel 37 data is **373465**

37 Channel number
346 is the channel data value
5 is the checksum, derived from taking all six bytes, breaking them into nibbles and XORing the nibbles from left to right and you should end up with 5

Figure 6. Dedicated UO-11 modem, circa 1989

One again you needed a special modem to copy this data. The tones were opposite from the standard 1200 bps computer modems of the day.

Today soundcard modems like MixW can demodulate the data and save it to a file for post processing.

ASCII telemetry Positives – Easy to understand, sent in 7 bits, easy to obtain/modify equipment, multiple receive stations, added date/time, checksum for each channel so don't lose entire data frame, large number of channels

ASCII telemetry Negatives – low data rate, low number of samples per pass, post process, few channels of data

PSK Telemetry

In the 1980's the first HEO Phase 3 satellites entered the picture. Now the telemetry signals would have to be copied from distances up to 50 times further. So it was time to employ a more efficient technology, PSK (Phase Shift Keying).

1200 bps PSK

This mode proved quite efficient on AO-10 and number of LEO satellite teams decided to employ this technology, such as the microsats and Fuji sats. Since they were in a LEO they could increase the baud rate, telemetry and data were sent at a 1200 bps rate. Yet again another modem was needed though. These satellites used standard AX.25 checksums and entire packets were trashed if one bit was incorrect.

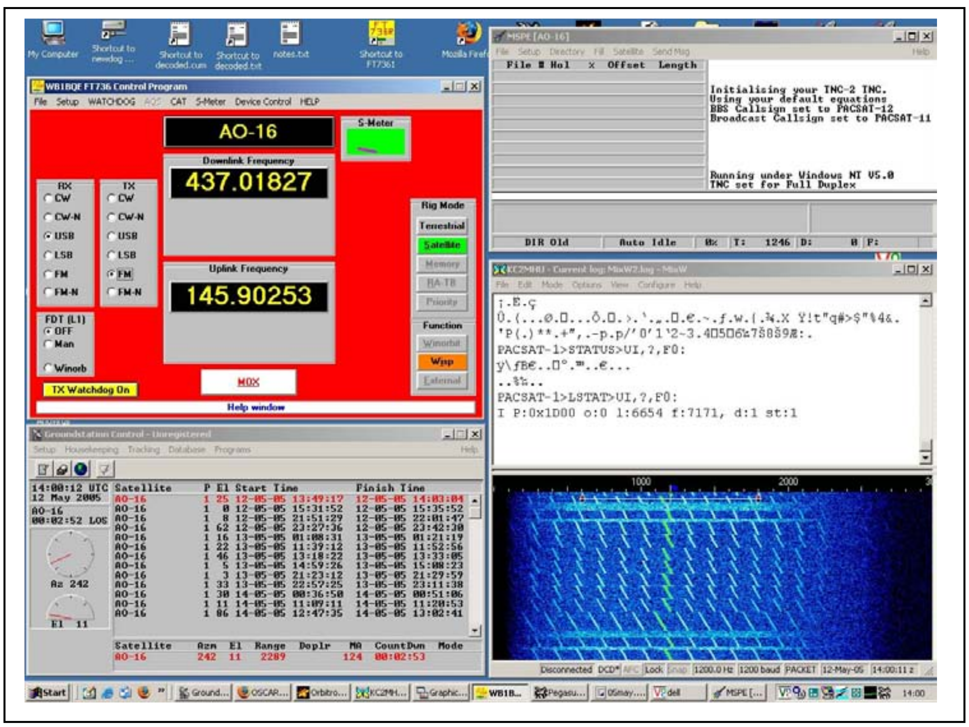
Figure 7. A host of satellite modems, lower right CCW - 1200 bps PSK modem addition to TNC 2, a 9600 bps FSK modified TNC 2 and DSP-12 modem.

DSP devices were coming of age and these seemed like the ideal solution to the problem of having to constantly get or build new modems. With DSP it is simply a matter of keeping the same hardware and having new software written. These boxes were somewhat expensive, but very versatile. With one box you had multiple modems and could add new modems by updating the software. In a poll taken in Jan 2005, about 1/3 of those that responded are using these DSP modems for there 9600 bps operation.

Figure 8. AEA DSP-2232 modem choices from the main menu screen

```
(920723)
.  1: RTTY/TOR 170: 2125/2295            2: RTTY/TOR 170: 1445/1275
.  3: RTTY/TOR 425: 2125/2550            4: RTTY/TOR 850: 2125/2975
. 10: p1 Packet 300 bps HF 2110/2310    11: p1 Packet 300 bps HF 1460/1260
. 12: p1 Packet 1200 bps VHF            13: p1 Packet 1200 bps PACSAT
. 14: p1 Packet 1200 bps PSK            15: p1 Packet 2400 bps V.26B
. 16: p1 Packet 4800 bps PACSAT         17: p1 Packet 4800 bps PSK
. 18: p1 Packet 9600 bps FSK K9NG/G3RUH 20: p2 Packet 300 bps HF 2110/2310
. 22: p2 Packet 1200 bps VHF            23: p2 Packet 1200 bps PACSAT
. 25: p2 Packet 2400 bps V.26B          28: p2 Packet 9600 bps FSK K9NG/G3RUH
. 30: RTTY/TOR 170: 2125/2295; p2 Packet 300 bps HF 2110/2310
. 31: RTTY/TOR 170: 2125/2295; p2 Packet 1200 bps VHF
. 33: p1 Packet 300 bps HF 2110/2310; p2 Packet 1200 bps VHF
. 35: p1 Packet 1200 bps VHF; p2 Packet 1200 bps VHF
. 40: Morse 750 Hz                      41: Analog FAX HF
. 42: Analog FAX APT                    43: Analog SSTV
. 44: DSP data 400 bps OSCAR 13         45: RTTY/TOR 1200 bps ASCII OSCAR 11
. 46: DSP data Spectrum                 50: p1 Packet 1200 bps MSK
. 51: p1 Packet 2400 bps MSK            52: p1 Packet 9600 bps G3RUH UO22 eq
. 60: p2 Packet 1200 bps MSK            61: p2 Packet 2400 bps MSK
```

Figure 9. Soundcard demodulator system for AO-16 by Bob, KC2MHU



HEO PSK Telemetry

The AMSAT Phase 3 satellites introduced PSK telemetry at a 400 bps rate. The benefit of PSK is that you can get about four times the amount of data recovery using PSK over an equivalent FSK signal. AO-10, AO-13 and AO-40 used this format. Since these are HEO (High Earth Orbit) satellites recovering data from a weak signal is important. These signals are weak for two reasons: 1) the increased distance causes path loss and 2) the increased squint angles (angle between the satellite antennas and the receiving station). Weak signal work is definitely the name of the game with HEO satellites.

You may wonder why was 400 bps was used; it is not a commonly recognized baud rate. At the time of its inception cassette recorders were the standard home computer data storage device. It was determined that 400 bps was the maximum rate that data could reliably be stored and retrieved from a cassette recorder and tape. In spacecraft design, once you have a proven system and the software works it is a prudent idea to stick with it. All three of these HEO satellites used the same IPS Operating system and much of the same system software; that is why 400 bps telemetry formats were used. Another important consideration is the in place ground station network. Changing to new hardware would drastically reduce the available network The Phase 3 satellites also sent the hexadecimal data in large 512 byte frames; so quite a bit of information about these large satellites was communicated. The entire frame used a proven CRC algorithm that could detect errors with a great deal of accuracy. On the other hand, one bad bit would negate the entire frame.

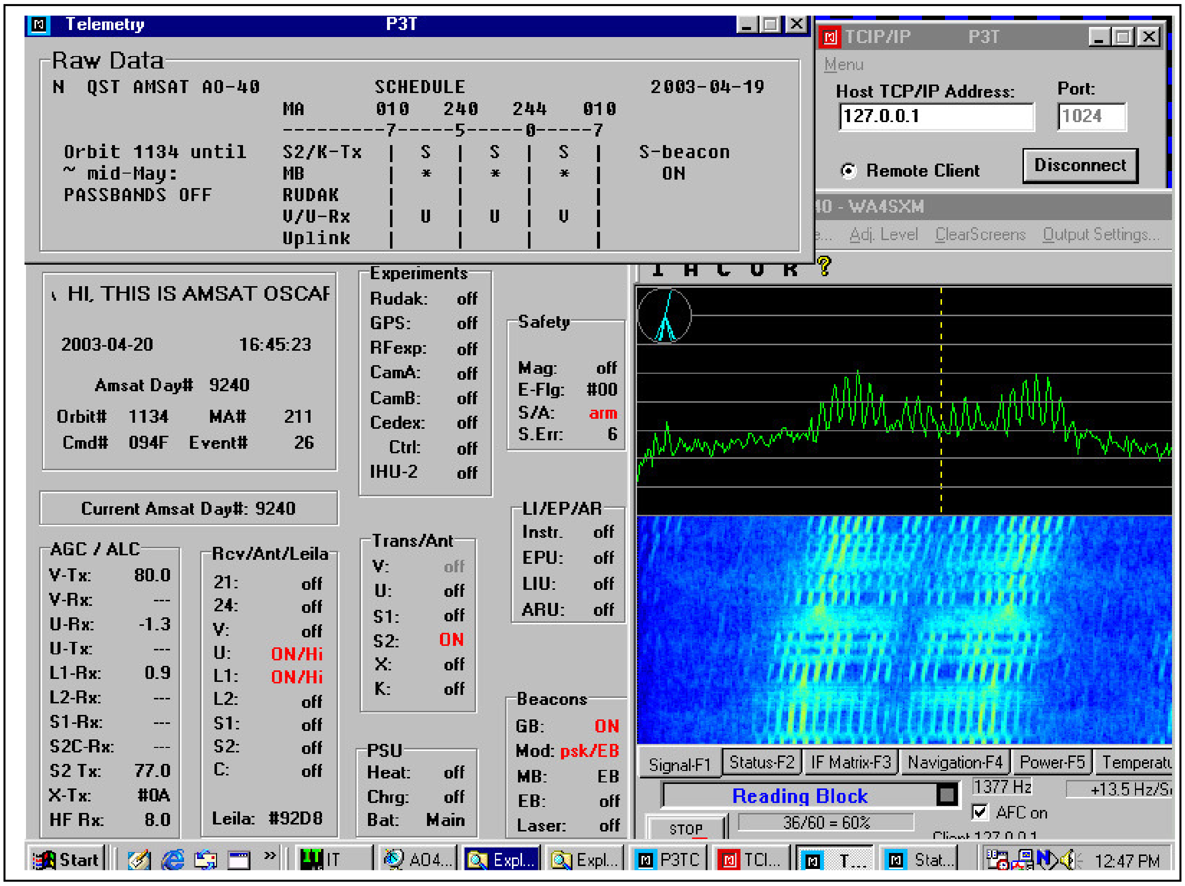
Figure 10. Yet another telemetry modem, 400 bps G3RUH modem for Phase 3 telemetry

AO-40 precipitated four gigantic leaps in amateur satellite telemetry reception.

1) Improved, inexpensive decoding using a standard computer soundcard
2) Internet feeds of real-time telemetry from around the world
3) Nearly constant, real-time satellite data capture and analysis
4) FEC techniques drastically improve the data reception efficiency

Looking at Figure 11 we see a number of these improvements in place. The soundcard demodulator for the 400 bps PSK data can be seen in the lower right. The IP connection in the top right is used to connect the data output from the soundcard demodulator AO40Rcv to the telemetry display program P3T. This screenshot is before the FEC was added and you can see the typical 60% efficiency at the bottom of the AO40Rcv portion of the screen. Another interesting feature of this screenshot is that you can see the effect of the sun's heat on the downconverter. The 32 second waterfall display shows a definite shift higher in frequency, while the Doppler is pulling it down in frequency. When small dark clouds would obscure the sun temporarily, the frequency would shift to the left (down).

Figure 11. Sample AO-40 telemetry capture screen using a soundcard mode



Soundcard Modems

As computer sound cards became standard equipment and DSP chips used to implement the sound functions, the world of amateur satellite telemetry now was readily available to all satellite operators. The sound cards would only need to use the 'dem'- demodulator part of a modem and would work almost universally. Moe Wheatley's AO40rcv demodulator program actually worked better than my dedicated 400 bps hardware modem and DSP boxes (DSP-12 & DSP-93).

IP feeds

One of the greatest features to be introduced into amateur satellite telemetry was the use of standard IP data packets. This opened the door to transferring real-time telemetry data around the world and to other programs on your computer. In Figure 11 the data demodulated by the AO40Rcv soundcard program is served to the P3T telemetry display program or other telemetry display program. When the satellite was out of range, you could connect to the Goddard server and get data streamed from other station in the footprint or connect to Goddard and actually serve the data to other parts of the world.

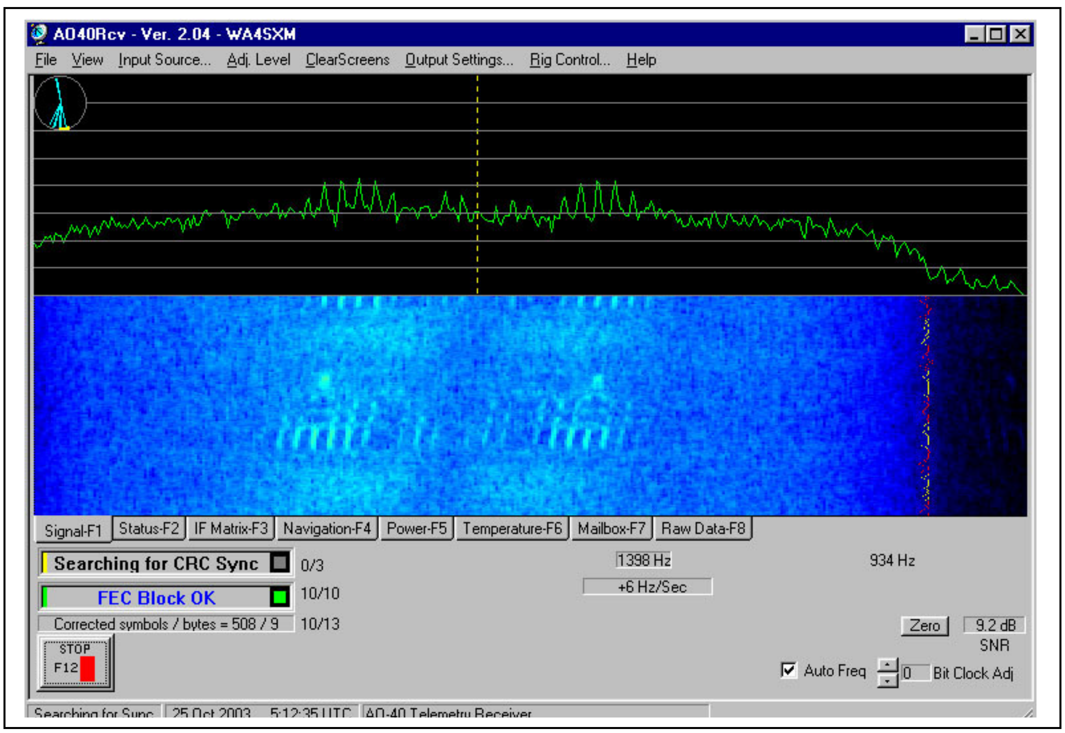
Decoding reliability

As you can see in Figure 11 (lower right), even with a good signal I am only decoding correctly about 60% of the received frames. On some of the AO-10 and AO-13 decoders the checksum wasn't used because the rate failure rate was so high. The old argument of some data versus no data comes into play. Published in an October 1996 AMSAT bulletin, Stacey Mills found that new software in the DSP-93 "gives acceptable download efficiency approximately 60-70% as good as the MK-II." With AO-40, the checksum was deemed more important. To be able to get a more complete picture from invalid data frames, Paul Willmott, VP9MU would manually vote on AO-40 channel data submitted by multiple sources to make the best guess at the actual data values for each channel. Certainly very time consuming, but the only way he had to get a good data pool.

FEC

Phil Karn, KA9Q proposed his FEC (Forward Error Correction) technique for AO-40 telemetry at the 2002 AMSAT Symposium in Fort Worth, TX. After some diligent lobbying and demonstrations of the advantage it provided the software was written and uploaded to AO-40 in 2003 for testing proof of concept. The results were impressive, Viktor, OE1VKW did an analysis and found he could get an efficiency of about 88% with the FEC blocks. Regular blocks received during the same period were only running 48% efficient.   Updates were quickly made to the AO40Rcv program and then entire world could participate in the experiment. Note the efficiency improvement in Figure 12.

Figure 12. AO-40 telemetry with FEC and AO40Rcv soundcard software demodulator



PSK telemetry Positives – Improved modulation scheme for weak signal reception, reuse demodulation equipment, included checksum for the frame, large number of channels, real-time display of current data, use soundcard modems

PSK telemetry Negatives – new equipment needed, great deal of lost data if bad checksum, lower data rates

9600/38,400 bps FSK Telemetry

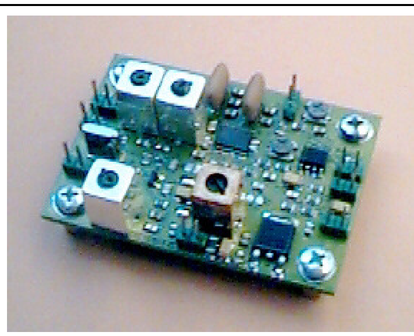
As satellite systems improved, the need to use faster data rates was recognized. This meant introducing new technology. UO-14/15 introduced 9600 bps FSK as part of the store and Forward BB. The telemetry data was sent as part of the broadcast data. This worked well for LEO satellites, but new equipment was needed to demodulate this data. AO-40 experimented with 9600 bps data and this proved quite challenging for ground stations to efficiently copy the data. In 1999 UO-36 introduced us to 38,400 bps FSK operation. This enabled us to download large picture files in nearly one pass. AO-51 has operational 9600 bps and 38k4 bps telemetry data and the capability for 78,600 and 153,600 bps operation. Currently the number of ground stations capable of these high data rates is quite small. The number of 2.4 GHz stations was also quite small, until AO-40 prompted many of us to venture up into the microwave world. Taking some liberties from the movie "Field of Dreams" - 'Transmit and they will come.'

Soundcard programs like MixW can demodulate the data, but present some interesting challenges in getting its serial output to display programs like WiSP and TlmECHO. The Kenwood radios TH-D7A and TM-D700A are very useful in that they have a built in TNC and can demodulate 1200 bps and 9600 bps data.

Figure 13. SYMEK 9600/38k4 modem

38k8 data is currently only used on the satellite downlink, the uplink is 9600 bps. In addition to a new modem for this data rate a change to the receiver is needed. Since the bandwidth needed to pass a 38k4 bps is much wider than a standard receiver can output, it is necessary to add an additional IF board with 110 kHz bandwidth. SYMEK makes a board for most of the major satellite radios. It connects right behind the 1st mixer and amplifies the signal as well as gives you the wider bandwidth.

Figure 14. SYMEK IFD (IF Amplifier/Demodulator) card

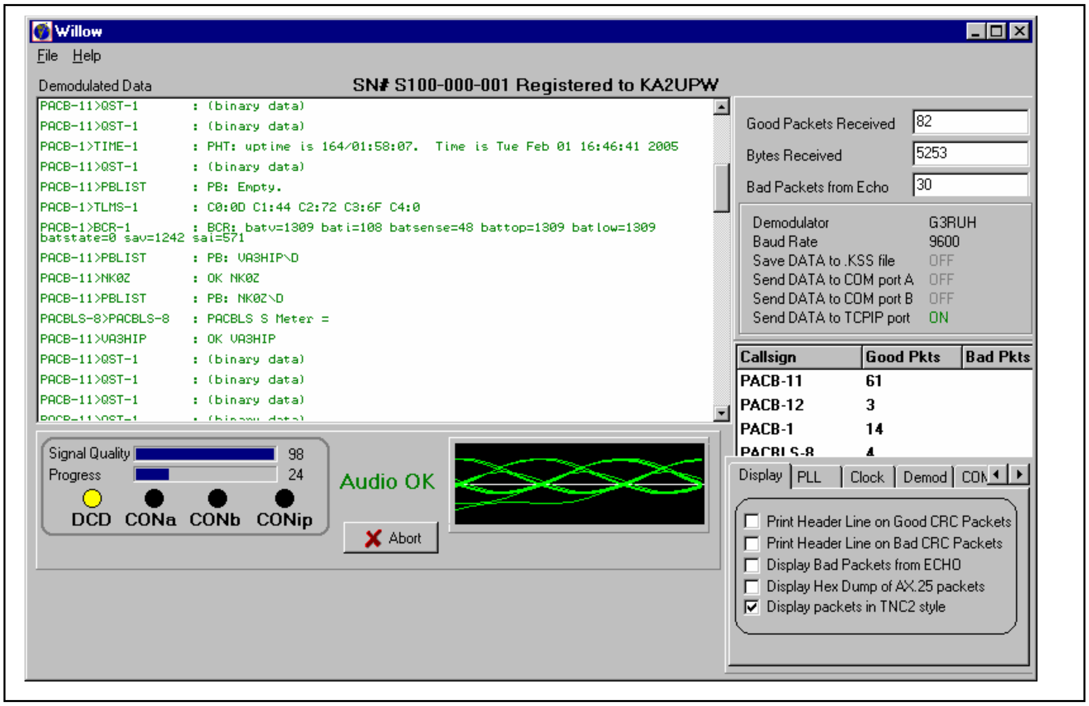


Many of these can be installed in the radios, but some need to be added externally. These will also serve for higher bit rate reception of 78,800 and 153,600 bps.

With most of the newer satellites incorporating these higher bit rates, this is the next step for digital satellite operators.

Since the soundcard demodulators have opened up the telemetry from most of the amateur satellites, it takes another volunteer to step up and provide this capability for the 9600 and 38k4 bps satellites. Douglas, KA2UPW has taken on this challenge and has working software for a 9600/38k4 bps soundcard demodulator as well as IP data transfer. The IP data can then be transferred to other programs or to other people via the internet.

Figure 15. KA2UPW preliminary 9600/38k4 soundcard demodulator and IP generator



PCSAT2

Bob Bruninga, WB4APR and his team at the Naval Academy have provided 1200 bps AFSK and 9600 bps FSK data from their suitcase package attached to the ISS. 1200 bps data received from PCSAT2 is sent through the standard APRS system. Real-time data from PCSAT2 is available on line at http://www.pcsat2.info/PCSat2Web/RealTime.jsp .

SSETI Express

The SSETI Express team is generating interest in the telemetry from SSETI Express by sponsoring a contest for who can send in the most telemetry. Realtime telemetry can be viewed on line from the SSETI Express site, you can get there from http://www.seti.net . Data will be sent from the satellite at 9600 bps and 38k4 bps. Howard, G6LVB has written an interesting article about using DTMF tones on the 2.4 GHz downlink on SSETI Express that can be found on his web site at: http://www.g6lvb.com/Articles/SSETI%20Express%20DTMF%20Telemety/

The Future

AMSAT-DL has signed an agreement for the non-commercial use of France Telecom's Turbo-Codes. Their use on the P3E flight will facilitate and test their operation for use on the AMSAT-DL P5A Mars mission.

Turbo codes are a class of powerful error correction codes. They were first introduced in 1993 by two French engineers along with practical decoding algorithms. The important thing about turbo codes is that they allow reliable communications with power efficiencies close to Shannon's theoretical limit. They have been used successfully for deep space communications as well as cellular telephones. This is a rearware looking technology, as opposed to FEC forward error correcting technology.

Summary

- Sound card demodulators have made telemetry demodulating affordable
- IP has provided a common interface between the demodulators and the display programs
- IP packets provide a world wide method of telemetry data sharing
- FEC techniques have greatly improved telemetry reception efficiency
- Telemetry offers a excellent means to optimize your station
- Telemetry offers an interesting challenge
- Telemetry offer you the opportunity to contribute to the amateur satellite program.

OSCAR Satellite Telemetry Formats

OSCAR-1	1961	CW (1 channel)
OSCAR-2	1962	CW (1 channel)
OSCAR-3	1965	CW intro with pulse train (2 channels)
OSCAR-4	1965	N/A
OSCAR-5	1970	CW intro with tone/channel (7 channels)
OSCAR-6	1972	CW (24 channels)
OSCAR-7	1974	RTTY (24 channels)
OSCAR-8	1978	CW (6 channels)
RS-1	1978	CW
RS-2	1978	CW
UO-9	1981	1200, 600, 300, 110, 75 bps, RTTY, CW, Digitized voice (First use of microprocessor) (70 channels)
RS-3/8	1981	CW
AO-10	1983	400 bps BPSK (first use), RTTY, CW (128 channels)
UO-11	1984	1200/4800 bps AFSK ASCII & Binary, Digitized speech (70 channels)
FO-12	1986	1200 bps PSK AX.25 (first use), CW (40 channels)
RS-10/11	1987	CW (16 channels)
AO-13	1988	400 bps PSK ASCII, RTTY, CW (128 channels)
UO-14	1990	9600 bps FSK ASCII (first use) (~148 channels)
UO-15	1990	9600 bps FSK ASCII
AO-16	1990	1200 bps PSK AX.25 (59channels)
DO-17	1990	1200 bps AFSK, Digitized speech (59channels)
WO-18	1990	1200 bps PSK AX.25 (59channels)
LO-19	1990	CW; 1200 bps PSK AX.25 (59channels)
FO-20	1990	1200 bps PSK ASCII, CW (40 channels, 20 channels)
RS-12/13	1991	CW (16 channels)
AO-21/RS-14	1991	1100/1200 bps BPSK AX.25, 400 bps PSK, CW (30 channels)
UO-22	1991	9600 FSK AX.25
KO-23	1992	9600 FSK AX.25
KO-25	1993	9600 FSK AX.25
IO-26	1993	1200 bps
AO-27	1993	1200 bps AFSK ASCII
PO-28	1993	9600/38k4 bps FSK

FO-29	1996	CW; 1200 bps PSK
GO-32	1998	9600 bps FSK AX.25
SO-33	1998	9600 bps FSK
UO-36	1999	9600/38k4 bps FSK(first 38k4 transmissions)
AO-40	2000	400 bps PSK, 9600 FSK; 400 bps PSK with FEC
NO-44	2001	1200 bps AFSK; 9600 bps FSK
MO-46	2000	9600/38k4 bps FSK
RS-20	2002	CW
AO-49	2002	9600 bps FSK
AO-51	2004	9600/38k4 bps FSK AX.25 (161 channels)
VO-52	2005	CW
PCSAT-2	2005	1200/9600 bps FSK
		==================================
SSETI Express	2005	9600/38,400 bps FSK
P3E	2006?	400 bps PSK with Turbo codes

References

AMSAT Newsletter, AO-7 Edition, December 1974
AO-13 Telemetry Needed, $ANS-300.02
AO-40 Experimental Downlink Coding (FEC), http://www.amsat.org/amsat/sats/ao40/fec.html
Bruninga, Bob, WB4APR, http://wweb.usna.navy.mil/~bruninga/pcsat2.html
Davidoff, Martin, K2UBC, "The Radio Amateur's Satellite Handbook", ARRL, 1998
Gape, R.A., "The AMSAT – UK OSCAR 10 Handbook", AMSAT-UK 1985
Gulzow, Peter, DB2OS, "IHU-3 Meeting", AMSAT-DL Journal, June/August 2005
Gulzow, Peter, DB2OS, "P3E-Status", AMSAT-DL Journal, March/May 2004
Guizzo, Erico, "Closing in on the perfect code", IEEE Spectrum Online, http://www.spectrum.ieee.org/WEBONLY/publicfeature/mar04/0304code.html
Jansson, Dick, WD4FAB, "Spacecraft Technology Trends in the Amateur Satellite Service", AMSAT-NA Technical Journal, 1988
Karn, Phil, KA9Q, "Proposed Coded AO-40 Telemetry Format v1.2", http://www.ka9q.net/papers/ao40tlm.html
Krome, Ed, KA9LNV, "Modifications to the G3RUH 400 Baud Telemetry Demodulator"; The AMSAT Journal, July 1990
Kudielka, Viktor, OE1VKW, Mixed Uncoded and FEC Telemetry Reception, http://cacofonix.nt.tuwien.ac.at/~oe1ukw/
Limebear, R.W.L., G3RWL, "AMSAT-UK OSCAR 13 Operations and Technical Handbook", AMSAT-UK 1989
Miller, James, G3RUH, "OSCAR-10 P.S.K. Data Demodulator"; Electronics & Wireless World, October 1984
Quagliana, Douglas, KA2UPW; "A Simple BPSK Software Modem", Proceedings of the AMSAT-NA Space Symposium, Toronto 1997
Smith, Gould, WA4SXM; "Decoding Telemetry from the Amateur Satellites", AMSAT-NA and AMSAT-UK, 1991
Smith, Gould, WA4SXM; "The Evolution of Amateur Satellite Telemetry", Proceedings of the AMSAT Mid-West Mid-South Regional Conference, Purdue University, June, 1992
Smith, Gould, WA4SXM; "AO-40 Telemetry from Generation to Interpretation", Proceedings of the AMSAT-NA Annual Meeting, Oct 2001, Decatur, GA
Sperber, Frank, DL6DBN/AA9KJ, "P3E Transponder Meeting", AMSAT-DL Journal, June/August 2005
Turbo Codes, http://www.csee.wvu.edu/~mvalenti/turbo.html
Wallis, Clive, G3CWV; http://www.users.zetnet.co.uk/clivew/
Wheatly, Moe, AE4JY, "AO-40 Telemetry Decoder Project", http://www.qsl.net/ae4jy/ao40rcv.htm

A First Look at a New Soundcard DSP Modem for Satellite Telemetry

Douglas D. Quagliana, KA2UPW
dquagliana@aol.com

Abstract

This new soundcard DSP modem will be used for demodulating satellite signals at 9600 and 38,400 baud along with a simple program for displaying satellite telemetry from AO-51.

Introduction

Over the last several years, there has been an increase in the computing resources available to amateur radio operators and a corresponding rise in the activity and interest in various radio communications modes that use only digital signal processing algorithms and a common PC soundcard.

There are now several software applications that offer a virtual Swiss army knife of popular soundcard modes and modems which allow the amateur radio operator to communicate using a plethora of digital modes. Some programs will even set the frequency on the radio, automatically logs contacts, and will also function as a TCPIP network interface over packet radio.[1] [2] Software modems for 38,400 baud seem to be rare[3], but demodulating the 38,400 baud signal is just barely possible using only a soundcard set to sample at the highest speed of 48,000 samples per second. Using only a regular PC soundcard and software, this modem will demodulate AX.25 packets sent at either 9600 or 38,400 baud.

Divide and Conquer

The modem, as originally designed, will take a recording of the audio from a satellite pass and process the recording rather than demodulate the signal in real time. This method of dividing the recording and analysis has several advantages. If your radio lacks the special extra-wide filter required for 38,400 signals, then someone else who has such a radio and filter can record the audio for you! This method might also be of interest to amateurs who have an interested in telemetry and have some form of antenna restrictions. The satellite antennas can be set up from a portable or mobile station, and the satellite pass can be recorded using a modest laptop. Later, the recording can be analyzed on the same laptop or on another computer. Finally, most telemetry analysis does not need to be performed in real-time, which permits the analyst to review the telemetry data shortly after the satellite pass is over.

KISS

The first recordings I made were from the satellite AO-51 (Echo). In a first desperate effort to get at least one packet, I constructed an absolutely minimalist telemetry station. The antenna was a quarter wavelength[4] of copper wire pushed directly into the N connector[5] on a DEMI 435-preamp. The preamp feeds an old Pro-38 handheld scanner through a short length of coax, and the audio is taken from the discriminator and fed to the soundcard through a couple inches of RG-174 coax cable. If one judiciously selects an optimal satellite pass, drives to an RF quiet area, sets the preamp carefully on the roof of the car so that it acts as a ground plane, and powers everything from batteries to eliminate AC hum, then the operator should get perhaps a minute or three of good signals as the satellite transmissions slowly doppler through the bandpass of the receiver. You should get at least a few packets. On one attempt, I managed to receive dozens of good packets.

For the typical telemetry reception station that wants to receive 9600 baud signals, the output from the radio discriminator is fed to the soundcard line-in or the microphone in connector. It is not possible to take the audio from the radio speaker output because of the bandwidth required for a 9600 baud signal. Moreover, while a 9600 baud signal can pass through regular FM radio filters, a 38,400 baud signal requires an even wider filter in the radio. In either case, the audio must come from the discriminator, not the speaker output. The soundcard is instructed to sample the incoming audio at 48,000 samples per second. This sampling rate is supported by most, but not all, soundcards. For 9600 baud, this rate results in exactly five samples per bit, which simplifies some of the work for the modem.

Engage the Nyquist Compensators

Several people questioned how it is possible to receive data at 38,400 bits per second when the soundcard is only taking 48,000 samples per second. Doesn't this violate Nyquist or some other laws of physics? Don't you have to sample at a rate that is twice as fast as the thing you want to measure?

Actually, it doesn't violate Nyquist. The bits are being sent at 38,400 baud, or 38,400 bits per second. This is not the same as a 38,400 Hertz tone, which would require a sampling rate of at least 76,800 samples per second. The bits are sent as raised cosine pulses not as a complete sine wave for each bit.

Neat Features

The modem incorporates a novel DCD circuit, which looks at the characters being received and which calculates a numeric value based on the number of HDLC flags received and the number of non-flag characters received in packets with a valid CRC. The DCD is displayed both as a sliding progress bar and a DCD light. Since the DCD algorithm checks for flag characters, it will illuminate even if no packets are being received. Thus, if the satellite is transmitting a constant stream of HDLC flags but no data packets, then the DCD will still be lit.

The modem also displays counters showing the number of good AX.25 packets received, the number of bytes received in those good packets, and the number of packets received with valid CRCs. Using these counters and the DCD, one can easily determine if a signal is really being received and whether not or any packets are being lost.

In order to be used with existing telemetry programs, the modem has options to send the received data out to other programs on up to two serial ports simultaneously. In addition, the modem can send the received data out via TCP/IP. This is only useful if the telemetry analysis program can receive the data over TCP/IP, but it allows the telemetry analysis program to be running on a different computer potentially anywhere on the Internet. (Does anyone want to write a generic satellite telemetry server that could receive and retransmit telemetry for multiple amateur satellites?) The modem can also save received packets (with valid CRCs) in KISS format to a .KSS file.

An eye-diagram is available to display the current input signal, as well as an indicator of whether the audio is too loud or too quiet. The user can use the Windows volume control to adjust the levels.[6]

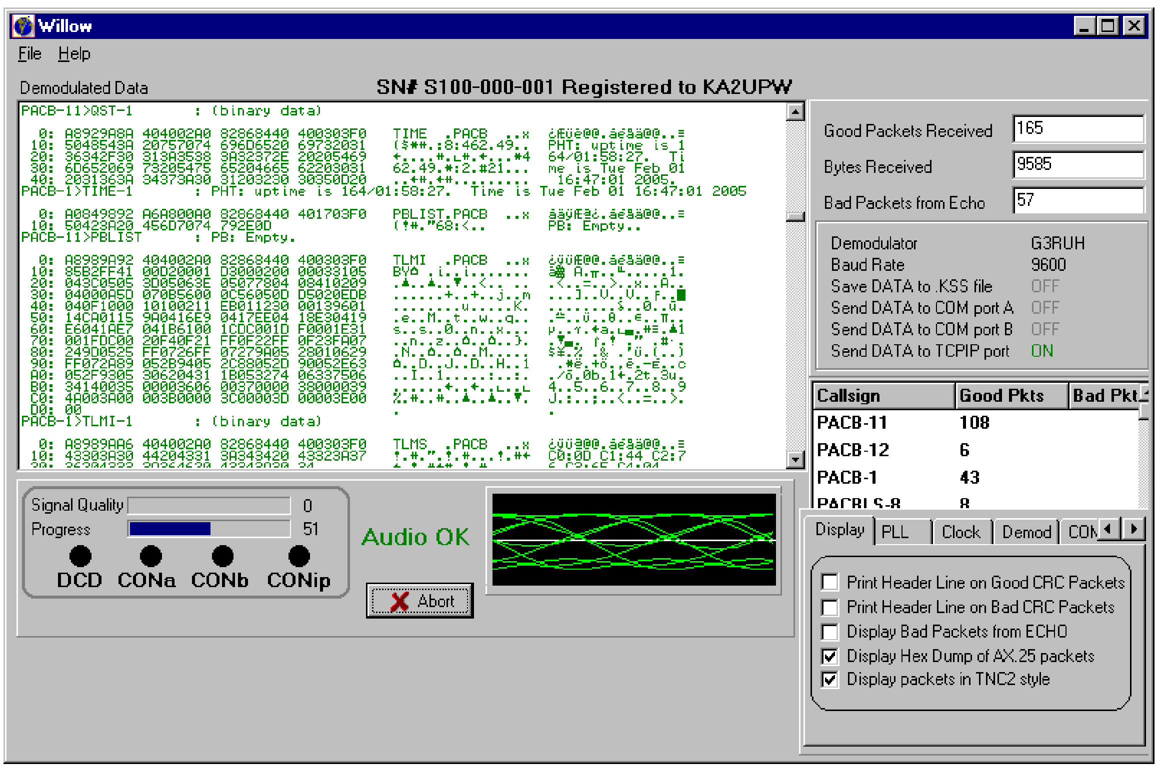


Photo 1: Screenshot from the soundcard modem.

The received packets can be displayed in any of several user-selectable formats including TNC2 style and/or with a hexadecimal dump of the packet. Packets with a good CRC will be displayed in green, and packets with a bad CRC will be displayed in red or not at all, if desired.

For demodulating, the modem incorporates a numeric oscillator, an interpolator for 38400 baud, a pair of moving-average peak detectors[7], and a fractionally spaced equalizer with decision feedback. An analysis on a recording from the satellite KO-23 shows that this combination works well. Testing on PSCAT2 and AO-51 signals also gave good results.

The demodulated raw bits are NRZI decoded and unscrambled[8], framed up into AX.25 packets and checked for valid CRCs. Good packets can be sent to the display, sent out two serial ports, and sent out over TCP/IP.

One interesting use of the TCP/IP connection is to send the AX.25 packets to a telemetry program running on the same PC. While the data could also be sent with a software based null modem cable, the author has had difficulties with the software null modem cables. The TCP/IP networking code incorporated into the operating system seems to be much more robust than the software null modem cable. As a proof-of-concept for the TCP/IP approach, I wrote a simple program called Sabins[9] to display Echo telemetry received over TCP/IP from the soundcard modem. The soundcard modem can easily send the same data at the same time to both Sabins and tlmEcho. Sabins receives TCP/IP data, and tlmEcho receives serial port data over a hardware null modem cable between two serial ports.


Telemetry As Text

0	TX A Power	0.34	Watts	22	-X V	15.53	V	44	Temp +X	8.22	Deg C
1	TX B Power	0.47	Watts	23	+Y V	15.09	V	45	Temp -X	6.92	Deg C
2	Torqr Cap V	998.48	V	24	-Y V	15.55	V	46	Bat 1 Temp	9.11	Deg C
3	Bat V	8.29	V	25	+Z V	15.37	V	47	Bat 2 Temp	7.37	Deg C
4	Cell 5 V	6.95	V	26	-Z V	15.46	V	48	Main Reg Temp	22.46	Deg C
5	Cell 4 V	5.51	V	27	Low V I	98.00	Counts	49	TX V Reg Temp	13.63	Deg C
6	Cell 3 V	4.12	V	28	Bat I	654.36	mA	50	+4V #1 V	4.03	V
7	Cell 2 V	2.76	V	29	Tx I	0.87	Amps	51	+4V #2 V	4.03	V
8	Cell 1 V	1.39	V	30	Bat sign	48.00	Counts	52	PHT time	20.00	Secs
9	4.6V Exp I	-4.72	mA	31	SQRX RSSI	236.00	Counts	53	Digipeat	0.00	On/Off
10	4.6V Exp V	4.60	V	32	SQRX Spkr	8.00	Counts	54	Txt bcd ratio	6.00	Ratio
11	3.3V I	74.47	mA	33	Torqr 1.2V ref	10.06	V	55	Bat Mgmt	0.00	State
12	3.3V V	3.33	V	34	Torqr Sense	0.00	Counts	56	WOD State	0.00	State
13	Total Array I	1075.90	mA	35	Not Used	2041.00	Counts	57	EDAC Errors	94.00	Counts
14	Total Array V	15.15	V	36	S Osc Temp	6.82	Deg C	58	Reserved	0.00	Counts
15	+X I	9.50	mA	37	TX B Temp	-46.03	Deg C	59	Reserved	0.00	Counts
16	-X I	235.38	mA	38	Not Used	2047.00	Counts	60	Reserved	0.00	Counts
17	+Y I	5.66	mA	39	S PA Temp	7.17	Deg C	61	Reserved	0.00	Counts
18	-Y I	398.71	mA	40	Temp +Z	9.11	Deg C	62	Reserved	0.00	Counts
19	+Z I	371.03	mA	41	Not Used	2047.00	Counts	128	Bat I	---	mA
20	-Z I	209.48	mA	42	Temp +Y	8.62	Deg C	129	Bat I	---	mA
21	+X V	15.38	V	43	Temp -Y	6.57	Deg C				

Photo 2: Telemetry As Text page from the Sabins AO-51 telemetry program.

When things go wrong, as they sometimes will...

Several things can go wrong with a soundcard modem. The signal input levels are critical at high baud rates, and it can take several attempts to get the levels just right. The soundcard might not be able to sample at 48,000 samples per second, or worse, it might claim to be sampling at 48,000 samples per second but actually sample at a slightly different rate. This will confuse the clock within the modem that times the lengths of the bits which can cause the modem to lose packets. In addition, not all soundcards are created equally. Some might have built in filters that distort data, and others may have poor frequency response. It is important to keep in mind that soundcards were meant for gaming sound effects and music, not for receiving data from satellites.

Thanks

My thanks to Mark Hammond, N8MH, Gould Smith, WA4SXM, and several other amateurs who sent me 9600 baud and 38,400 baud recordings from various amateurs satellites so that I could test them against this modem. Without them, this project would not have been as successful. In particular, I am in debt to Howard Long, G6LVB, who sent me my first 9600 recordings which got this project started (one recording of known content, several APRS packets, and one recording from a satellite pass of KO-23). I was eventually able to extract over three hundred and thirty packets from that one KO-23 recording.

That's all folks! And of course, thanks to my wife who assisted in the preparation of this work. I am continuing to develop and improve the modem. Suggestions and criticism are welcome. I hope this soundcard modem will encourage others and generate further interest in digital signal processing as well as telemetry collection using simple ground stations.

See you on the birds.

---

[1] MixW - "Multimode operating software for HAMs" from the Ukraine available at http://www.mixw.net/index.htm.

[2] AGWPE - AGW packet engine by SV2AGW (George Rossopoulos) available at http://www.raag.org/sv2agw/inst.htm.

[3] Another DSP modem that demodulates 38,400 baud G3RUH signals is available for the DSP56002EVM. "EL MÓDEM G3RUH A 38K4" available at http://bips.bi.ehu.es/prj/modem/tossa/index.html.

[4] Bob Bruninga, WB4APR, has an interesting graphical plot for vertical antennas. See "Elevation Plot of Vertical Whips at 435 MHz" at http://web.usna.navy.mil/~bruninga/astars.html.

[5] The "wire in the N connector" idea was inspired by the article "Constructing a Cardboard-box Antenna for Receiving AO-40 on S-band" by Anthony Monteiro, AA2TX. http://www.barc.org/ao40_antennas/rxantenna.html

[6] Hint: click once on the control to be adjusted, then use the arrow keys to adjust the levels up or down. This offers finer control than repeated mouse clicks.

[7] For a hardware version of the peak detectors, see the 9600 modem by John Magliacane, KD2BD at http://www.amsat.org/amsat/articles/kd2bd/9k6modem/9k6modem.html

[8] For a complete description of the G3RUH modulation format see "The Shape of Bits to Come" by James Miller, G3RUH, available at http://www.amsat.org/amsat-new/archive/articles/James_Miller/txt/108.txt.

[9] The Sabin in a unit of measurement for how well a substance absorbs sounds and echoes. Sabins is the name of the program that displays the telemetry measurements from the Echo (AO-51) satellite.

Calibrating Azimuth Mounts Using Solar Shadows

or

"Give me an antenna and a star to steer her by…"

by

John M. Franke
WA4WDL

Abstract

Whether operating as a microwave rover or repositioning a home antenna mount, it is important to know what direction your antenna is pointed. Elevation calibration is easily done with a level, but determining a true azimuth is not as easy. A number of amateur radio operators use the Sun to calibrate their azimuth-elevation (az.-el.) antenna mounts. Solar tracking requires a sensitive receiving system and a solar tracking program. Use of the local noon position of the Sun is popular, but can only be done during a narrow window in time. A simple technique using Sun shadows that is equally applicable for az.-el. mounts or simple azimuth only mounts any time the Sun is visible is described. The technique was originally used to measure the orientation of my apartment patio and for aiming a 0.6m diameter dish antenna at a geosynchronous satellite. The source of Sun shadow information is the USNO astrometric web site which can provide information for any lat./long. for any day, past or future, in time increments of the user's choosing. Once a known direction has been established, a simple disposable PowerPoint setting circle is used for determining other bearing directions.

Introduction

Like many amateur Radio operators, I live in an apartment and under rather strict rules as to what can and cannot be placed on the balcony. Hence, my antenna mounts must be portable. Each time I reposition the antenna mounts, I know my calibration changes. I would also like to take the antenna mounts on local expeditions and will need to be able to re-calibrate the azimuth indicator. The elevation is handled with a simple inclinometer protractor. The main problem is calibrating or re-orienting the azimuth indicator.

Past Methods

One method is to use a magnetic compass. However, compasses are affected by local concentrations of ferrous metals, speaker magnets, and drive motors. They are also affected by the local magnetic variation or declination, which itself slowly shifts each year. I have tried orienting pairs of cameras on buildings within a mile of each and seen errors as high as twenty degrees, which exceeded the camera fields of view.

Another method is to use local landmarks and determine the azimuth bearing with topographic maps. However, unless you have an optical sight aligned with the antenna or there is an RF source at the distant landmark, you cannot be certain the antenna is actually pointed at the landmark. And, of course, there must be an easily recognizable landmark available.

GPS could be used by marking your antenna position and then moving away and performing a bearing measurement. But, this method also requires an optical sight already aligned to the antenna or a RF source at the remote position. This method is like having a transportable landmark. The site might not be amenable to your moving around.

Many amateurs are familiar with using the shadow of the Sun at local solar noon when, for amateurs in the northern temperate zone, the Sun is direct south of your position. But, you must either wait for local solar noon or if the Sun is blocked or you arrive late you must wait another day, which is impractical.

Tracking the Sun by solar noise could be used in conjunction with a very sensitive receiving system and a good tracking program, complex mathematics or tables, until now!

One last method is the subject of this paper. If you knew the azimuth of the Sun, at your position, for times other than local solar noon, you could use the shadow of the antenna to calibrate the azimuth mount anytime the Sun is shinning. The key is knowing the azimuth of the Sun for reasonable increments of time at the antenna location. This can be done very easily.

Background

I wanted to know the orientation of my patio windows for aiming astronomical cameras and some small dish antennas. So I decided to try making an astronomical observation. The project was doable, but the math was too complicated for routine use. So, I went to the web and found a resource! Then, I decided to use the technique to aim an antenna.

The First Experiment

I decided to use the morning Sun and the shadow of the right-hand edge of my patio door frame to determine the orientation of my patio doors. The distance from the patio door to adjacent wall is 46 inches, see Figure 1. The throw distance or distance from patio door to the measurement area is 179 inches. One inch traverse of the shadow is approximately 0.32 degrees. For timing and determining the position of the patio door, I used a Garmin GPS76 receiver. The experimental setup is depicted in Figure 2. I wanted to know when the shadow of the right hand edge of the patio door was 46 inches from the wall. But, I decided to record the time the shadow moved from 43 to 49 inches from the wall in half inch increments. The times are presented in Figure 3. First, the time between marks was about one minute. Hence the timing is not critical. Also note there were no readings for 47.5 to 48.5 inches because of a tree branch that blocked the view. The Time (Fraction) is calculated by subtracting the actual time from 13:00 GMT and converting to decimal minutes. This was only done to aid in plotting the data and is not normally done. Figure 4 is a plot of the data. I was immediately impressed with how closely the data fit a straight line.

From the figure, it can be seen that the shadow was 46 inches from the wall at 13:04.75 GMT. Okay, big deal. How do you convert this time measurement to azimuth bearing? Now is when the Internet comes in play.

If you go to: **http://aa.usno.navy.mil/** , you will find the site shown in Figure 5. This site has a wealth of astronomical data. Scrolling down you see "Data Services" as shown in Figure 6. Clicking on "Data Services" takes you to Figure 7 where you can find reference to the position of the Sun and Moon. Clicking on "Altitude and Azimuth of the Sun or Moon During One Day" takes you to a web page with two forms, A & B. Form A is used for major U.S. cities and towns, and Form B, see Figure 8, is a more general form. Use Form B. Merely fill out the form for the place and date you are interest in generating a table. The location name is just a label. The Tabular Interval is the spacing in minutes between readings. One to ten minutes should be sufficient. Once populated, click on "Compute Table." Figure 9 is a portion of the printout for the experiment. From the chart it is easy to see that the orientation of my patio door is 113.5 degrees.

General Usage

This first case was when I wanted to know the azimuth alignment of a specific direction. For field antenna alignment, I merely point the antenna at the Sun, record the time, look up the azimuth from a chart made for that day and location, and I then know the azimuth heading of the antenna mount. Hence the measurement can be made whenever you can get a shadow. As can be seen in Figure 10, I have placed several pieces of vinyl tape on the dish to know when shadow of the feed is centered on the dish surface and the antenna is pointed at the Sun. Tom Clark, W3IWI, has suggested placing pieces of reflective tape randomly on the dish surface. When the antenna is pointed directly at the Sun, the reflected spots of sunlight will converge on the center of the feed, which in this case is a patch antenna.

I have made a PowerPoint drawing of an azimuth scale. The scale is printed on sticky back paper and applied to the fixed or non-moving portion of the antenna mount. A small pointer is printed at the same time. Once the antenna orientation is known, the pointer is applied to the moving portion of the mount opposite the determined azimuth reading as shown in Figure 11. In this case, the determined azimuth was 141 degrees. The complete mount is shown in Figure 12. The antenna is in my living room. This image of a 0.6m diameter dish in my living room proves I am either divorced or soon to be divorced.

Conclusion

A microwave antenna can be easily aligned anytime you know the location of the mount and have access to the Sun by simply aiming the antenna at the Sun and using a very friendly web site to deduce the azimuth heading of the antenna. The charts from the web site can be printed weeks or months in advance. Hence web access is not needed at the antenna position.

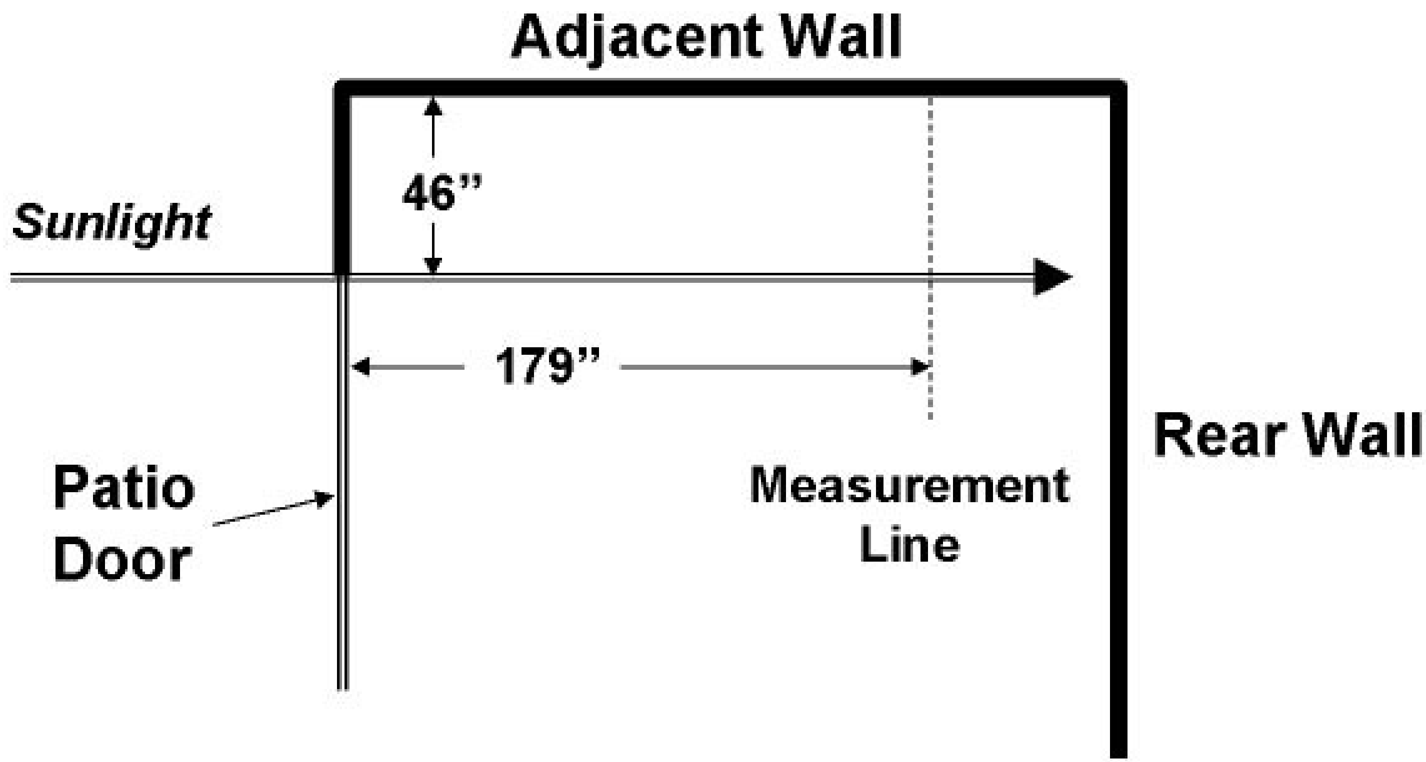


Figure 1: Layout of First Experiment

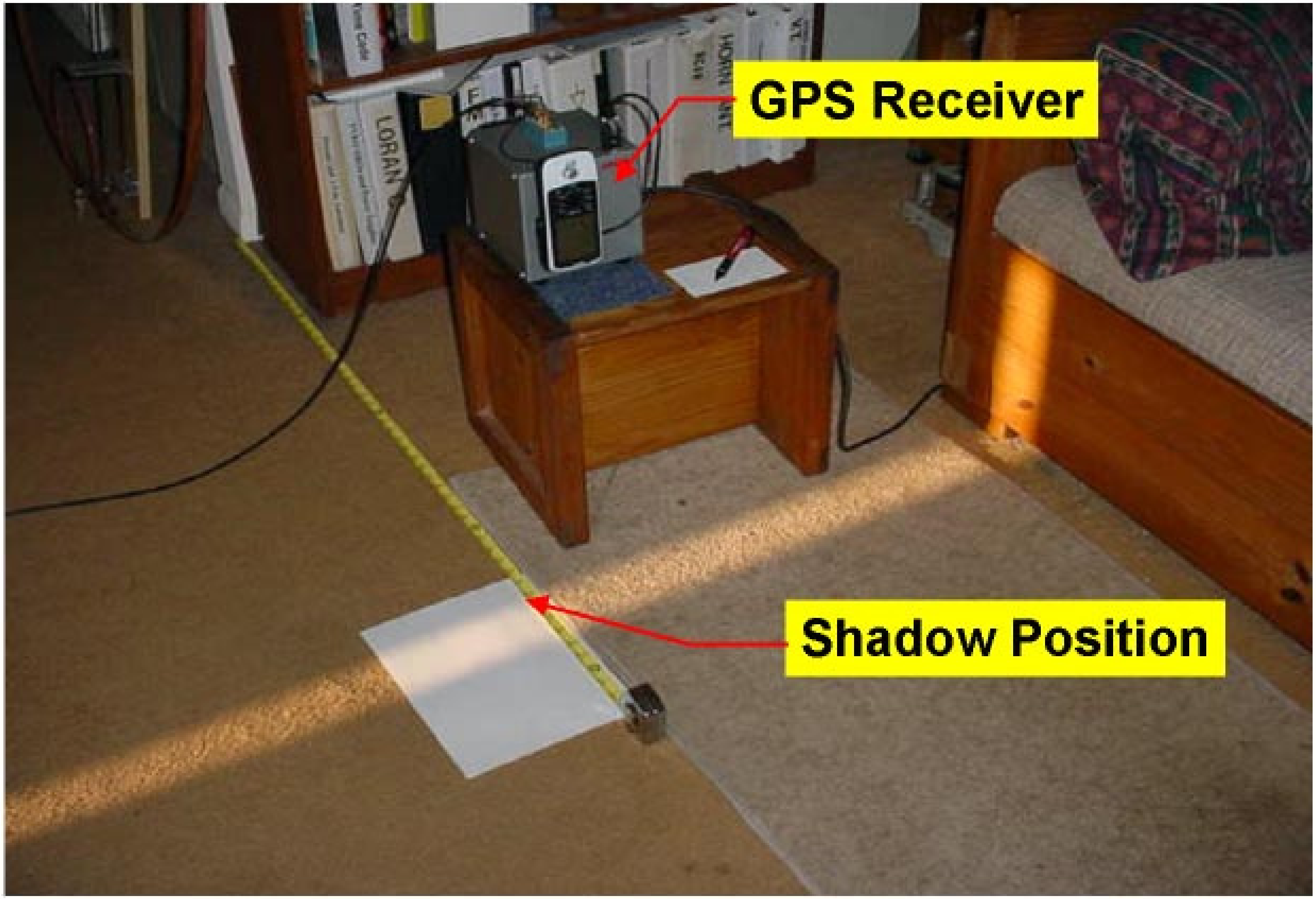


Figure 2: Experimental Set-Up

Position (inches)	Time (GMT)	Time (Fraction)
43	12:59:10	-0.833
43.5	13:00:10	0.167
44	13:00:50	0.833
44.5	13:01:56	1.933
45	13:02:52	2.866
45.5	13:03:53	3.883
46	13:04:46	4.767
46.5	13:05:32	5.533
47	13:06:27	6.450
47.5	Blocked	
48	Blocked	
48.5	Blocked	
49	13:10:04	10.067

Figure 3: Experimental Data

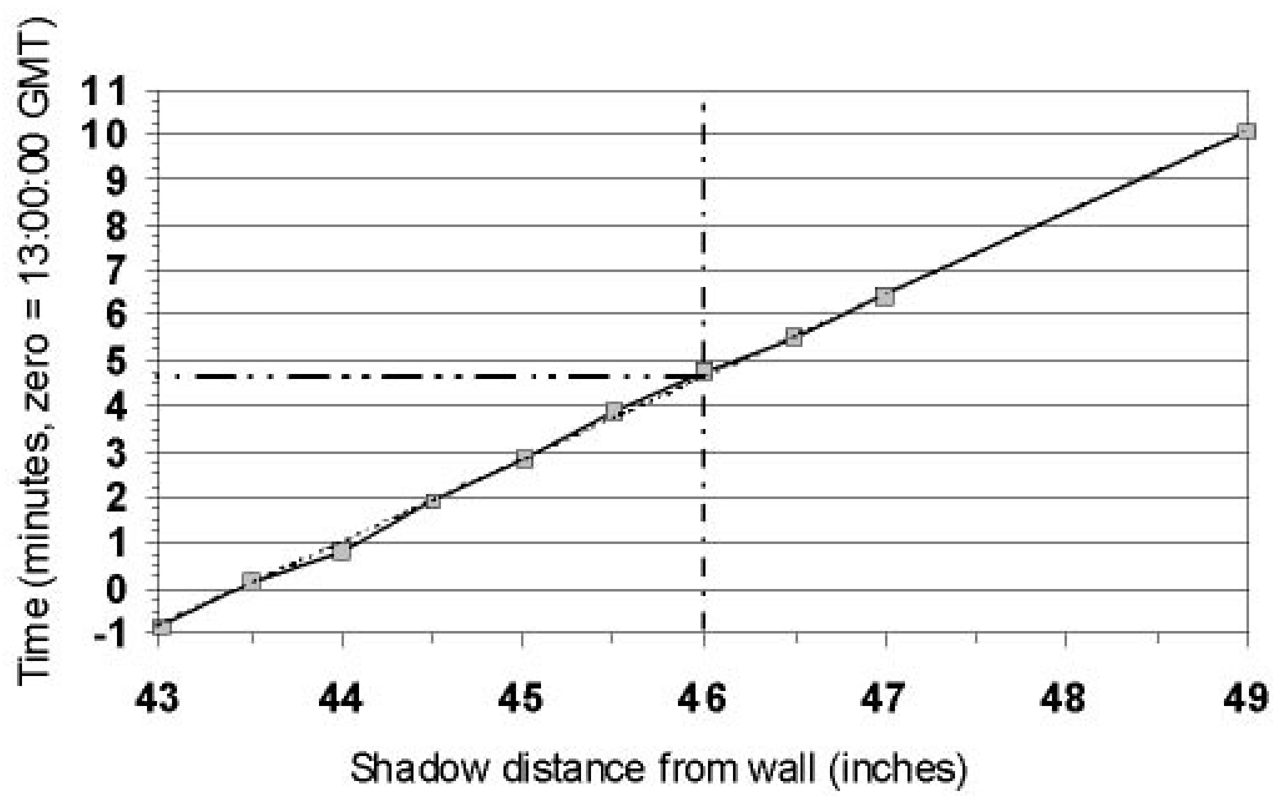


Figure 4: Plot of Experimental Data

Date: February 26, 2005

http://aa.usno.navy.mil/

Welcome to the web pages of the Astronomical Applications Department of the U.S. Naval Observatory. Our products - almanacs, software, and web services - provide precise astronomical data for practical applications, serving the defense, scientific, commercial, and civilian communities.

Figure 5

This is an official U.S. Navy Web site

U.S. Naval Observatory

Astronomical Applications Department

Data Services

Positions of the Sun and Moon

- Altitude and Azimuth of the Sun or Moon During One Day
- Position of the Sun at Noon for Washington, D.C.
- Day and Night Across the Earth

This is an official U.S. Navy Web site

Figure 6

U.S. Naval Observatory

Astronomical Applications Department

Sun or Moon Altitude/ Azimuth Table for One Day

This page provides a way for you to obtain a table of the altitude and azimuth of the Sun or Moon during a specific day, at a time interval that you specify. Simply specify the **object**, **date**, **tabular interval**, and **place** below and click on the "Compute Table" button. The altitude and azimuth values are tabulated as a function of the standard time of the place requested (daylight time is **not** used) on a 24-hour clock.

Use Form A for cities or towns in the U.S. or its territories. Use Form B for all other locations. Both forms are immediately below.

Please read the Notes section for details on the data and definitions of altitude and azimuth.

Figure 7

This is an official U.S. Navy Web site

Form B - Locations Worldwide

Object: ○ Sun ○ Moon

Year: [ ] **Month:** [ ] **Day:** [ ]

Tabular Interval: [ ] minutes (range 1-120 minutes)

Place Name: [ ]

The place name you enter above is used only in the table header; you can enter any identifier, or none (avoid using punctuation characters).

Longitude: ○ east ○ west [ ] degrees [ ] minutes

Latitude: ○ north ○ south [ ] degrees [ ] minutes

Time Zone: [ ] hours ○ east of Greenwich ○ west of Greenwich

Need coordinates? Try NGA's GEOnet Names Server.

Need U.S. coordinates? Try this USGS web page.

Need a time zone? Try the time zone map.

[Compute Table] [Clear all fields]

Figure 8

This is an official U.S. Navy Web site

Astronomical Applications Dept. U.S. Naval Observatory
for: Yorktown, Virginia W 76º 25' N37º 06'
Altitude and Azimuth of the Sun Feb 26, 2005

Time (UTC)	Altitude	Azimuth (E of N)
12:58	14.1	112.4
12:59	14.2	112.6
13:00	14.4	112.7
13:01	14.6	112.9
13:02	14.8	113.1
13:03	15.0	113.2
13:04	15.2	113.4
13:05	15.3	113.6
13:06	15.5	113.8
13:07	15.7	113.9
13:08	15.9	114.1
13:09	16.1	114.3
13:10	16.2	114.4
13:11	16.4	114.6
13:12	16.6	114.8

Measured Value (113.5°)

Data was computed using Form B, with 0 hours difference to GMT at:
http://aa.usno.navy.mil/

Figure 9

Figure 10: Shadow Alignment

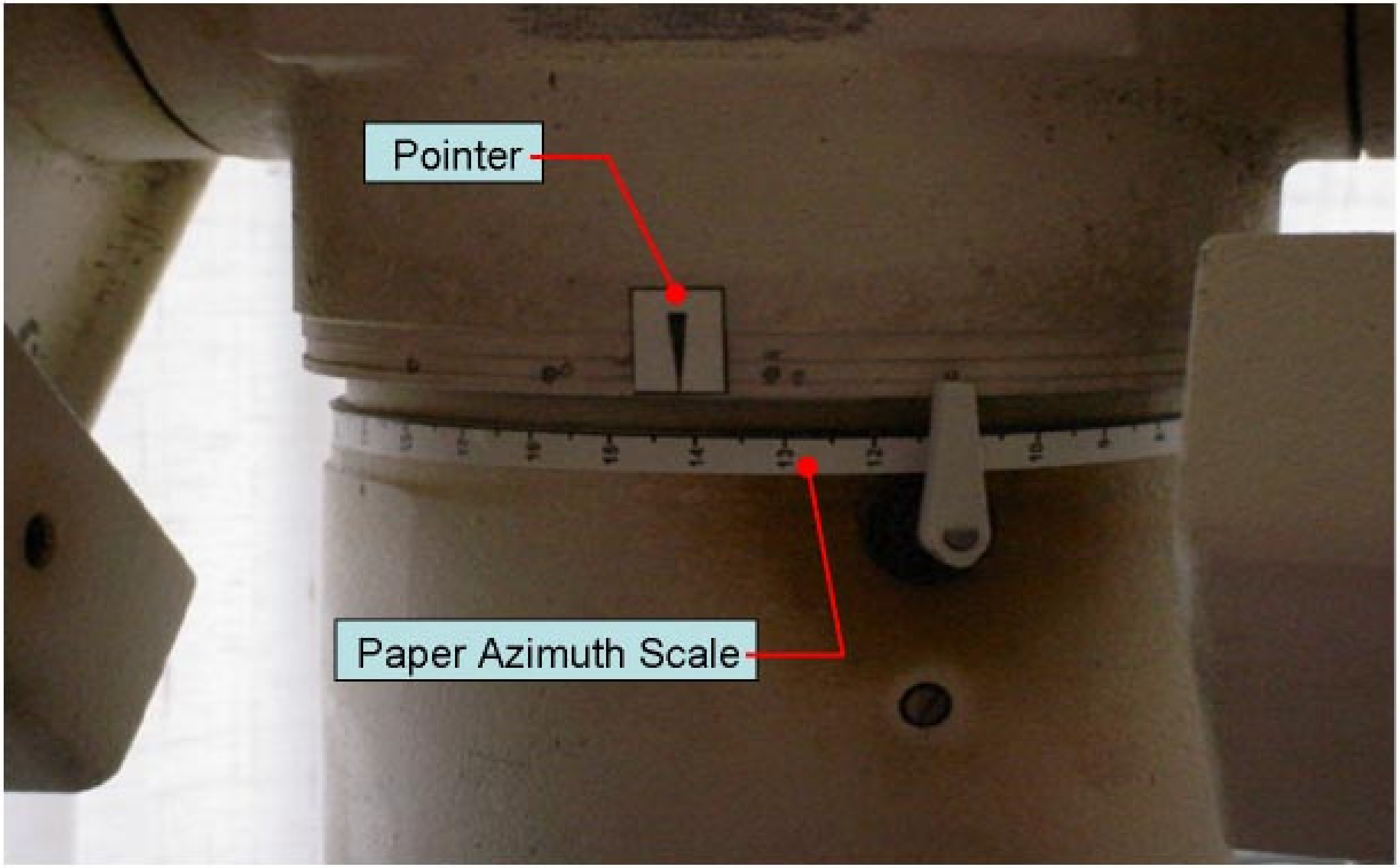


Figure 11: Scale and Pointer Taped to Antenna Mount

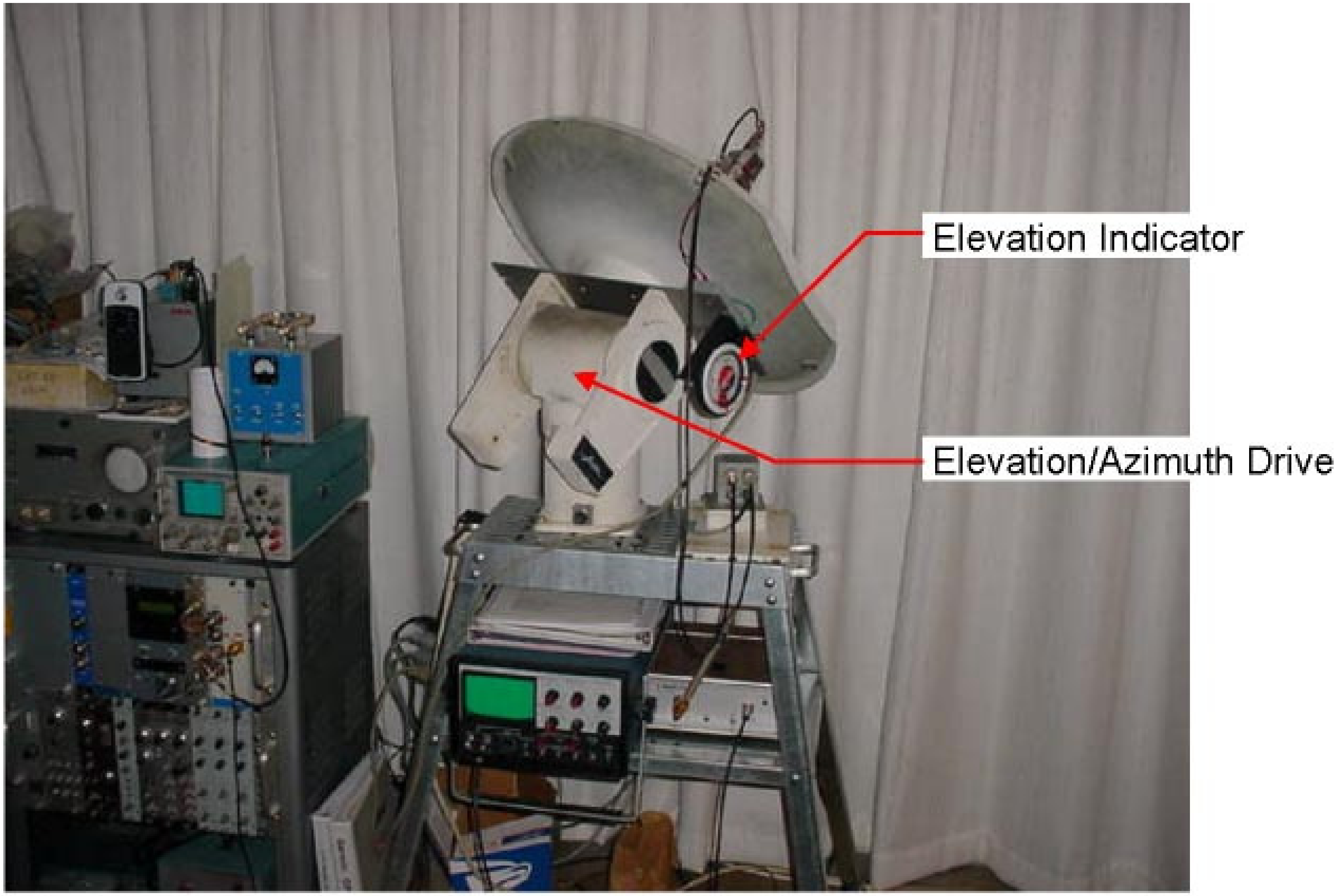


Figure 12: Two-Foot Diameter Dish Mount

Satellites and Cruising – A Winning Combination

Allen F. Mattis, N5AFV, n5afv@amsat.org

Abstract

Operating FM LEO satellites from a cruise ship is relatively easy. However, advance planning and preparation are needed to obtain the necessary amateur radio licenses, prepare for obtaining permission to operate on the ship, and select and become familiar with the equipment. Those who operate on the satellites from a cruise ship soon find out how much fun it is to be called by dozens of amateur radio operators pursuing new grid squares for the ARRL VUCC satellite award. Anyone planning to operate from a cruise ship should begin their preparations at least several months before the cruise.

Requirements for Maritime Amateur Radio Operation

The information available on the ARRL web page regarding maritime operation by US amateur radio operators (http://www.arrl.org/FandES/field/regulations/io/maritime.html) states "When an FCC licensed amateur is operating an amateur rig aboard a US-registered vessel in international waters, he or she must follow Part 97 of the FCC rules, particularly Section 97.11…. If the ship is of foreign registry, (he or she) must obtain a reciprocal operating authorization for the country of registry in addition to being in compliance with Section 97.11."

The text of Section 97.11 of the FCC rules is quite clear and to the point:

"97.11 Stations aboard ships or aircraft

(a) The installation and operation of an amateur station on a ship or aircraft must be approved by the master of the ship or pilot in command of the aircraft.

(b) The station must be separate from and independent of all other radio apparatus installed on the ship or aircraft, except a common antenna may be shared with a voluntary ship radio installation. The station's transmissions must not cause interference to any other apparatus installed on the ship or aircraft.

(c) The station must not constitute a hazard to the safety of life or property. For a station aboard an aircraft, the apparatus shall not be operated while the aircraft is operating under Instrument Flight Rules, as defined by the FAA, unless the station has been found to comply with all applicable FAA Rules."

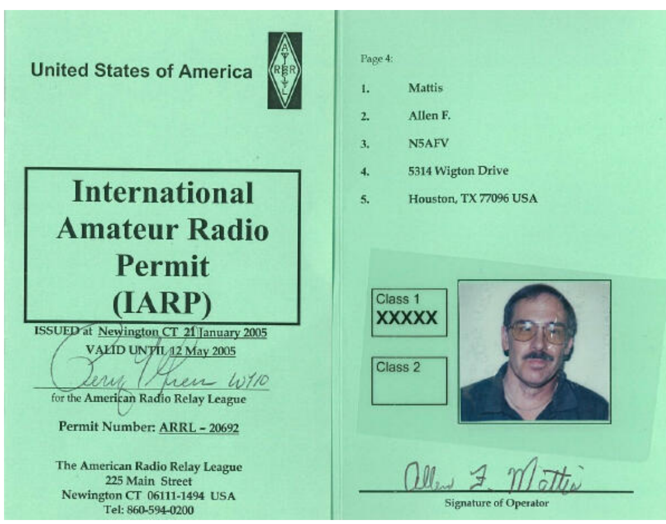
The two primary requirements for operating amateur radio while on a ship are proper amateur radio licensing and obtaining permission to operate.

Licensing on Foreign Flagged Vessels

The basic rule regarding licensing for amateur radio on a ship is that operation in international waters requires the operator to have an amateur radio license from the country in which the vessel is flagged. If the vessel is not in international waters, but in the territorial waters of a nation, it is necessary to have an amateur radio license from that nation in order to operate amateur radio from the ship. Fortunately, a number of international treaties and conventions make foreign licensing relatively easy for US amateur radio operators. The American Radio Relay League (ARRL) web page (http://www.arrl.org/FandES/field/regulations/io/) has a great deal of information on these international agreements, as well as on reciprocal licensing (Mattis, 2003).

European Conference of Postal and Telecommunications Administration (CEPT)
The European Conference of Postal and Telecommunications Administration (CEPT) agreement T/R 61-01 gives US radio amateurs operating privileges in most European nations. All that is necessary is to have in your possession proof of US citizenship, your original FCC amateur radio license (Technician class or higher) and a copy of the FCC public notice entitled "Amateur Service Operation in CEPT Countries" (DA 99-2344, dated October 29, 1999) which is available on the ARRL web page. I have used CEPT operating privileges to operate on ships flagged in the United Kingdom and Norway, and to operate from Curacao in the Netherlands Antilles.

International Amateur Radio Permit (IARP)
The Inter-American Telecommunication Commission (CITEL) has adopted an agreement for an International Amateur Radio Permit (IARP) similar to CEPT, but it includes eleven countries in North and South America. The IARP is issued to US amateur radio operators by the ARRL and costs $10 per year. The application form is available on the ARRL web page. It is necessary to provide a passport photo and a copy of your FCC license (Technician class or higher) when applying for an IARP. Processing may take a month. I have operated from Panama and Venezuela under the authority of an IARP.


United States of America

International Amateur Radio Permit (IARP)

ISSUED at Newington CT 21 January 2005
VALID UNTIL 12 May 2005
for the American Radio Relay League
Permit Number: ARRL - 20692

The American Radio Relay League
225 Main Street
Newington CT 06111-1494 USA
Tel: 860-594-0200

Page 4:
1. Mattis
2. Allen F.
3. N5AFV
4. 5314 Wigton Drive
5. Houston, TX 77096 USA

Class 1 XXXXX
Class 2

Signature of Operator

An International Amateur Radio Permit (IARP) authorizes amateur radio operation in eleven countries in North and South America.

Reciprocal Licensing
In addition to CEPT and IARP, the United States has a large number of reciprocal agreements with other nations regarding amateur radio. These agreements make it possible for FCC licensed radio amateurs to obtain a foreign amateur radio license without having to take an examination. The fees for these reciprocal permits usually range from $10 to $25 per year. In some nations, such as the Bahamas and Bermuda, reciprocal operators use their home call sign appended with

the amateur radio prefix for the reciprocal country (for example, N5AFV/C6A or N5AFV/VP9). Many ships are flagged in Bermuda, and a four-month reciprocal license is available from Bermuda by mail at no cost. Some nations, such as Belize and the Cayman Islands, issue reciprocal operators a call sign from their country.

One downside of reciprocal licensing is that most of the permits cost $20 or $25 a year, and personnel checks or cash are not accepted for payment. US Postal Service money orders are accepted in most, but not all, nations. The Cayman Islands is an example of a nation that does not accept US Postal Service money orders; however, the Cayman Islands will accept a cashier's check from a US bank.

Another drawback to reciprocal licensing is that some nations take a long time to process an application. My application for a reciprocal permit in Belize took six months to process, and I did not receive it in time to use on my cruise. It has been my experience the most countries take at least six weeks to process an application. Those who are planning to operate on a cruise should begin their application procedure at least three months in advance, and as I found out with my application to Belize, it sometimes takes even longer.

The ARRL web page does a good job of providing information on reciprocal licensing; however, the information that is posted on the ARRL web page is not always up to date. For example, the name of the agency that issues amateur radio licenses and permits in the Cayman Islands had changed since the information was posted on the ARRL web page, and the cashier's check I sent with my application was returned with a request for a check made out in the new name of the agency. Also, my application for a reciprocal permit in Jamaica was returned to me six weeks after I mailed it with notations on envelope stating "No such box number" and "Returned for better address." There was not enough time left before my cruise to re-apply for a reciprocal license in Jamaica, even if I could find the correct address. One possible solution to out of date information is to attempt to verify the information on the ARRL web page by either contacting the licensing agency in the foreign country if an e-mail address is given, or by contacting another amateur radio operator who has recently operated from that country. Verifying the information on the web page takes additional time, and I found out that the three months I had allowed for obtaining licenses in Jamaica and Belize was too short.

Finally, there are some places visited by cruise ships where you can operate with a US amateur radio license. Examples are Puerto Rico and the US Virgin Islands. However, cruise ships seldom spend more than six to eight hours in a port, and most radio amateurs who operate on a cruise do the majority of their operating while the ship is underway and spend the time in port seeing the sights and enjoying the things that tourists do.

Obtaining Permission to Operate

The stipulation in Section 97.11 of the FCC rules that states "installation and operation of an amateur station on a ship or aircraft must be approved by the master of the ship" is another hurdle that faces those who wish to operate amateur radio on board a cruise ship. In years past, the captain of the vessel would delegate authority to approve such requests to the radio officer. However, the international regulation requiring all ships at sea to monitor the international CW distress frequency of 500 kHz was dropped in 1999 and many cruise lines no longer have radio officers. Most cruise ships have replaced the radio officer with a communications officer whose responsibility includes maintaining both the information technology (IT) network and the radio systems on board the ship.

It used to be possible to meet with the radio officer on a cruise ship (MacAllister, 1997), and this often made it easier to obtain permission to operate. With the tighter security imposed because of the increase of terrorism in the world, it is usually no longer possible to speak with the communications officer. Requests to operate amateur radio on a ship today are generally made in writing, and submitted to the purser's desk for forwarding to the communications officer. After my first cruise, I learned that it is better to write a letter requesting permission to operate before leaving home, and to print out several copies to take along on the cruise. A neat legible typed letter that has been carefully worded has a better chance of obtaining approval to operate than a letter written by hand while standing at the purser's desk with little advance thought given to the wording.

The primary concern when deciding whether or not to allow amateur radio operation on board a ship is that of safety and preventing possible interference to any apparatus or systems installed on the ship. It is very unlikely that any cruise ship would allow a passenger to put up an antenna and a run of coaxial cable. We all know that operation of radio transmitters sometimes causes RFI, and that is probably why some cruise lines forbid passengers to operate any kind of two-way radio on board their ships. Fortunately, the UHF/VHF bands employed by FM LEO satellites lend themselves to the use of low power and handheld antennas, and seldom result in RFI.

Many of today's communication officers do not have the in depth knowledge of radio theory possessed by the radio officers of the past, and when requesting permission to operate it is necessary to address any negative perceptions regarding amateur radio that they may have in their mind. It is important that several points be clearly made in the written request to operate. The letter I have developed after several cruises requests permission to operate a small low-power handheld amateur radio on board during the cruise. I state that the radio is very similar to the Family Radio Service (FRS) radios used by many passengers, but operates on the 145 MHz VHF and 435 MHz UHF amateur radio bands. I tell them that I typically operate for very short periods of time, usually 10 to 15 minutes three or four times a day. I do not tell them that I will operate through a satellite or give them any details they do not need to know. The cruise line does not want any passenger to do anything that will disturb other passengers, so I state that I use a small headset with a microphone when I operate the radio so that I do not disturb other people. I usually end my letter by stating that I have operated this equipment on cruises in the past and that it did not cause any problems.

The time it takes to receive a response after a request to operate amateur radio has been submitted varies with both the cruise line and the ship. On one cruise with Princess Cruises, written approval to operate amateur radio was delivered to my stateroom eight hours after I submitted my request at the purser's desk. On a later cruise with Princess I turned in my written request at 5 PM and received a telephone call from the communications officer at 7 AM the next morning giving me verbal approval to operate. Princess Cruises is one of the more amateur radio friendly cruise lines. Other amateur radio operators have reported having a good experience operating from ships of the Holland America Line.

In the past two years, some amateur radio operators who sailed on Carnival Cruise Lines have reported that they did not receive a reply to their written requests to operate amateur radio while on the ship. What most amateur radio operators do in this situation is to assume that if after reading the request the communications officer hasn't notified them that it is not permitted, they are allowed to do it. I experienced a similar situation on a cruise with Royal Caribbean International a year ago. My written request was returned to my stateroom the next day by ship's mail with no comments or markings on it. Since the communications officer knew I wanted to operate amateur radio and he didn't notify me that I couldn't operate, I assumed it was permitted.

The Celebrity Cruise line reportedly has a current policy of not allowing passengers to operate any kind of two-way radio on their ships. Even though the promotional material that Celebrity sends to passengers and prospective passengers does not mention the policy, my travel agent was told by a Celebrity agent that they would confiscate any amateur radio equipment they found on board one of their ships.

Sometimes approval is given to operate amateur radio on a cruise ship, but with restrictions. For example, one radio officer approved my request to operate, but not at a full power of five watts. He was concerned about possible interference to the ship's radios on the 156 MHz VHF marine band. During that cruise I was careful not to transmit near any antenna on the ship that looked like it was used for VHF. In some instances, radio amateurs are asked not to transmit during critical periods such as when the ship is entering or leaving a harbor, or docking (MacAllister, 2000). On my last cruise, I chose not to transmit while passing through the Panama Canal. There were so many different simultaneous radio transmissions that I heard almost constant intermod on my HT. If I had transmitted at that time it is likely that I would have contributed to the intermod and been heard by other radio operators along the canal and on the ship. It is very important that amateur radio operators on board ships be careful not to do anything that may result in the denial of future requests by amateur radio operators for permission to operate on the ship.

In some ways, obtaining permission to operate is probably the single largest obstacle facing those who wish to operate amateur radio on cruise ships. There is always the possibility that once you have obtained the necessary licensing and boarded the ship you will not be able to operate.

Selecting Equipment and Preparing for Operation

When most people think about operating amateur radio on a cruise ship, they visualize someone sitting in a comfortable deck chair in the warm sun sipping a cool drink between or even during contacts. Only a small percentage of amateur radio satellite contacts made from a ship resemble that mental image. The fact is that the operating conditions on the open deck of a ship at sea are often hostile in nature. First of all, there is usually a strong wind. If the ship is moving at approximately twenty knots into a twenty five knot wind there will be a fifty mile per hour wind blowing across the deck. If you have ten to fifteen foot seas the ship will be rocking significantly. Also, the deck may be wet from

N5AFV enjoying ideal maritime mobile operating conditions in the Caribbean.

ocean spray, and it could even be raining. It may be cold; I have experienced temperatures in the 40-to-45 degree Fahrenheit range on ships in the northern Gulf of Mexico during December and January. As we know, some satellite passes occur in darkness. If all of these conditions happened to occur at the same time, the operating conditions could be extremely hostile, and care must be taken not be fall overboard while operating.

It is important to keep these operating conditions in mind when selecting the equipment to be used for operating the amateur radio satellites on a cruise. The equipment should be light weight, water resistant, and operate on self-contained batteries. I also take the approach that the equipment should not draw undue attention to the operator. If just one other passenger makes a negative comment to the ship's crew about the amateur radio operation, it is possible that the communications officer or captain would shut down the operation. On my last cruise another passenger watched me operating a satellite pass and asked me what I was doing. I thought it would be a good opportunity to talk up ham radio and AMSAT, so I explained what I was doing. The passenger's first comment after I finished my explanation was to ask about people's right to privacy on the satellite. There was no way he would believe that I had authority to talk over a satellite, and he was convinced that I was illegally listening to telephone calls. If he had reported the incident to the ship's crew my maritime mobile amateur radio operation would possibly have been shut down.

Equipment spread out on the table of the veranda in preparation to work a pass.

Because I feel that it is important to keep a low profile and not attract attention, the Icom W32A HT with a Premier (Pryme) AL800 telescoping antenna has become my choice of equipment for operating FM LEO satellites on a cruise. Other satellite operators such as Lee Devlin, K0LEE, (Anonymous, 2000) and John Sheets, N8QGC, have used the Arrow antenna on cruises, and I also used it on a cruise where I operated from veranda of my stateroom. An Arrow antenna is a little cumbersome to carry around when assembled, and it takes a minimum of several minutes to assemble. It is difficult to match the portability of an antenna like the Premier (Pryme) AL800 that fits in your pocket and only takes a couple of seconds to attach to your HT and be ready for use. Soifer (1999) has had success using the MFJ-1717 16-inch rubber-coated dual-band antenna for working FM LEO satellites, and MacAllister (1997) used the similar Diamond RH77 15-inch rubber-coated dual band antenna on his cruise. On my last cruise, I was able to switch back and forth between the Premier (Pryme) AL800 and MFJ-1717 antennas while making contacts on SO-50 and AO-27. I found that both antennas performed acceptably; however; the Premier (Pryme) AL800 appeared to provide better reception than the MFJ-1717. I usually take an MFJ-1717 along on my cruises as a back up antenna.

While I use an Icom W32A HT on cruises, other brands and models that have full dual-band capability may also be used. For example, Soifer (1999) has used the Yaesu FT-50R HT and Sheets (1999) has used the Alinco DJ-G5T for portable operation on the FM LEO satellites. A larger rig like the Yaesu FT-817 with self-contained batteries may also be used for portable operation (Glasbrenner, 2005). Gene Marcus, W3PM, operated on the amateur radio satellites from the Queen Elizabeth 2 in the North Atlantic in both 2002 and 2003 using an FT-817. Whether you plan to use an HT or a larger rig, you should take along extra rechargeable batteries and a battery charger. Staterooms on almost all cruise ships in North America are equipped with 120 volt AC power systems compatible with standard battery charging devices.

Besides the transceiver and antenna, other equipment is needed to efficiently operate on board a ship. A GPS unit is essential to know the maidenhead grid square in which the ship is located, as well as the direction the ship moving. It is necessary to know the direction the ship is moving to determine which side of ship to be on in order to work a low elevation satellite pass. I have already mentioned that I use a headset so my radio will not disturb other passengers; an inexpensive MFJ-288I headset has served me well. I have also found that a small, voice-activated tape recorder allows me to record the call signs of the stations I work. In order to keep the set up simple, the recorder does not record from the radio, but records only my voice. After the satellite pass, I transcribe the information on the tape recorder into a hard copy log. Other miscellaneous items to remember to take along include extra batteries for the GPS unit and tape recorder, and the user's manual for your radio. I sometimes take a few pieces of backup equipment along such as a speaker microphone or extra headset, a trickle battery charger, and few basic tools like black electrical tape, screw drivers and pliers.

Each amateur radio operator on a cruise ship must decide the best way for them to obtain pass predications for the satellites. I try to travel light on cruises, so I do not take a Palm Pilot or lap top computer with me. Because I know the itinerary of the cruise ship before I leave home, I am able to print out pass predictions in advance for the entire cruise. Most ships have Internet access available to passengers for a fee, and on the rare occasions when it appeared that my pass predictions were not correct I was able to go to the Heavens Above web site (http://www.heavens-above.com/) and obtain the information I needed.

It may also be desirable to have copies of the receipts showing when and where you purchased your radio and any other expensive pieces of gear. This documentation may be needed if you plan to take these items ashore at a stop or when you go through customs upon return. I generally put together a small three-ring binder containing these items along with a few maps, my amateur radio licenses and permits, the pass predictions, log sheets and any other related items I feel I may need.

It is also a wise plan of action to thoroughly inspect and check out each piece of equipment before you leave. If something needs repair, you will have time to do it or have it done. On one cruise I packed my Arrow antenna without testing it, and when I assembled it on the ship and tried to work an SO-50 pass I could hear the satellite, but I could not get into the bird. The duplexer in the Arrow handle was defective on the two meter side, and the Premier (Pryme) AL800 I had packed as a backup antenna became my primary antenna for the cruise.

One way to check out the equipment is to make contacts with it before the cruise. My usual procedure consists of using my W32A HT and AL800 antenna to make 75 to 100 satellite contacts during the month prior to the cruise. On the final day of practice operation five days before my first cruise I was working a satellite pass and received two reports of low audio. Testing indicated that the microphone in my MFJ-288I headset was not working properly, and I replaced the headset before leaving. Making practice contacts before the cruise also prepares you for operating on the ship. It is easier to make contacts in the dark or under hostile conditions when you are used to using the equipment. Also, it is essential that an amateur radio operator have experience operating on the satellites before attempting a cruise operation, and a "newbie" or new operator can gain that experience in a few weeks of practice operation.

Summary

Operating amateur radio satellites from a cruise ship is not difficult if proper advance planning and preparation have been done. Licensing usually takes at least several months, and a carefully worded written request prepared in advance increases the likelihood of receiving permission to operate. Selection and thorough testing of the equipment to be used should not be left to the last minute. An amateur radio operator attempting to operate on FM LEO satellites during a cruise should have prior satellite operating experience. If these steps are followed, operating FM LEO satellites from a cruise ship can be a very rewarding experience.

References

Anonymous, 2000, Alaska Inside Passage with K0EEE: The AMSAT Journal, July/August (Volume 23, Number 4), p. 26.

Glasbrenner, Andrew, 2005, A Short Introduction to Using Your FT-817 and Arrow for SSB Satellite Demonstrations: The AMSAT Journal, January/February (Volume 28, Number 1), p. 8.

MacAllister, Andy, 1997, Cruising for AO-27 on the Carnival Sensation: 73 Amateur Radio Today, HAMSATS column, March, p. 60.

MacAllister, Andy, 2000, Cruising for Satellites: 73 Amateur Radio Today – Special HAMSATS issue, October, p. 22-28.

Mattis, Allen, 2003, Prior planning - key to a successful DX cruise: The AMSAT Journal, May/June (Volume 26, No. 3), pp 24-26, (reprinted from Worldradio, 2002, April, p. 18-21).

Sheets, John, 1999, AO-27 Satellite Operations are Possible on a Small Budget: The AMSAT Journal, May/June (Volume 22, Number 3), p. 22-23.

Soifer, Ray, 1999, AO-27: An FM Repeater in the Sky: The ARRL Satellite Anthology, p. 4.11-4.12, (reprinted from QST, January, 1998, p. 64).

TEN FAQs ABOUT AN ARISS SCHOOL CONTACT

By Gene Chapline, K5YFL

This brief treatise is in response to questions often asked by hams or teachers who are working on an ARISS application or are waiting for a contact to be scheduled. The answers here will help to ensure a successful application or contact.

What kind of antenna should we use?

The most successful contacts have been made with multi-element circularly polarized antennas. The ARISS school selection committee considers technical possibilities and preparedness, and it is much more likely to approve an application that specifies this type of antenna. Further, the ARISS mentor assigned to the contact will recommend, if not insist, that it be used. An ISS pass lasts for only ten minutes. A contact can certainly be made with an eggbeater, a four-element vertically polarized yagi, or even a quarter wave whip, but it won't last for ten minutes. A properly guided circularly polarized yagi will ensure ten minutes of contact.

How much power should we use?

The very least amount of power should be 25 or 30 watts. More is better. A successful contact is typically made with 50 to 150 watts of power. The burden of success is on the ground station. The ISS has limited power and a stationary antenna. The inside of the station is noisy. The astronaut will appreciate every bit of signal strength the ham can produce.

How many questions should be asked by how many students?

The most successful formula has been to have ten students prepared to ask two questions each. Each student asks one question, then goes to the end of the queue to await a turn to ask a second question. Ten minutes later each student will have asked at least one question. If the students are eight or nine years old, and 25 of them are standing in line ready to ask one question each, have a mop ready. There WILL be tears on the floor at the end of the line when the contact is history.

What sort of software should we use?

That question indicates that the applicant really wants the application to be approved, and really wants a ten-minute contact. Any of the current tracking software capable of controlling an az-el rotator is fine. Take your pick. The plug-and-play items that come with an interface to the rotator are great. The important issue is to use up-to-date tracking software to control the antenna. The very few hams who have been less than candid with their ARISS mentors, and have guided their antennas by hand, could have had longer contacts.

How should we test the station?

The station should be tested with the old reliable end-to-end method. Shortly before the contact the ground station should make contact with another ham acting as a proxy ISS. The frequencies for that contact should be the same as those to be used during the ISS contact. If the test contact is a success, and no controls are touched afterwards, the ISS contact will be a success. The tracking software and antenna should be tested on several satellites well before the ISS contact. Finally, make sure that the computer's clock has the correct time and date.

Should we get publicity?

Get as much publicity as you can. ARISS is an educational outreach endeavor. Appoint a publicity committee. Send several progress report press releases to each of as many news reporting agencies as you can. Everyone gets out the word to newspapers, TV and radio stations, but don't forget local magazines.

How about an IRLP hookup?

Feeds to IRLP reflectors have been technical successes and have been very helpful in meeting the educational outreach goals of ARISS. Ask your ARISS mentor about the details.

How important, really, is the application for a contact?

The application is extremely important. The ARISS school selection committee meets regularly to review applications for seriousness and technical competence. The committee regards time on the ISS as a limited and precious commodity. The application should reflect the same stance. It is extremely important that the application set forth an educational proposal detailing how the contact will be incorporated into the school's curriculum, and how as many students as possible will be involved. The application must be approved unanimously by the committee.

How long is the waiting period between application approval and the contact?

The waiting period currently may be as much as three years. The ARISS Operations Committee determines the order of contacts to fit operational constraints such as orbital mechanics and crew schedule. It further decides whether a contact should be implemented as a direct or telebridge contact. Further, if an ISS crew member has a request for a contact with a specific school, that contact will be scheduled during that member's stay aboard the station.

Is there anything to be done after the contact?

NASA, one of the U.S. partners in the ARISS project, requires that the school complete a questionnaire concerning the contact for the purpose of assessing the educational effectiveness of the ARISS project. Continued participation by NASA depends on such statistics. The process takes only a few minutes online. The ARISS mentor will provide the URL.

The Montgomery College Parabolic Antenna Project

David Bern, W2LNX
Montgomery College, Rockville, Maryland
DavidBern@Engineer.com

Muhammad Kehnemouyi, Ph. D.
Montgomery College, Rockville, Maryland
Muhammad.Kehnemouyi@MontgomeryCollege.edu

Abstract

The first engineering course at Montgomery College is **ES100: Introduction to Engineering Design**. This is a laboratory course where the students have a required design and construction project. The current projects are mechanical engineering in nature and require little or no calculations in their design. In the Spring 2005 semester, we piloted a new electrical engineering project that required several calculations in the design. The project was to design and construct a 2.4 GHz parabolic antenna. The students were divided into design teams and each team was provided with a patch antenna for the feed, a down-converter, and a hand held communications receiver. The students were required to design and construct a parabolic reflector for the parabolic antenna. The students needed to calculate the correct shape and dimensions in their design. In this paper, we will describe the experience of this pilot project and what we learned.

Introduction

Montgomery College at Rockville, Maryland, is a two year college with identical engineering courses as the Clark School of Engineering at the University of Maryland, College Park. The first course in the engineering curriculum taken by all freshmen engineering majors at the Department of Physics, Engineering and Geosciences is **ES100: Introduction to Engineering Design**. It is a hands-on laboratory course with no prerequisites. In the course the students are assigned a group design and construction project. In addition, the students learn Pro/ENGINEER, a 3-D solid modeling program, learn the application of spreadsheets in engineering and learn about engineering design.

Next to the classroom is a workshop with hand tools and electric hand tools. There is a drill press and a band saw. The students are provided with construction materials and a small budget to buy more construction material that they may need. The instructor oversees the students in the workshop and is available to answer questions about the project. Students are allowed access to workshop at other times and staff and faculty members oversee the students in the workshop.

The goal of the design and construction project is for groups of students to experience designing and building an object. No more than three students are assigned to a group. The student groups are also required to write an engineering report and prepare an oral presentation. This provides for some students the experience to present a technical presentation for the first time before their peers.

Background

About three years ago, Professor Kehnemouyi asked the first author to propose an electrical engineering project for the ES100 course since all the projects so far have been mechanical engineering in nature. This was a challenging request since the students have not yet taken any electrical engineering courses. At the 2002 AMSAT-NA Space Symposium, Tony Monteiro, AA2TX, displayed as part of his presentation [Mont] horn antennas for receiving the AO-40 amateur satellite on the 2.4 GHz band built by a group of elementary school children. This inspired the idea that ES100 students could design and build a parabolic antenna to receive the telemetry of AO-40. Specifically, the project would be to design the parabolic reflector for a 2.4 GHz parabolic antenna.

The 2.4 GHz parabolic antenna was an interesting project idea since it has an interesting shape in addition to its electrical engineering aspects. And, importantly, it addresses the issue that the prior mechanically oriented construction projects mostly involved tinkering with little or no engineering calculations in their design. For this project the students would have to apply the appropriate formulas to calculate the correct shape of the parabolic reflector in their design. The formulas would need to be simple and understandable. The construction materials would need to inexpensive and commonly available. It would need a simple “it works” test. Also, the construction tolerances of a one-tenth of a wavelength at 2.4 GHz, about one centimeter, would make it “student-friendly.”

In the summer of 2004, the first author built a prototype 100 centimeter 2.4 GHz parabolic reflector to test the feasibility of this project idea. The parabolic concave shape was provided by eight ribs constructed out of solid quarter inch square Plexiglas rod that were stressed into a parabolic shape. Eight gauge solid copper wire was bent into a circle to form the rim of the reflector. The Hanover Wire Cloth aluminum window screening purchased from the local Strosnider Hardware Stores in Potomac, Maryland, was used since it easily conformed to a concave shape. A single four foot by four foot piece of aluminum window screening was lashed to the Plexiglas ribs with dental floss. This simplified the construction and did not introduce additional construction errors from cutting up the aluminum screening into pieces. Other brands of aluminum screening purchased at the local Home Depot store resisted conforming to a concave shape.

A used Hewlett-Packard 8614A signal generator was purchased on Ebay to be used as a 2.4 GHz signal source. The 8614A is a 800 MHz to 2400 MHz signal generator and it uses a klystron tube with a tunable cavity to generate its signal. It also has an internal audio signal generator that modulates the RF output signal which makes it easy to find the signal on a receiver. It was turned into a low-powered one milliwatt 2.4 GHz transmitter by attaching a quarter wavelength ground plane antenna on top of a right angle adaptor to the calibrated RF power output.

Two circularly polarized 2401 MHz patch antennas were purchased from Robert Suding, W0LMD. Robert also sold us two AIDC 3731AA down-converters that were modified by Robert Seydler, K5GNA, for a two meter intermediate frequency (IF) output. A Khune Electronic DCC-12N bias-tee power injector was used to power the AIDC 3731AA down-converters. The communications receiver was a Yaesu VX-2R portable transceiver with transmit inhibit set.

The prototype parabolic reflector was tested at Montgomery College. The 8614A signal generator was set up in the workshop and we discovered that the concrete and cinder block walls of the building provided good attenuation for the 2400 MHz signal. This allowed us to easily test the parabolic reflector without having to leave the building. Initially, the receiver was set to frequency modulation (FM) mode but the receiver needed to be constantly tuned to receive the signal from the 8614A signal generator due to its frequency drift. Then it occurred to us that the receiver should be set to wide-band frequency modulation (WFM). This greatly reduced the drift problem and made the received signal noticeably louder. Letting the 8614A warm up for 24 hours before also helped reduce the drift in the output signal. We walked through the hallways while orienting the patch antenna until the signal was no longer heard. Then we placed the parabolic reflector where the feed point should be for the patch antenna and the signal was heard again.

ES100 Parabolic Antenna Pilot Project

For the Spring 2005 semester, we decided to test this construction project on a small group of

ES100 students. The class consisted of four students and the students were randomly assigned into two groups by picking numbers out of a hat. The first author was the instructor for this class. The project assignment to design and build a parabolic reflector was given to the students. Specifically, the assignment required the students figure out the correct shape of the parabolic reflector. The instructor explained the purpose of a parabolic reflector and reviewed graphing parabolas on graph paper. The instructor brought to class a G3RUH 2.4 GHz 60 centimeter parabolic antenna [Mill] to show the students what a commercial antenna looks like. It made it easier to explain for a parabolic reflector its feed point, its diameter D, its depth d, its focal length f and its shape described by the f/D ratio. The students were given a spreadsheet of the required formulas for designing a parabolic reflector with several worked out examples. The formulas and their derivations were explained to the students. In particular, the formula that describes the relationship between the beamwidth of a patch antenna placed at the feed point of a parabolic reflector and its shape was explained. This formula is key to calculating the correct shape of a parabolic reflector.

The following resources were provided to the students:

- handouts with notes about parabolic antennas

- a spreadsheet with design formulas and worked out examples

- a pad of large graph paper with a one inch by one inch grid: the students were required to do all their measurements in centimeters. That required explaining that the graph paper should be viewed as a grid of lines 2.54 centimeters apart and not one inch apart.

- aluminum window screening: roll of four foot by seven foot Bright Aluminum Insect Screening, Hanover Wire Cloth, Star Brand Screening, A division of CCX, Inc., Hanover, Pennsylvania 17731. This particular aluminum window screening has the useful property that it is sufficiently flexible to easily conform to a shallow concave surface without having to cut it into pieces.

- a 2400 MHz signal source: Hewlett-Packard 8614A signal generator placed in the workshop. It was turned into a low-powered one milliwatt (0 dBm) 2.4 GHz transmitter by attaching a quarter wavelength ground plane antenna on top of a right angle adaptor to the calibrated RF power output.

- patch antennas: circularly polarized 2401 MHz labeled with their beamwidth of 130 degrees at the -10 dB point. These were purchased from Robert Suding, W0LMD [Sude].

- down-converters: modified AIDC 3731AA with an intermediate frequency of 144 MHz. These were supplied by Robert Seydler, K5GNA [Seyd].

- 12 V power injectors: Khune Electronic DCC-12N bias-tee. The AIDC 3731AA receives power through its RF output connector.

- 12 V batteries: nine 1.5 volt alkaline D cells were soldered together to create a long lasting battery for the AIDC 3731AA which draws about 100 ma of current.

- communications receivers: the Yaesu VR-120 receiver has a BNC connector which is more durable than the SMA connector found on the Yaesu VX-2R transceiver. The VR-120 receiver was purchased to eliminate the risk of a student destroying a down-converter by accidentally transmitting into it with the VX-2R transceiver.

- manuals for all the equipment

The following test procedure takes advantage of the concrete and cinder block walls of the building to provide the right amount of signal attenuation to test a parabolic reflector:

- turn on the 8614A signal generator in the workshop by depressing the LINE, RF, ALC and SQ WAVE buttons. Turning it on for several hours before the start of testing reduces the amount of drift of its output signal.

- turn on the VR-120 communications receiver to 146 MHz set to WFM in the workshop with the 8614A signal generator.

- set the frequency of the 8614A signal generator to end of the FREQUENCY dial to 2400 MHz. Adjust the ΔF knob until a tone is heard on the receiver. Adjust the ATTENUATION dial to get the loudest tone. Adjust the ALC CAL OUTPUT control until the meter indicates 0 dBm. Peak the signal on the receiver by turning its tuning knob to get the loudest signal and maximum indication on its S-meter.

- take the patch antenna and receiver out of the workshop and walk through the hallways until the tone is barely heard. Orient the patch antenna so that the tone disappears. Place the parabolic reflector so that the patch antenna is at its feed point.

- the test is successful when the tone is heard again.

The student teams were give about a month to design and assemble their parabolic reflectors. Team 1 did quite well. Their design was based on using a hula hoop for the outside rim of their parabolic reflector. They drilled holes in it to secure the ends of stiff aluminum wires that they had bent into appropriate parabolas. Pieces of aluminum screening were lashed to the aluminum wires. They asked many questions and were receptive to suggestions for improvements and corrections. They also had a means of adjusting the position of the patch antenna. There was a distinct rise in the signal when their parabolic reflector was tested with the above procedure.

Team 2 did poorly. They rarely asked questions. In their design, they had decided to use a child's round plastic sled as their parabolic reflector. They were unable or unwilling to justify that the round plastic sled was parabolic and, if it was, of the correct shape. Their parabolic reflector did poorly in the above test procedure; a sharp increase in the signal was not observed.

Some Lessons Learned

The students were initially uncomfortable with the parabolic antenna design formulas. For the next semester, more class time will be devoted to using a spreadsheet to do parabolic reflector calculations. Two commercial parabolic antennas [Mill] [Pavi] with their patch antenna feeds removed will be brought in to have their dimensions measured by the students. With the spreadsheet, the students will calculate where the feed points should be and then compare their predictions with actual the feed point after they reassemble the parabolic antennas.

The students appeared to have little practice plotting on paper curves of functions such as parabolas. Next semester, more class time will be devoted to teach that the equation of a curve in fact describes the graph of that curve. The students will calculate the equations of the parabolas for the commercial parabolic reflectors and for the parabolic reflectors that they will design. Then the students will plot full scale graphs of these parabolas.

The project needs to start more towards the beginning of the semester and more guidance needs to be provided. Just handing out the project notes near the middle of the semester and leaving the design up the students was not effective; they spent two unproductive weeks trying to figure what to do. For the next semester, more class time will to be devoted to the students working on their design. They will need to prepare a design document with calculations and diagrams to be reviewed by the instructor before they start construction. This should reduce “on-the-fly” designing during construction. Any design changes after the students start construction will need to be reviewed by the instructor and then incorporated into their design document.

One of the specifications for the parabolic antenna were originally missing. The diameter of the parabola reflector was left to the discretion of the students but that caused confusion. This was indirectly added to the project specifications by specifying its gain (see **Appendix: Parabolic Antenna Design Project Specifications**).

Conclusions

We plan to adopt this project for the 2005-2006 academic year at Montgomery College with full classes of students. The parabolic antenna project is challenging but feasible for freshmen students who have little background in mathematics. This project requires an understanding of the formulas needed for the design of a parabolic reflector. The students will be taught how to use the formulas for this project.

Our long-term goal is for the students to build a parabolic antenna that is capable to receive 2.4 GHz signals from amateur radio satellites. We plan to share the knowledge and experience gained from this project with the rest of the amateur radio community.

The conference presentation with photographs and all class materials are available from the first author. We invite comments, suggestions, ideas and, importantly, corrections. You can correspond with the authors at the email addresses provided at the beginning of this paper.

References

[Krau] Kraus, John D., Ronald J. Marhefka, **Antennas for All Applications**, third edition, McGraw-Hill, New York, 2002.

[Mill] Miller, James G3RUH, **S-Band Dish Antenna System,** `www.jrmiller.demon.co.uk/products/s_ant.html`

[Mont] Monteiro, Anthony AA2TX, A *Disposable* Antenna for Receiving AO-40 on S-Band, **Proceeding of the AMSAT-NA 20th Space Symposium**, Fort Worth, Texas, 2002.

[Pavi] Pavia, Marco IK2CFR, **S-Mode satellite complete receive system,** `www.keps.it/en/sat_products/system/system.html`

[Seyd] Seydler, Robert K5GNA, **AIDC 3731AA Down-Converter**, `www.k5gna.com`

[Stra] Straw, R. Dean, ed., chap. 19: Antenna Systems for Space Communications, **The ARRL Antenna Book**, 20th edition, ARRL, Newington, Connecticut, 2003.

[Sude] Suding, Robert W0LMD, **Dish Feed Systems,** `www.ultimatecharger.com/Dish_Feed.html`

[Wade] Wade, Paul W1GHZ, **The W1GHZ Online Microwave Antenna Book,** `www.w1ghz.org/antbook/contents.htm`, 2005.

Appendix: Parabolic Antenna Design Project Specifications

The International Children's Educational Foundation is soliciting proposals for designs of inexpensive parabolic antennas. You are to design, build and test a parabolic reflector for a 2.4 GHz parabolic antenna constructed out of inexpensive materials. The formulas for parabolic antenna design are provided below. The tolerance for the dimensions of your parabolic reflector is one-tenth of a wavelength. Your reflector should have a gain of 23 dBi; assume an efficiency η of 50% in your calculations. Your design should have a means for adjusting the position of the patch antenna at its feed point.

You can use any construction material commonly found in hardware stores for the development of your prototype. There are some construction materials in the workshop for you to use. Additional construction materials can be provided to you by discussing it with your instructor or lab coordinator.

You can use any appropriate material you wish for the reflector surface of your parabolic reflector. It can have holes not larger than one-tenth of a wavelength. Rolls of Bright Aluminum Insect Screening is be available to you. A single piece of this particular aluminum window screening easily conforms to a shallow concave surface without needing to cut it into pieces.

You are provided with a 2.4 GHz patch antenna mounted on the ADIC-3731AA down-converter. Its beamwidth at the -10 dB point is specified with a label on it. You are to incorporate the patch antenna and down-converter into your design. The test equipment include a Yaesu VR-120 communications receiver, a DCC-12N 12 volt power injector and an Hewlett-Packard 8614A Signal Generator. Your instructor will instruct you in the use of this equipment. The manuals for this equipment are found on the CD-ROMs that were handed out in class.

Your instructor is available to answer all your questions, provide guidance and otherwise discuss your project with you.

Parabolic Antenna Design Formulas

- focal length of a parabolic reflector

$$f=\frac{D^2}{16d}$$

D is diameter

d is depth

f is focal length

- equation of a parabola

$$y=ax^2 \qquad \text{where} \qquad a=\frac{1}{4f}$$

- f/D given the beamwidth of an antenna feed

$$\frac{f}{D}=\frac{1}{4\tan(\theta/4)}$$

θ is the beam width

- length of a parabolic segment

$$L=\frac{\ln(\sqrt{a^2D^2+1}+aD)}{4a}+\frac{D\sqrt{a^2D^2+1}}{4}$$

a is defined above

L is length

- surface area of a parabolic reflector

$$S=\pi\frac{(a^2D^2+1)^{3/2}-1}{6a^2}$$

a is defined above

S is surface area

- gain of a parabolic reflector

$$G=10\log_{10}\left(\eta\frac{4\pi A}{\lambda^2}\right) \qquad \text{where} \qquad A=\frac{\pi D^2}{4}$$

η is efficiency

λ is wavelength

G is gain

SSETI Express -
Helping to launch the dream!

David Bowman G0MRF, Jason Flynn G7OCD, Sam Jewell G4DDK, Howard Long G6LVB, & Graham Shirville G3VZV

The Student Space Exploration & Technology Initiative was started by the ESA Education Office to enable University students in Europe to experience the challenges and opportunities of actually building a satellite and having it launched into space.

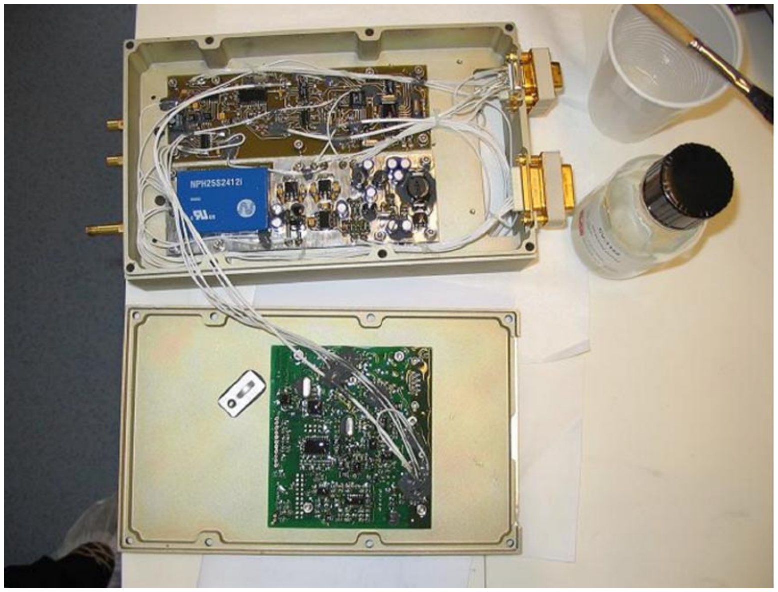
Their first satellite is SSETI Express – 62kgs 600x600x700mm and scheduled to be launched into a 98 degree sun synchronous orbit from Plesetsk in Northern Russia. It was intended as fast mission, which only began January 2004. It was planned to use existing or highly developed hardware with earth observation and technology demonstrations . It incorporates experiments from a number of teams and will "launch" three cubesats shortly after it is separated from the launcher. SSETI Express was integrated at the facilities at ESA ESTEC in the Netherlands during the first half of 2005.

AMSAT-UK became involved in June 2004 when it was offered the opportunity to provide an S Band data and voice transmitter. This was needed to download telemetry and pictures and also could be linked to the receiver part of the existing UHF transceiver (built by Holger DF2FQ) to provide a single channel U/S FM transponder in the amateur satellite service.

The project team amended the "Mission statement" for SSETI Express to take this new facility into account - *"The SSETI Express mission is an educational mission that shall deploy CUBESAT pico-satellites developed by universities, take pictures of Earth, act as a test-bed and technology demonstration for hardware of the complementary project: the European Student Earth Orbiter, and function as an radio transponder for the rest of its mission duration"*

We were fortunate that a suitable 3 watt PA had just been flown in AO51 so we could claim "space heritage" for at least one part of the transmitter but the remainder of it was created from scratch and a "flatsat" was built and demonstrated within 6 weeks of our work being started.

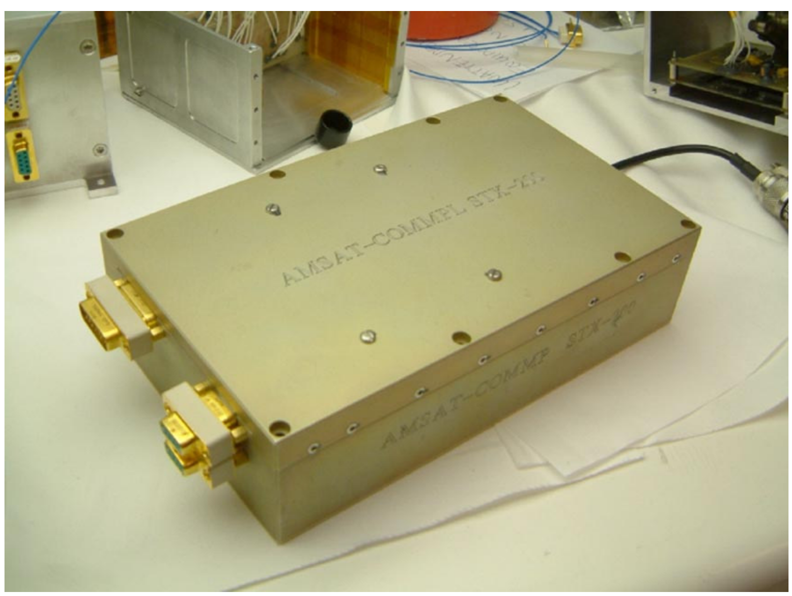
The flight model was built and assembled into a beautiful aluminium enclosure (provided by the team at the University of Wroclaw in Poland) and delivered to ESA in Nov 2004.



The S Band Control deck with PSU and the control board with the TNC on the lid

The unit includes the 13cms exciter, the 3 watt PA from G3WDG, a switchmode power supply, a TNC, sensor board and control board.

After some wiring issues had been resolved the various boards were given a conformal coating to help prevent vibration damage during testing and launch. Unfortunately, although great care was taken, some of this coating managed to find its way into one of the hi-Q filters and its performance was severely compromised as a result. It was replaced and the unit was declared “flight ready” in mid March.



The completed S band transmitter

The AMSAT-UK team has, of course, thoroughly enjoyed working with the various graduate and undergraduates who are involved with the SSETI program. It seems that we have a lot to offer these projects as, generally, they do not have any communications experience and they appreciate that comms are an important part of any space project.

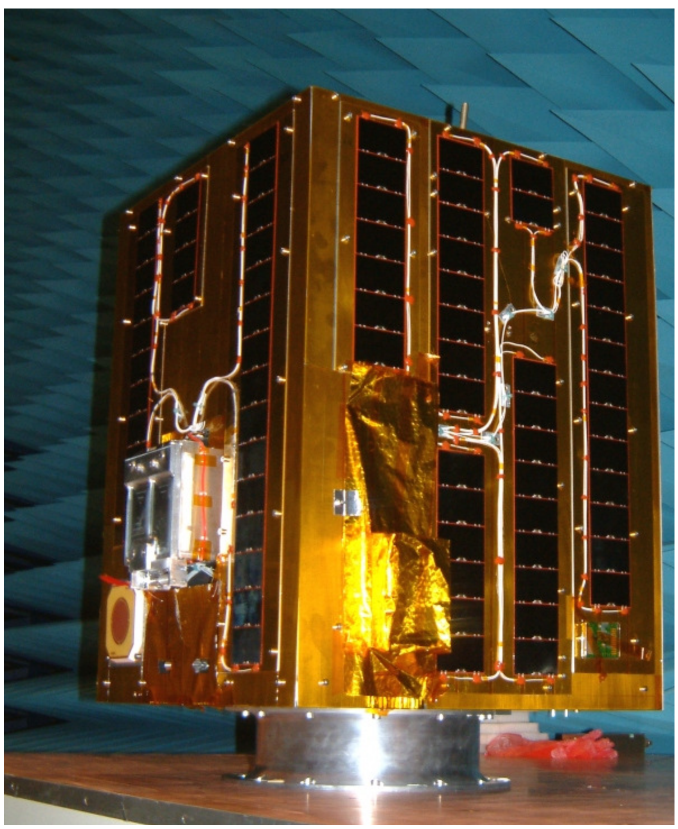
It has not been a one-way street however as we have learnt many lessons! In response to the request at last year's AMSAT Symposium for these to be recorded - here are some of them:
Don't necessarily use the first PTFE wire you are offered.
Smaller is better and white is best -No pink wire!
Use proper wire strippers - You don't want to cut ANY strands.
Use multistrand wire. Tin the exposed end of the wire.
Use the proper tool to limit the solder to the wire so that it doesn't leach under the insulation.
Use flight qualified solder. Maybe it has flux. Maybe it doesn't! Any flux must be non-corrosive.
Try to wrap the tinned wire around a solder post on the PCB if possible.
If you need to solder down onto a pad, the wire MUST be glued to the board near the joint but not to any adjacent components.
Make sure you use gloves after the initial cleaning.
A microscope reveals a lot!
IPA cleaning is best done with a lint-free tissue and a stiff brush applied gently to the surface of the board.
Don't use solder resist. It interferes with the conformal coating adhesion.
You can use tantalum capacitors. You can't use tantalum capacitors.... Ditto Flash RAM
Don't use trimmer capacitors or resistors. They will change value with vibration.
All tuned circuits are preferably implemented with SMD inductors and capacitors. You need a SMD tuned circuit 'tuning kit.
Use only space qualified glue -It can be peeled back if necessary, later.
There is a proper way to 'dress' the wire away from the joint.
Use only PTFE wire tie wraps. You can use aluminium wire anchor points.
They should be self adhesive- but watch the glue type used.
Coax leads should be small gauge.
Coax ground (braid) should be soldered to light gauge stranded wire and not pigtailed.
Dress back from the joint and seal with heat shrink tubing.
Conformal coating is messy and can get where you don't want it.
Keep it clear of RF components and tracks, especially ones operating above a few hundred MHz.
Use small RF connectors where possible - Plan ahead as they have limited connection/disconnection cycles.
Use 'savers' where possible and where you anticipate a connection being opened for subsequent testing. SMA connectors will be torqued for flight and may be glued. Think ahead.
Make sure you note down all test voltages before the unit is integrated.
It can help avoid having to scrape away glue etc later when you realise you needed to know!
Space glue doesn't seem to affect either ferrite coil cores or helical filter cores if applied sparingly.
It does hold well in vibration testing.
Transmitters and receivers are well tested before flight but maybe not as well as you might expect!
Make certain the transmitters perform when seeing less than a perfect match
Heat cycle and test the transmitter and receiver before and after integration
Have a method to non-invasively test the transmitter and receiver after integration and sealing.
Check the transmitted field strength and record with the other test results.

A complete record of the integration of SSETI Express is available as .pdf download at http://sseti.gte.tuwien.ac.at/WSW4/downloads/express/EXPRESS_D_ESA_Integration_Logbook.pdf

At the time of writing (mid August), we are waiting for the final confirmation of the launch date and time. Almost everything is ready but work on the software needed to request and collect the telemetry that will be downlinked on at 9k6 on 437.250MHz and at 38k4 on 2401.835MHz is still underway. All details will be available at the www.sseti.net website – click on the "Express Mission Operations" tab.

ESA and the SSETI team are very keen that radio amateurs should be encouraged to collect the telemetry and for them to forward the data to the Mission Control Centre over the internet and an exciting prize is offered for the amateur who manages to send them the largest amount. We have a unique facility in our worldwide ad-hoc network of satellite groundstations and this may help us negotiate for the inclusion of amateur transponders on similar projects in the future.

Hopefully by the time the AMSAT Symposium takes place in Lafayette, SSETI Express will have been launched and be orbiting and operating correctly!



The SSETI Express Flight model in the anechoic chamber

The Postscript – November 3, 2005

As most readers will be aware, after a number of further delays in the time schedule, SSETI Express was eventually launched successfully from the Plesetsk Cosmodrome in northern Russia at 06:52:26 UTC on October 27th 2005.

The launch campaign team, consisting of five SSETI team members, including G3VZV, had spent almost five weeks in Plesetsk preparing Express for launch. This involved testing every system, fuelling the nitrogen attitude control system and charging the total of seven on-board batteries. This progressed almost without a hitch except that we were initially surprised when we experienced some difficulty communication with Express on 437.250MHz. We quickly discovered that this was due to some major QRM emanating on almost exactly our frequency from the computer system in some other test gear being used in the integration facility! Luckily we found that QSYing our test groundstation radio, a THF6 handheld, by 5kHz LF solved the problem.

The launch was flawless and 103 minutes later the launch team were able to use the THF6 handheld, with a 7 element Arrow antenna in the other hand, to hear the first bursts of data that the satellite transmitted. This demonstration and the fact that the official groundstation in Aalborg were also able to hear the signals, download the data and command the satellite on the very first pass was considered near miraculous by the ESA personnel and other the VIPs who attended the launch. The latter success was as a result of the very strong involvement of Ib OZ1MY and other members of the AMSAT-OZ team who gave great support to the students.

Sadly, after the intial euphoria, the telemetry showed that the battery volts were declining rapidly and it seems that the solar cells were not charging. From suspense to elation to amazement to despair - all within about six hours - it was a really roller-coaster day.

It is still believed possible that Express could reappear sometime in the future, if it is heard first by an amateur they will get a major prize from ESA - please send a report to missioncontorl@sseti.org

The SSETI team will be preparing a full report on their analysis of the problem and the general lessons learnt on the project and this will be published before the end of the year. One of the problems that we identified was that the teams were not using UTC everywhere but a mixture of UTC and Central European Summer Time (actually UTC +2). The effects were similar to mixing standard and metric units..

Although the primary amateur radio objective of this mission has not been fulfilled, the mission has given us a great and valuable opportunity to work with ESA and other major players. I doing so we were able to show them the benefits that this type of cooperation can bring to everyone involved.

The websites mentioned previously continue to be maintained and, where needed, are being kept updated. The AMSAT-UK team are keen to expore other opportunities in the future!

PCSAT2 and AX.25 Packet Radio for University Payloads

Bob Bruninga, WB4APR, and Midshipmen C. Otero,
H. Evans, T. Kolwicz, M.Silver, E.Henry, D Jones (see photo 1)

US Naval Academy Satellite Lab
590 Holloway Rd, Annapolis, MD 21402
bruninga@usna.edu 410-293-6417 FAX 410-239-2591

Abstract

PCSAT2 was activated on 3 Aug 2005 and is a follow-on digital communications payload to the highly successful PCsat[1] that was launched on 30 Sept 2001. PCSAT2 evolved from our success with PCsat's off-the-shelf command, control and telemetry design and the Navy's availability of a solar cell experiment that was going to fly as an external payload on ISS. Due to the Navy's short fuse and with only 9 months development time available, the Navy payload was going to be a passive sample-return mission with no external communications capability. But since it was a solar experiment, the non solar facing half of the experiment box was available for an educational payload.

Combining the two missions lead to synergistic advantages for both parties and a resulting communications experiment that was perfect for operating within the rules of the Amateur Satellite Service[2].

The original PCsat was a complete success and it has been used by thousands of users in its first 19 months of flight. It has validated the viability of using off-the-shelf AX.25 for all Telemetry Command and Control as well as supporting a bent-pipe user communications mission. We have many lessons learned and experiences with spacecraft operations from PCsat and many ideas for the future. This paper summarizes the design and operations background from PCsat and then provides details for the PCSAT2 mission design.

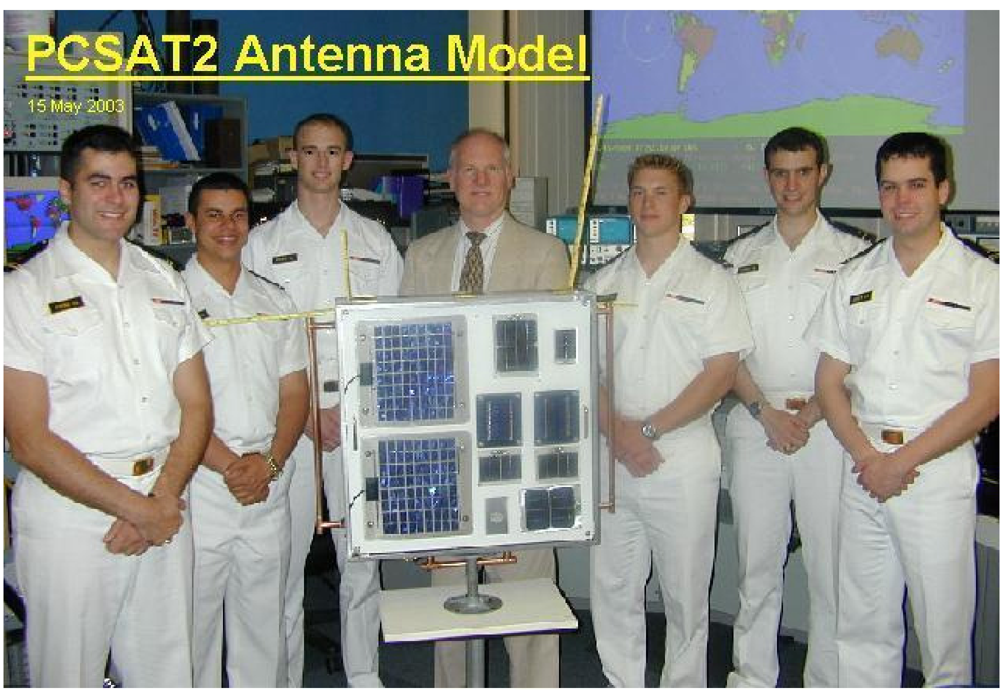


Photo 1. The PCSAT2 Design Team at the US Naval Academy

The PCSAT APRS Mission

The digital communications mission implemented in the original PCsat and now PCSAT2 is a generic mission using the ubiquitous AX.25 protocol used in many of the satellites in the Amateur Satellite Service. The digital transponder provides real-time message, position, and status relay via satellite to a worldwide Internet linked amateur radio tracking system. Any amateur or university payload can support this mission by simply enabling the DIGIPEAT-ON function in any AX.25 compatible transponder (TNC). The users of such a relay system can be for Boats at Sea, remote environmental sensors[3], cross country travelers, expeditions, school projects, or any other users which are far from any existing APRS terrestrial digital network.

The AX.25 satellite downlink from this mission is fed into the existing worldwide Internet linked ground system by participating ground stations. Our ultimate objective is to have all such AX.25 satellites work together as a constellation of digital transponders to provide connectivity to everyone in the Amateur Satellite Service[4].

Photo 2. Prototype Communications Satellite (PCsat) with Antennas

The Space segment of PCsat/APRS had been demonstrated a number of times in space via MIR School tests[5,6], the Shuttle SAREX[7], the SPRE mission, AO-16, UO-22 and more recently via SUNSAT and ISS and PCsat. Full details of the PCsat mission can be found at:

http://www.ew.usna.edu/pcsat

http://www.ew.usna.edu/~bruninga/astars.html

PCsat Mission Accomplishments

Although the original PCsat was only designed for a one year mission, it continues to operate (now after 48 months) with no on-orbit failures except for the failed –Z solar panel on launch. This reduced power budget by over 20% and caused early weakening of the battery system due to deep cycling during long eclipses. Still, PCsat comes alive on every orbit if it is in midday sun. During the first 19 months of operations, it logged over 2000 users all around the world and the worldwide amateur tracking network fed all data live to the http://pcsat.aprs.org web page so that it was available to everyone participating live.

Further PCsat communications were used in a number of high profile Amateur Satellite demonstrations and events. See the PCsat paper in last year's proceedings[8].

Also, PCsat carried a successful GPS system which conducted several acquisition and accuracy experiments[9].

The popularity of PCsat was evidenced by coverage on National Public Radio on 13 Nov, Online-Tonight and CNN on 27 Jan 2002. Stories were also widely published by the Associated Press, Air and Space magazines as well as all of the Amateur Satelliite literature giving great exposure to the Amateur Satellite Service and student developments.

Design Validation

The following elements of PCsat's design were validated and performed flawlessly:

- Dual Redundant payloads/systems
- Commands and Hardware redundancy
- Commercial Teflon coated solar panels
- Orbit temps within 10 deg variance
- Thermal design balanced within 5 deg
- Radiometer spin between .5 and 1 RPM
- Magnetic Stabilization
- Good link budgets
- Ground station Internet Linked system
- Fail-safe circuits and SEU recovery
- Discipline of User Service Agreement

The only failure was the –Z solar panel, which was actually anticipated as it had had two problems during manufacture but was flown anyway because we had no backup.

AX.25 Digital Communications Protocol

An advantage of the AX25 protocol is that any node in the system can be used for relaying data between any other nodes. Thus, the TNC can not only provide the dedicated up and downlinks and command/control channels, but also serve as a generic relay for other applications on a secondary basis. Examples of TNC's on orbit are SAREX, SPRE, MIR, ISS, SUNSAT, OPAL, PCsat, SAPPHIRE and STARSHINE-3. But PCsat was the first to use the TNC as the complete Spacecraft system controller with no other CPU's on board.

PCSAT2 HARDWARE REQUIREMENTS

The full design of PCSAT2 is on-line at www.ew.usna.edu/~bruninga/ pcsat2.html.

Since PCSAT2 was designed in our Aerospace Department and there were no participating students with experience in software or CPU design, the satellite control system was designed around two KPC-9612+ Dual Port TNC's. These TNC's have all the latest APRS generic digipeating advantages as well as telemetry, command and control and can even cross route packets between ports. By using standard off-the-shelf TNC hardware and FIRMWARE, on orbit risk was minimized due to the track record of thousands of identical hardware in use all across the country.

The dual baud rates of the dual port KPC-9612+ were used differently. The bulky solar experimental data was transmitted in short 1 second bursts at 9600 baud to minimize channel load while user communications took advantage of the 7 dB better link budget on the 1200 baud port.

Further, the availability of the dual receivers and transmitters allowed for other experimental communications modes to be supported such as PSK-31 multi-user narrowband transponder and a voice FM repeater as shown in Figure 3 and later in Figure 7.

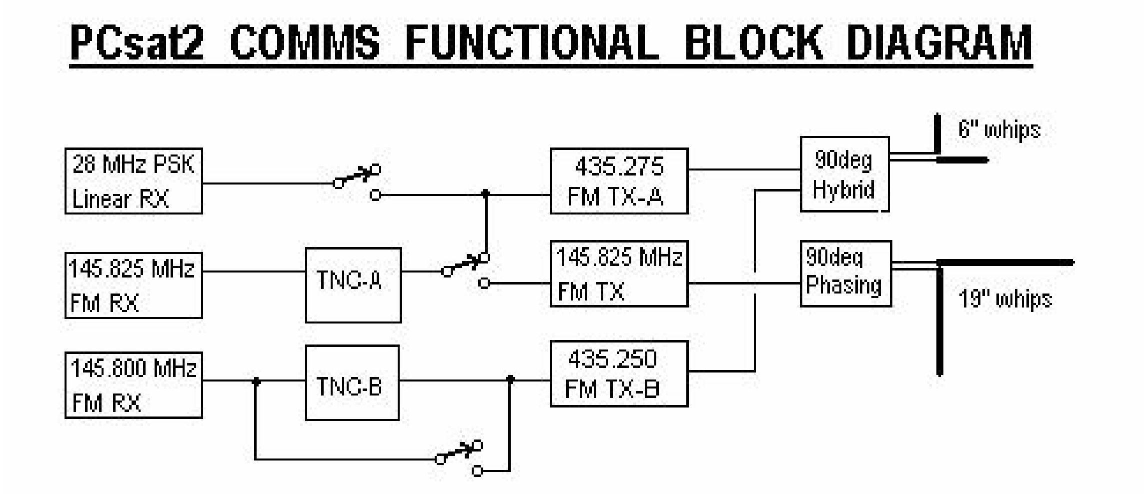


Figure 3. PCSAT2's dual AX.25 command and control system transponders can also be switched into modes to support PSK-31 and FM voice operation.

The PCsat 9600 Baud KPC-9612+

The Kantronics 9612+ TNC as used on PCsat and now designed into PCSAT2, has dual serial comm ports supporting both 1200 and 9.6 to 38.8 Kbaud. The 9612+ also offers 5 analog telemetry channels and a total of 8 configurable command or I/O bits, plus four ON/OFF command bits and one input bit. These features were sufficient to handle all of the Telemetry Command and Control for PCsat and PCSAT2 as detailed below.

PCSAT2 Design for Space Station

PCSAT2 is not a free-flying satellite, but an attached external payload for installation on the ISS by an Astronaut during an EVA. This presented many design challenges that are quite different from a free-flyer in the areas of power, safety and thermal. The PCSAT2 comms

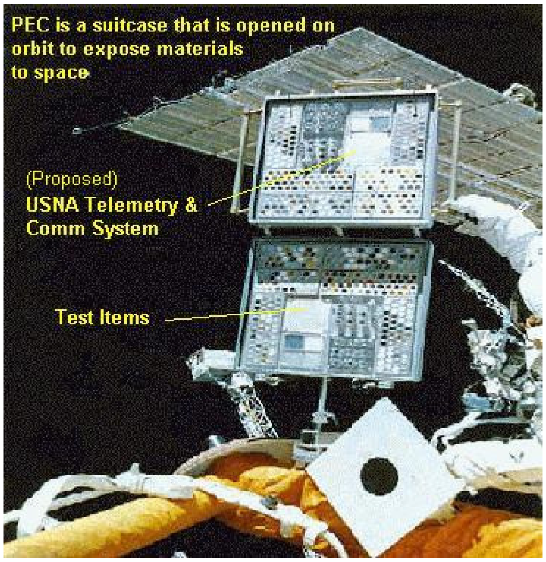


Figure 4. The PCSAT2 "suitcase".

payload is in the back half of a suitcase like box that is opened on orbit to expose the new technology solar cells to the space environment as shown in Figure 4.

Since the ISS is flown in a stable attitude, this means that the solar arrays on one side of PCSAT2 would only face the sun under unique orientations. Fortunately, the articulated solar array truss was to arrive on station prior to PCSAT2's arrival so we were offered an attachment point beyond the alpha solar joint so that our panels would move with the station's arrays. Unfortunately, delays in the Shuttle program have now made our arrival after this solar array truss and current plans may attach us in a fixed orientation with much less average solar power available.

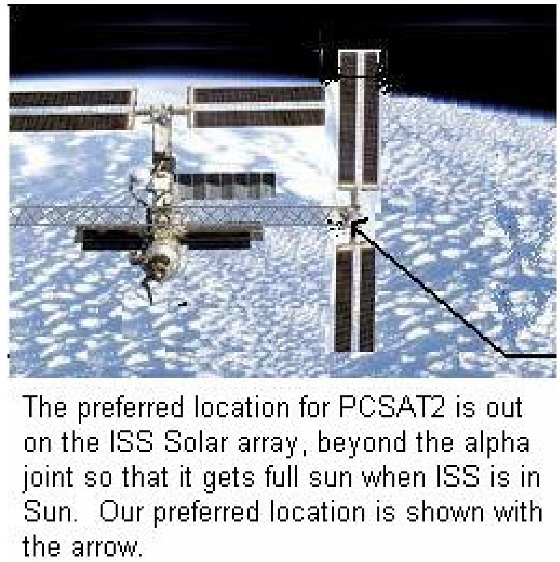


Figure 5. Ideal location of PC2.

PCSAT2 EVA Safety Issues

Since PCSAT2 is flying on ISS, and was installed by an astronaut during an EVA, the man safety requirements were significant. The 2 watt transmit power for the PCSAT2 communications systems exceed the

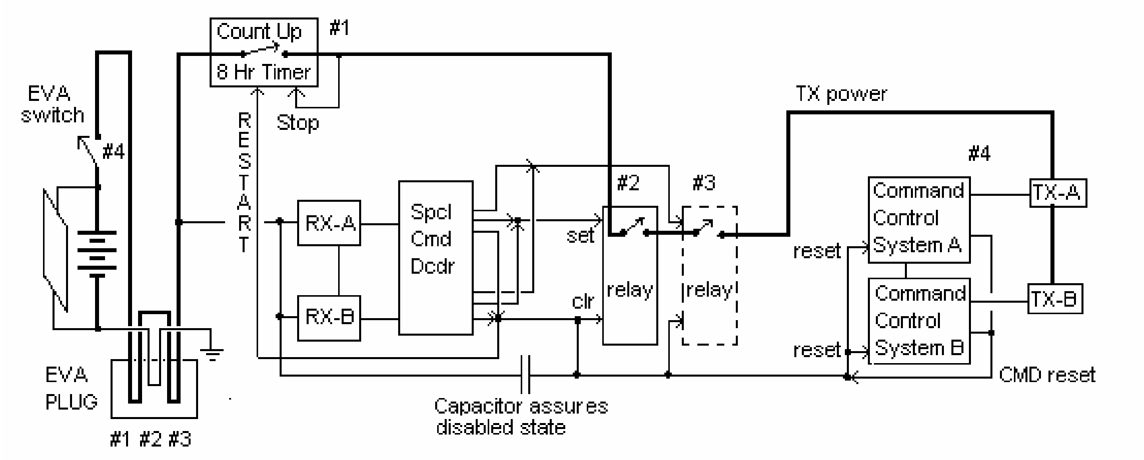


Figure 6. Transmit Inhibits required for Astronaut Safety during EVA.

safe limits for operation near an astronaut in an EVA suit and are considered a catastrophic hazard by NASA. To assure safety, one switch and 3 more redundant power-inhibit contacts were required while the PCSAT2 was in the payload bay and while being handled by an astronaut. Further, once PCSAT2 is installed by a crew member, there has to be four additional transmit inhibits to preven any inadvertent activation from the ground until the installing astronaut is clear of the device. This was accomplished via an additional 8 Hour timer and 3 more ground commandable inhibits.

PCSAT2 PSK-31 Multi-User Transponder:

PCSAT2 is the first satellite to support a dedicated PSK-31 digital transponder[10]. PSK-31 is a digital Phase Shift Keying mode that is very successful with weak signals and is an ideal mode for students to learn about easy communications via satellite. PSK-31 is only 31 baud and because of its narrow bandwidth, up to 20 or more signals can share a single voice equivalent transponder channel.

Another significant advantage to PSK-31 is that the original author wrote the modem in software and made it public. Thus, only a PC with a sound card is needed for this very exotic communications technique. Figure 7 below shows the typical audio spectragram showing that there are 6 PSK-31 signals in the passband. Two of them are decoded in the text boxes shown and a seventh station has transmitted his callsign in what is called Hellinschreiber which is a quasi FAX technique in the same spectrum.

PSK-31 communications has not been practical through other satellites because of high Doppler. Being only 31 Hz wide, accurate decoding has to be with a Hz or so and with satellite downlinks experiencing as much as +/- 10 KHz during a typical pass, it is just not practical. But PCSAT2 solves the problem of Doppler by using an HF frequency for uplink which only has about +/- 600 Hz Doppler spread over the 10 minute pass, but then eliminates all linear downlink Doppler by sending down the entire passband as a single FM audio channel. As long as the FM signal stays within the passband of the receiver, the signals are received without Doppler. Thus, everyone sees the same audio spectrogram and the only source of Doppler is each stations own uplink Doppler for which he can easily compensate.

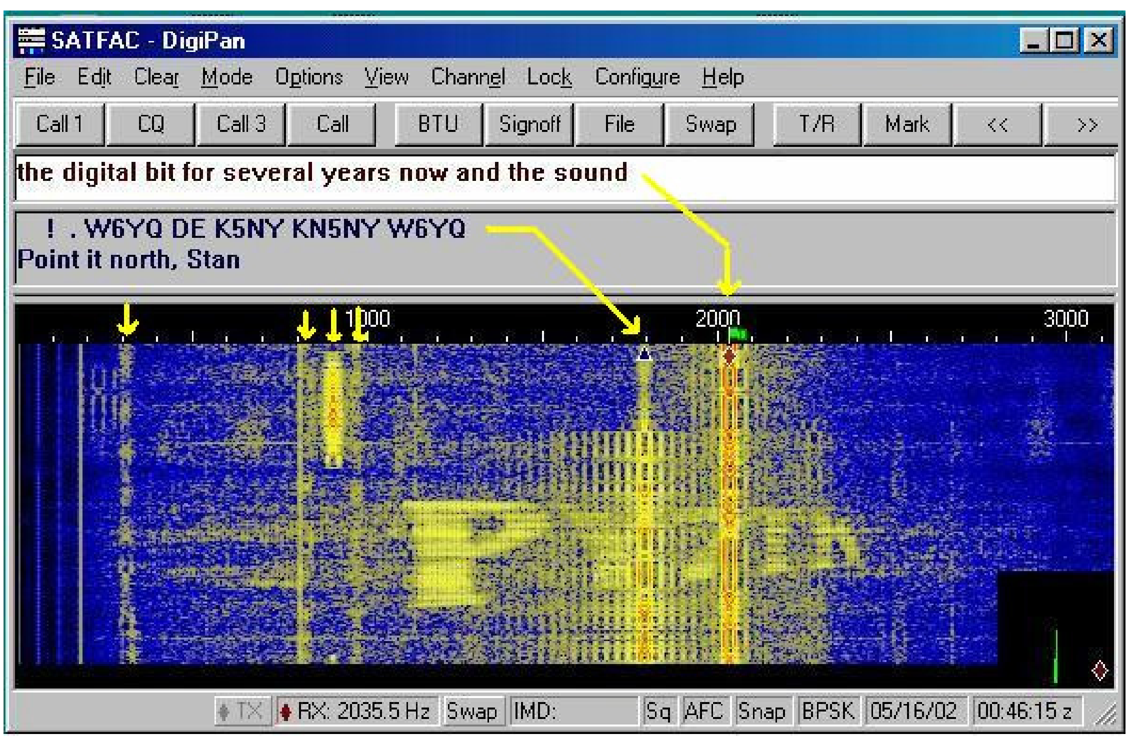


Figure 7. The PSK-31 audio spectragram showing 7 user signals.

PCSAT / ASTARS BACKGROUND

ASTARS (for APRS Satellite Tracking and Reporting System) is the space segment of the APRS system which has evolved through a number of existing and previous satellite experiments. First was **1200 Baud PSK ASTARS** (called TRAKNET [11] at the 1998/99 AMSAT conferences) using AO-16, LO-19 and IO-26. But these required specialized modems.

Satellite packet experiments using **1200 Baud AFSK ASTARS,** however, which *any* TNC can do, were demonstrated many times during experiments with the Space Station MIR[6] packet system and SAREX[7]. A week long experiment via MIR which used the new Kenwood TH-D7 During this test[5], over 55 stations conducted 2 way hand-held message communications.

In the year 2000, experiments were conducted with **9600 BAUD ASTARS** using UO-22 and SUNSAT and the new Kenwood 1200/9600 baud APRS data mobile radio, the TM-D700A shown below.

Photo 8. Chas Richard, W4HFZ's mobile APRS Satellite capability (including HF.

PCSAT and the INTERNET

Unlike previous Amateur Satellite design, PCsat capitalized on the connectivity of the Internet by linking together multiple disparate downlink sites to provide a tremendous gain in reliability through space and time diversity reception. Instead of each station requiring their own downlink receiver and then only being able to hear packets within his own footprint, the Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure (TELNET to second.aprs.net) for delivery to any APRS operator anywhere.

Photo 9. The front panel of the TM-D700 showing an incoming 15 byte message (Messages can be up to 64 bytes).

FAILSAFE RESET

To recover from a SEU or other lockup condition in these commercial off-the-shelf TNCs, PCSAT2 uses 3 methods of hardware resets back to launch defaults. First, there is a 96 hour hardware reset timer that will reset the TNC's if it has not been contacted at least once every 4 days. Second, a hardware command via one TNC can reset the other. Third, a backup command system has a backdoor reset capability for each TNC.

TELEMETRY

PCSAT2 uses the APRS five channel TELEMETRY format published for the MIM module in 1995 that Kantronics subsequently added to their "plus" family of TNC's. To make this usable on PCSAT2, we added a 20-to-5 hardware multiplexer to allow telemetry to read as many as 20 analog values and 5 status bits transmitted in four consecutive telemetry packets. For others contemplating similar AX.25 satellite systems, photos of the MIM module and KPC-3+ are shown below.

The MIM Module

The simplest Telemetry module is the one cubic inch MIM module developed at the Naval Academy which provides for multiple periodic AX.25 packets at 1200 baud AFSK with up to 5 analog channels and 8 on/off bits. Different rates can be set for the BEACON, Telemetry, GPS position and CW ID's. The module has no command and control capability, but that is easily added with CTCSS or DTMF decoders. The MIM module, developed at the Naval Academy, is no longer available, but represents the compact size of many of the follow-on PIC processor TNC developments..

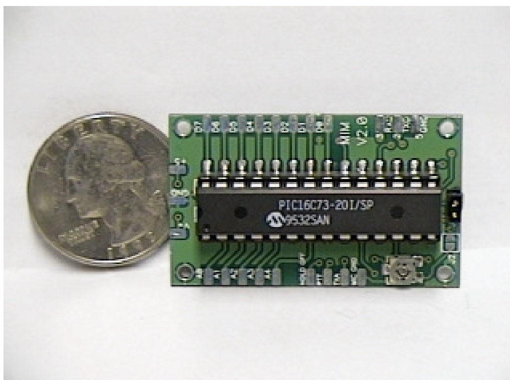


Photo 10. The MIM module developed at the Naval Academy. A complete TNC transmitter with telemetry on a chip (no receiver).

1200 Baud KPC-3+

The second and more capable telemetry is the use of a Kantronics KPC-3+ TNC which has the advantage of an AX.25 data receiver and thus the ability to do command and control. It can even be carved down to fit within a four inch cubesat with some drastic mods. The KPC-3 is being used as the comm. Payload on the ANDE and RAFT missions [12, 13].

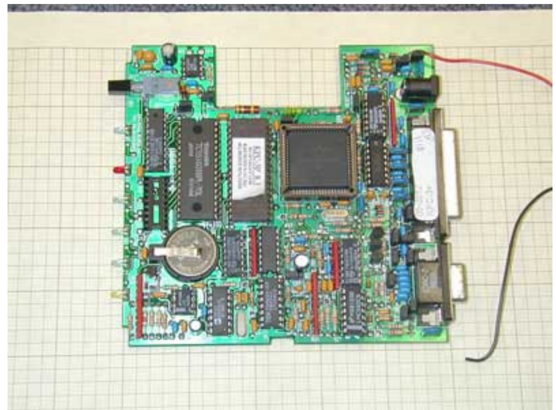


Photo 11. The KPC-3+ TNC system.

This gives the same Telemetry, Beacon, GPS and CW ID capability as with the MIM module, but includes a full TNC DIGIPEATER and 4 channel COMMAND/CONTROL channel as well.

LINK BUDGET

The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. For this, the downlink needed to be at least 12 dB stronger than most existing digital satellites. PCSAT2 accomplishes this by taking advantage of the 9 dB link improvement of 2 meters compared to 70 cm and by using a 2 watt transmitter. Unfortunately, 2 meters may often conflict with other Amateur Radio Experiments (ARISS) on the ISS, so PCSAT2 was designed with the less desirable UHF downlinks as the default. If operations permit, the VHF downlink will be used when possible. The digital trasnponder operates at a low transmit duty cycle so it is easy to power relatively high power transmitters. The Amateur Satellite user population only covers 10% of the earths surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of PCSAT2's average transmit power budget is required for AX.25.

The VHF link budget on the uplink is also suitable for low power devices and other experiments. There are several student projects using stand-alone tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [3].

SAT-GATE OPERATIONS

The Mobile-to-mobile and HT-to-HT communication missions work without any special considerations on the satellite or on the ground. But the more useful application of linking these packets to any other APRS station worldwide requires the use of many volunteer ground stations. They feed every packet heard into the APRS-Internet system (APRS-IS). These SAT-Gates perform the following functions:

1) Monitor both downlinks and feed ALL packets into the Internet
2) Maintain a track on all Calls heard via satellite
3) Monitor the Internet and capture MESSAGES for these Calls
4) Deliver these messages repetatively but at a "fair" rate

OMNI NO-TRACK SAT-GATES

Setting up a SATgate is trivial requiring nothing more than a normal packet station and omni antenna. Any APRS station can do it with existing software which contain the built-in Igate capabilities. For stations not interested in the map features of conventional APRS, the ALOGGER program by Bill Diaz provides a background data capture and SATgate capability. Even without horizon-to-horizon coverage, each such station simply contributes their packets to the same worldwide stream as all the other Igate receivers. The combination results in over a 99.96% chance of capturing every packet over the USA! Just 4 such stations even if they only have a 60% chance of decoding each packet, combine to a probability of 98%. If the original packet is replicated TWICE, then this probability becomes 99.96%! A Certainty!

CONCLUSION

Current Technology caters to the man on the move. Satellite Wireless is the leading edge of technology and in the Amateur Satellite Service, it should be a major driver for future amateur satellite and educational missions. PCsat has fulfilled this mission objective and now PCSAT2 and ANDE will continue this mission. During the the first 18 months, over 2000 users were logged by the PCsat system feeding the http://pcsat.aprs.org web page and browsers scored over 1000 hits a week from users checking on the status of PCsat or other users.

AX.25 transponders on 145.825 MHz are ideal for extending Amateur Satellite digital communications services to mobile and handheld users because of the availability of not only the off-the-shelf end user mobile and handheld fully integrated data radios but also the off-the-shelf spacecraft design demonstrated by PCsat, PCSAT2 and ANDE.

Combining this with the recent maturity of the Internet as a global resource for exchanging data worldwide suggests that there is a unique opportunity to join the Internet and Amateur Satellites as a means of tying together SatGates throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist.

By encouraging UI digipeating as auxiliary payloads on most small satellites the Amateur Satellite Service can bring all of these pieces together into the most powerful and far reaching Amateur Satellite project to date. Student projects and educational institutions can easily contribute to this capability while also serving their own needs of viable payloads and ongoing operations training.

REFERENCES:

1. The PCsat Mission and Cubesat Design Notes, Small Satellite Conference, Ogden Utah August 2001
2. http://web.usna.navy.mil/~bruninga/pec/pec-itu.txt
3. Antarctic Expedition, AMSAT Journal, Winter 2000
4. Satellite Builders Channels, 17^{th} Annual AMSAT Symposium, pp191-5
5. http://web.usna.navy.mil/~bruninga/mir-ht.txt
6. http://web.usna.navy.mil/~bruninga/mirex.html
7. http://web.usna.navy.mil/~bruninga/sarex.html
8. PCsat…. Small Satellite Conference, Ogden Utah, August 2002
9. GPS Operations on the PCsat Microsatellite, ION GPS 2002, Sept 24-27, 2002, Portland Oregon

10. http://web.usna.navy.mil/~bruninga/psk31uplink.html
11. http://web.usna.navy.mil/~bruninga/traknet.html
12. http://www.ew.usna.edu/~bruninga/ande.html
13. http://www.ew.usna.edu/~bruninga/raft.html

NEAR SPACE SCIENCE IN EDUCATION

Jerome, K5IS, and Bobette, N5IS, Doerrie

There is increasing interest in using weather balloons as "the poor man's space shuttle" to carry student experiments aloft in science courses at all levels of education. Ham radio operators are often called upon to assist with the tracking and recovery of these balloons. You may be interested in joining one of the ham balloon groups, forming a balloon group, or in mentoring a school class. In this paper we describe some of our experiences and tell about what we have learned from flying "weather" balloons for 13 years up into the thin air of near space at altitudes of 70,000 to 120,000 feet (13 to 22 miles).

In the fall of 1992 physics teacher Bobette Doerrie, N5IS, started the Perryton High School Reach For Space program as an enrichment project for her science students. Our first balloon flight was in the spring of 1993.

First, we thought we needed balloons.

It began when Bobette attended a presentation on remote sensing at the state science teachers conference. A contest sponsored by the Texas Space Grant Consortium called SkyView involved taking pictures from some platform carried up into the air by a balloon, a kite, or a model airplane. It had obvious amateur radio applications, because she wanted to use radio signals to command the camera. In 1992 at a hamfest in Amarillo, Texas, we found a surplus dealer with a case of weather balloons. A deal was made and we had balloons. We knew nothing about lift capacity, ascent rates, burst altitude, tracking, recovery, amounts of helium needed, regulations, or the effect of age on latex balloons. We had balloons and we began our journey on the learning curve. Published information at that time was very difficult to find. Bill Brown, WB8ELK, was encouraging ATV interest groups to use balloons as a platform for television repeaters. Details of various first flights were featured in his 73 Magazine ATV column. We had read several of the articles and decided we were ready to fly.

On a Saturday in March, 1993, painters' drop cloths were spread on the floor of the auto shop at Perryton High School, payload pieces were assembled in a Styrofoam picnic cooler, Balltrack (DOS version) was running on a computer, a Samsung 35 mm camera was taking pictures of shoe laces every 3 minutes, and a label with our contact information and offer of a reward was taped on the cooler. The balloon, a surplus 1400 gram Kaysam, was getting larger and larger as it filled. Maybe it would be a good idea to finish the filling process outside. Something about helium going into a balloon causes wind to appear. It's magic. In this case, as the helium was going in, some wind started spinning our balloon around and around, twisting the neck tight. Each time the helium had to be shut off and the balloon untwisted. In a few minutes of what seemed like forever, the filling was finished and while we were attaching the payload to the balloon at the neck, the balloon envelope broke free, flying about as if it were an escaped bird. The payload stayed behind for us to stumble over. **Lesson # 1:** Don't start the camera until just before liftoff. **Lesson # 2**: Have extra helium on hand. We had more balloons, but were out of gas. We were initiated into the Fraternal Order of Ham Balloonists!

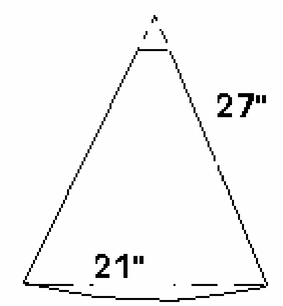
Same song, second verse, and preparations were under way for launching in July. Again, we used the auto shop, but this time because of strong wind gusts of surface winds, we finished filling inside. When we took the balloon outside we had difficulties clearing the building and vehicles before releasing. The sight of the ascending balloon and payload was beautiful, encouraged along by shouts of joy from the launch team. The Balltrack predictions indicated the flight would start out to the northeast, then loop back around and travel 100 miles west in 6 hours. We thought we had lots of time, so we let our attention be diverted from the balloon and 93 minutes into the flight, the beacon signals vanished. **Lesson # 3**: Have trackers' attention on balloon position at all times. We had to run a newspaper article titled "Lost, One Really Ugly Balloon." We got lucky when some boys, riding dirt bikes in a pasture 17 miles northwest of Perryton, found the remains and called us. Thirty days later we retrieved. **Lesson # 4**: Use better packaging than Styrofoam picnic coolers. The payload hit a boulder and the contents inside shot upward, bursting through the lid. The crystal came out of the socket, causing the 2 watt 146.52 transmitter to cease operation. Even after 30 days in the rain and sun, the transmitter worked when another crystal was plugged in! Incidentally, chase team members had driven within a mile and a half while blindly looking to signs of the parachute and payload. The videotape of the launch shows someone grabbing the balloon with a pinch grip to prevent the balloon from hitting a vehicle. **Lesson # 5**: Handle the balloons gently. The Kaysam balloon has an initial thickness of 0.0035 inch and at burst altitude it will be approximately 0.0001 inch. We wear soft brown cotton or surgical gloves while working with the balloon to protect the fragile surface from our hands. Now we purchase new Toltex balloons from Kaymont Consolidated Industries of Huntington Station, New York. (www.kaymont.com) (631-424-6459) **Lesson # 6**: Have plenty of line between sections of the payload; we often use six feet or more, to prevent tangling, as apparently happened in flight # 2. A payload without an open parachute can hit the ground over 100 mph! **Lesson 7:** Use a wooden embroidery hoop on the parachute lines to help keep the lines from tangling and the chute open.

All balloon enthusiasts work on the same basic problems: payload components, selection of power sources, tracking, payload packaging, telecommand, recovery, flight prediction, balloon selection, and how to improve our techniques. In true ham fashion, there was much being done by trial and error. Murphy's Law was a frequent visitor to each launch. One group near the Gulf of Mexico had put color TV, and other nice electronics into a payload package that was not waterproof or floatable. The winds aloft carried this flight out over the Gulf, never to be seen again. They now launch much further inland and pay much closer attention to the winds aloft! There are lots of stories about the bumps in the learning curve. A conference dedicated to ham ballooning, the first National Balloon Symposium, was hosted in Denver by Edge of Space Sciences (EOSS) in August of 1993, just two days after the recovery of our Flight #2. Groups represented at this first conference included the host EOSS, Pacific Northwest Balloon Launch Team, Bill Brown WB8ELK, Perryton High School "Reach For Space", Wichita Area Balloon Chasers, Space Science Over Kansas (SSOK), North Texas Balloon Project, Utah State

University, and HABET (Iowa). The EOSS Handbook and Symposium Proceedings helped fill the information void and allowed many more individuals and groups to get into ballooning. We estimate that over 600 ham missions have now flown. For instance, Reach For Space #20 was one of the six that flew on Saturday April 16, 2005. Interest in flying balloons is on the rise. Ralph Wallio, WØRPK, is collecting records of the various balloon flights and posting them to a web page at *http://users.crosspaths.net/~wallio/*

There is always a parachute

The parachute is made from rip-stop nylon, which costs about $5.00 a yard. The most visible fabrics are fluorescent pink, yellow, or orange, and a yard and a half makes two parachutes. Of course, you need two only if you lose the payload, since the parachutes are reusable! Cut six panels, using the pattern, and sew them together. Press each seam to the side and sew again, ¼" from the seam, and trim off the excess. The top of the parachute is open and hemmed, with crossed straps made of 1"strips of the nylon folded in half, then the sides folded into the middle and sewn. These are pinned in an X across the opening and securely sewn to opposite sides of the hole. Hem the bottom of the parachute, and attach grommets (metal eyes) through the hem at each seam (and halfway between if you prefer). These are applied with a special pair of pliers (about $12.00) or a hammer and the little shaped rod that comes with the grommets. Four feet of nylon string is tied through the grommets, double knotted, and hot glue is put on the knots. One of the tips we got from other groups was to add a hoop at the bottom of the parachute strings, to prevent tangling and loss of the payload if the parachute doesn't open. The end of each string is then tied to the hoop, double knotted, and hot glued. A swivel is attached to the center of the crossed strips at the top, to separate the rotation of the balloon from the payload. Four lines go from the hoop through the eye of another swivel for the payload string below.



50" diamater for six lb. payload

Keep it legal

As individuals, we like to think we are free to fly balloons and kites when ever we desire. However, there are regulations concerning what can be located in the air above us. For instance, few people realize there are regulations for the little rubber balloons that you see at car emporiums. We suspect the owners of the car lots are not aware of the regulations, either. Rules for blimps, kites, unmanned rockets, moored balloons, and unmanned free balloon are found in Part 101, subchapter F, Air Traffic and General Operating Rules, of Title 14 of the Code of Federal Regulations. (This string of words is the official name for the regulations.) There is some room for interpretation as to what is meant by "use a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon." We had some students run a series of drop weight tests on #18 stranded nylon string. They found the breaking point to be 11 pounds. We use up to 4 strings in parallel for our load bearing lines that hold payload to parachute and parachute to balloon. Some other groups interpret this to mean a cutting force and use a stronger string than we do. We know to melt the ends of the nylon string after we cut it…but learned the hard way that knots in the string can untie themselves. **Lesson # 8**: Hot glue all knots. Needless to say, knot failures are not any fun, especially when they untie themselves at some altitude!)

There is a blanket exemption for payloads under four pounds. If you meet certain size requirements, then the payload can be up to six pounds and it is possible to string on several payloads packages if everything is 12 pounds or under. "No person may operate an unmanned free balloon in such a manner that impact of the balloon, or part thereof including its payload, with the surface creates a hazard to persons or property not associated with the operation." "Nor may you operate during the first 1,000 feet of ascent over a congested area of a city, town, or settlement or an open-air assembly of persons not associated with the operation." **Lesson # 9:** Move launches away from the school and town setting. Also, "At least two methods, systems, devices, or combinations thereof that function independently of each other, are employed to terminating the flight of the balloon envelope; and the balloon envelope is equipped with a radar reflective device." If you fly latex balloons, the natural bursting ability of the balloon counts as one of the cut down devices. Rubber balloons are required to have two devices. Cut down methods will be discussed in another section of this paper.

A radar reflector is a simple addition. A friend connected with the oil field told me about a field experience in the late 60s near Midland, Texas. Work was slow, so to entertain themselves someone brought out a big party balloon, they filled it with some helium, tied a roll of aluminum foil to it and let the foil unroll as the balloon took off. They were having a lot of fun until a couple of interceptor jets appeared overhead. They ended up agreeing with the Air Force officials that chasing jack rabbits would be a much better cure for their boredom and they certainly would not ever do any party balloons again. We assume this story confirms the usefulness of using aluminum foil as a lightweight radar reflector. For several flights, we laminated 12 to 15 feet of aluminum foil.   Now we use the "space blankets" to make mechanically stronger reflectors.

These rules can be found on the EOSS web page at www.eoss.org.

Payload containers

Container design doesn't follow any rules.   On our flight #20, we experimented with duct taping things to the outside of a payload container. As long as the batteries don't freeze (- 60 Celsius), it appears the electronics may function fine. We have many great photos from a $20.00 Vivitar 35 mm digital camera that was included in the duct tape experiment. Michael Helm WC5Z, built a two meter beacon transmitter that provided a good signal until the center conductor of the antenna broke off at the circuit board.

The taping of additions to the outside of the packages is not a recommend practice. We have used Styrofoam picnic coolers, Styrofoam minnow buckets, insulation board (for houses), foam core, aluminum boxes, cardboard boxes, and plastic food containers. A plastic food container is our favorite. Inside the container, a Styrofoam block is cut out so each item has its own space and is surrounded on all sides when the lid is put on. Since switches can be accidentally turned on or off at the wrong times, we bring the power lines outside the box and use a polarized quick-disconnect power cable (#270-026). It is very easy to visually inspect for connection status of plugged or unplugged. We have experienced deep fading by signals from the balloon when using horizontal polarization, so now we use vertical dipoles made from hook up wire. Ice picks are used to poke the necessary holes and after the wire is passed through, hot glue is used to seal the wire in place. If we will need some warmth inside the container, we use chemical foot or hand warmers we obtain from a sporting goods store. Right before lift off, someone crumples the warmer, puts it inside the container, closes the lid and tapes it. For power we use a surplus lithium battery rated 3 volts at 7.5 amp-hour. These are available from S & G Electronics, 618 S. 62 St., Philadelphia, PA. 19143 (215-474-7663).

Each group has their own favorite design for improving range or protecting their payloads. In order to increase the ground range of the 2 meter signals, some are experimenting with designs for always landing top up, placing the 2 meter antenna up off the ground. Some are using nylon jackets to protect the outer surface of their packages. The packages range from the simple to complex depending on the goals and talents of each team.

Cut down devices

There are times a group may want to bring down its payload before the balloon bursts. This is typically done if the balloon is traveling to an undesired area, such as over a large body of water, restricted airspace, or over a city. There are three kinds of devices: incendiary, heated nichrome wire, and a guillotine, using a razor blade. The most common is the nichrome wire used to melt nylon cord. Each is activated by a radio signal, sometimes independently of the rest of the payload, and sometimes as part of a set of commands. The device usually has its own power supply. Craig, N7TSZ, of the Reno (Kansas) County Amateur Radio Association, RCKARA, describes their device in these terms:

“We use ~3.5" of 30awg Nichrome wire and heat it with either 2 each 2/3 A (6v) or 3 each 2/3 A (9v) lithium batteries. This is used to cut 215lb, 550lb, & 1000lb nylon cord. It will cut the cord in 3 to 5 seconds. The Nichrome is wound around the cord with 7 loops. This is the standard cutter that we use for NASA & NOAA. It is not affected by the cold & has been tested dozens of times to well over 100k ft.”

Their website has pictures from the Great Plains SuperLaunch 2004, as well as other information, and is well organized. See *http://www.rckara.org*.

A very clear photo of the device used by KD7LMO, of Arizona Near Space Research, is on the group's website at *http://www.kd7lmo.net/cutdown.html*, along with a short description. Wire may become brittle at the extremely low temperatures of near space, and the group recommends Teflon coated wire, instead of common CAT-5 Ethernet cable or telephone hookup wire.

Recommendations and devices are the result of flights with failures, and it is valuable to learn from other groups, rather than repeating the experience!

Decisions

Operating on a very limited budget, we had to decide if we wanted to do a few higher altitude flights, or accept lower altitudes and do more flights. We found 1000,000 feet to be just a few degrees cooler and fewer air molecules than 76,000. Otherwise, the flights are equal in fun. For a really cheap electronics we use a $3.00 clock oscillator on 28.322 MHz from Digikey and a $6.00 K-id from K1EL (*www.k1el.com*).

Our trackers usually use 3 or 4 element 2 meter Yagi antennas and turn their handheld radios to the 5th harmonic at 141.61 MHz. Every ten or 15 minutes the tracker position and bearing reports are plotted on a map. As long as we can keep trackers on three sides of the balloon, we usually recover our $12 payload. To date our shortest flight distance is 4.5 miles and the longest is 170 miles. We find speed to be relative. A balloon drifting along at 30 mph will out run 70 mph chasers on the ground! We now fly GPS and ARPS to improve our recovery rate. However, if something happens to the ARPS data or signal, manual tracking skills can save the day.

How expensive is it? On a $80 tank of helium, we can make 4 flights with 300 gram balloons or one flight with the 800 or 1200 gram size. The 300 gram flight will cost us $50 while the 800 gram flight will be $250 or more because of the additional cost of the balloon and the additional components we can carry.

Toltex: size in grams	**Burst Altitude (feet)**	**Payload weight (lb)**
100	40,000	1.5
300	76,000	4
800	99.000	6
1200	104,000	Over 6

HOBO Data Logger

The HOBO data logger is a tiny, lightweight logger that receives input from sensors and stores it until it is downloaded upon recovery. Onset, the manufacturer, produces a line of sensors for recording temperature data, as well as a variety of other sensors. Paul Verhage has published instructions for building your own light and temperature sensors in Nuts and Volts, a publication we strongly recommend if you enjoy hands-on electronics. Paul gives lucid, detailed instructions for building components, and high school students can independently follow his directions. One of the benefits of our balloon flights is the enthusiasm for science and interest in the environment students experience, especially when they build some of the payload themselves. The HOBO data logger is an excellent addition to a flight.

Possible Student Experiments

One of the goals of Near Space research is to give students the opportunity to try some of their own experiments in conditions they would not have had otherwise. Our students at Perryton (Texas) High School have flown experiments investigating cosmic rays and devices to sample air pollution at different heights of the atmosphere. In other groups, the students involved are university students, who may design their own circuits, test data collection devices, radio propagation, or control commands in writing their own programs. Simple experiments that fit in a ping-pong ball are an exciting idea for younger students, and they have tested ideas such as the effect of conditions of near space on seed germination or bacteria viability. The research and design of simple experiments is a valuable exercise on problem solving.

NASA has worked with public schools, and flown experiments that have tested the effects of solar radiation on seed growth, paint and other insulation materials as shielding from solar radiation, and the effects of altitude on cell phone reception. ANSR (Arizona Near Space Research) actively seeks involvement with school groups, and has a grant program to help with expenses through a program called "Changes in Altitudes". Project Aria is a Washington University School of Engineering outreach, research and education program that has involved about 3,000 K-12 students from the U.S. and Australia in aerospace projects. They have investigated the effects of ultraviolet light and cold weather on a range of materials such as nail polish, chewing gum, and a collection of New Jersey rocks. Students at Stanford are experimenting with a roundworm to see how weightlessness and space radiation affect an organism's genes. Project HALO (High-Altitude Lift-Off") has involved dozens of schools from its Huntsville, Alabama headquarters.

Publications of university experiments, especially with stamp controllers, may be found at *http://www.parallax.com/html_pages/downloads/apps/third_party_articles.asp*. Paul Verhage, KD4STH, is collecting his articles in Nuts & Volts into an e-book published on the Parallax web site. He includes suggestions for student experiments. Look at *http://www.parallax.com/html_pages/resources/custapps/app_nearspace.asp*

While telemetry data can be sent down via radio frequencies, with our simple circuits only a very limited amount of data can come down. Paul brought data loggers to our attention in his articles. These tiny modules record lots of data. We chose a 4 channel HOBO from Onset. The unit is very small, about the size of a small matchbox, and weighs less than 1 ounce. Recording data every second, it will collect for 2 hours and 15 minutes, while recording on 60 second intervals it will collect for 5 days and 15 hours. With these devices it is easy to become buried in data!

APRS

One of our trackers, Joel Bennett, KK5XS, says, " The use of APRS is somehow like cheating." Joel prefers the manual triangulation methods of tracking. Receiving the position reports from the balloon is fantastic until something causes the loss of data. We find it is a good idea to have our chasers equipped for both the APRS and manual techniques. A program called Balloon Track is available from EOSS, and provides a prediction of the eventual touchdown spot, if the information entered into the program is accurate. Necessary information includes winds aloft, lift, ascent rate, payload weights and balloon size and type. The winds aloft are available from the National Weather Service from their twice-daily releases; we download them from the University of Wyoming website at *http://weather.uwyo.edu/upperair/sounding.html*.

GPS units are available as engines, built into the antenna, or as complete hand held units. Check on the Ralph Wallio, WØRPT, web pages for the units that will work above 60,000 feet. Many units are altitude-limited. The hand held Garmin Etrex and model GPS-35 (engine build into antenna module) have been flown successfully by many groups. Look at the link *http://users.crosspaths.net/~wallio/* .Also, his balloon links list 59 groups, so there may be a group near you. The records lists are very interesting reading.

Popular TNC units are the Tiny Track and Pocket Tracker from Byonics (*www.byonics.com*) and Scott Miller's Opentracker (*http://n1vg.net/opentracker/*). Scott offers group and education discounts.

Balloonists use the 144.390 MHz national APRS frequency and more are going to 144.340 to get away from the congestion of the national frequency.

Many groups I-gate their balloon's ARPS information onto the internet. Many use a –11 on their call signs. On Findu.com watch for WBØDRL, KD4STH, K5IS, KE5BFH, WB8ELK, KD7LMO, W5ACM, KC7NAX, KEØVH, N4TXI, N9XTN, and W5SJZ. This is a partial listing. On any Saturday and Sunday you will find balloon tracks being displayed.

Into the future

More groups will be flying. It would be interesting for weak signal operators to have the use of linear translators as cross band repeaters for SSB and CW signals. More experiments need to be done on the microwave frequencies. Much more work needs to be done to eliminate the electromagnetic interference (EMI) between the components within a payload package. In our own projects, we would like to add an interface to translate sensor data into Morse code. We hope to see many more partnerships between balloon groups and students of all ages. The age of Near Space exploration by private citizens has arrived!

Summary

We have had a steep learning curve, and it has been an exciting adventure. We began with the idea of designing balloon flights that were inexpensive, with a basic package of two beacons, transmitters, a camera, and simple packaging. We learned we could use 300 gram balloons and make four flights on a tank of helium with each flight costing $50 dollars, or make one flight to 100,000 feet with a 1200 gram balloon and use a whole tank of helium in the process. We have come to appreciate the addition of more complex components such as digital cameras and BASIC stamps. No one warned us that balloon flights can be addictive, even if they are frustrating. One of the most enjoyable parts of the experience has been the cooperation between groups and individuals. Few people can master all the skills needed in a complex flight, and the contributions of fellow hams have been welcome and appreciated. We have learned from each launch we have attended or done ourselves. And when you get down to it, it is just a lot of fun to reach out and explore near space!

Bibliography

Doerrie, Jerome and Bobette. "Reach for Space", *QCWA Journal*, Vol. XLIV, Number 1, Spring 1994, pp 7-10.

Doerrie, Jerome and Bobette, "Ballooning 101", *Proceedings of the ARRL 1995 National Educational Workshop,* pp. 50 – 63.

Doerrie, Jerome. "Flight #9: Ballooning on a Budget", *CQ VHF,* Sept. 1996, pp. 32 –37.

Doerrie, Jerome. "Reach for Space-Flight 9", *Central States VHF Society Proceedings, 1996,* pp. 137-141.

Doerrie, Jerome and Bobette. "Greater Range at 100,000 ft.", *Central States VHF Society Proceedings, 2005,* pp. 33-40

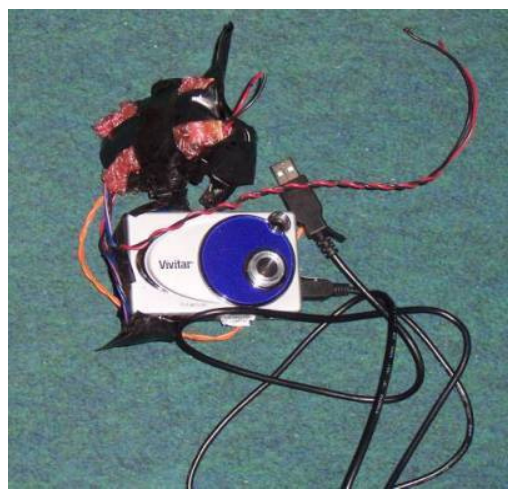
Author information: The Doerries live on an ideal ham location: a farm in the northeast corner of the Texas Panhandle, with few neighbors. The only thing missing is height above terrain. Jerome farms and Bobette is a retired high school science teacher. You can reach us at k5is@hotmail.com and bdoerrie@yahoo.com .

“Reach For Space” Flight # 20 Jerome and Bobette Doerrie, K5IS and N5IS

It takes a committee to prepare the payload, especially when there are problems.

Filling the balloon is a committee effort- one to control the helium, one to be sure the balloon doesn’t twist, and at least two to keep the balloon upright

Tying the balloon off is an art, and it takes more than one ham.



Inexpensive digital camera with transmitter and connector built by Mike Helm, WC5Z

Each part of the payload is controlled by one person, with the lines lying flat on their hands.

Mike Helm, WC5Z, with his “little” direction finding antenna.

It’s out in this field, somewhere……

Recovered in less than half an hour from “splashdown”!

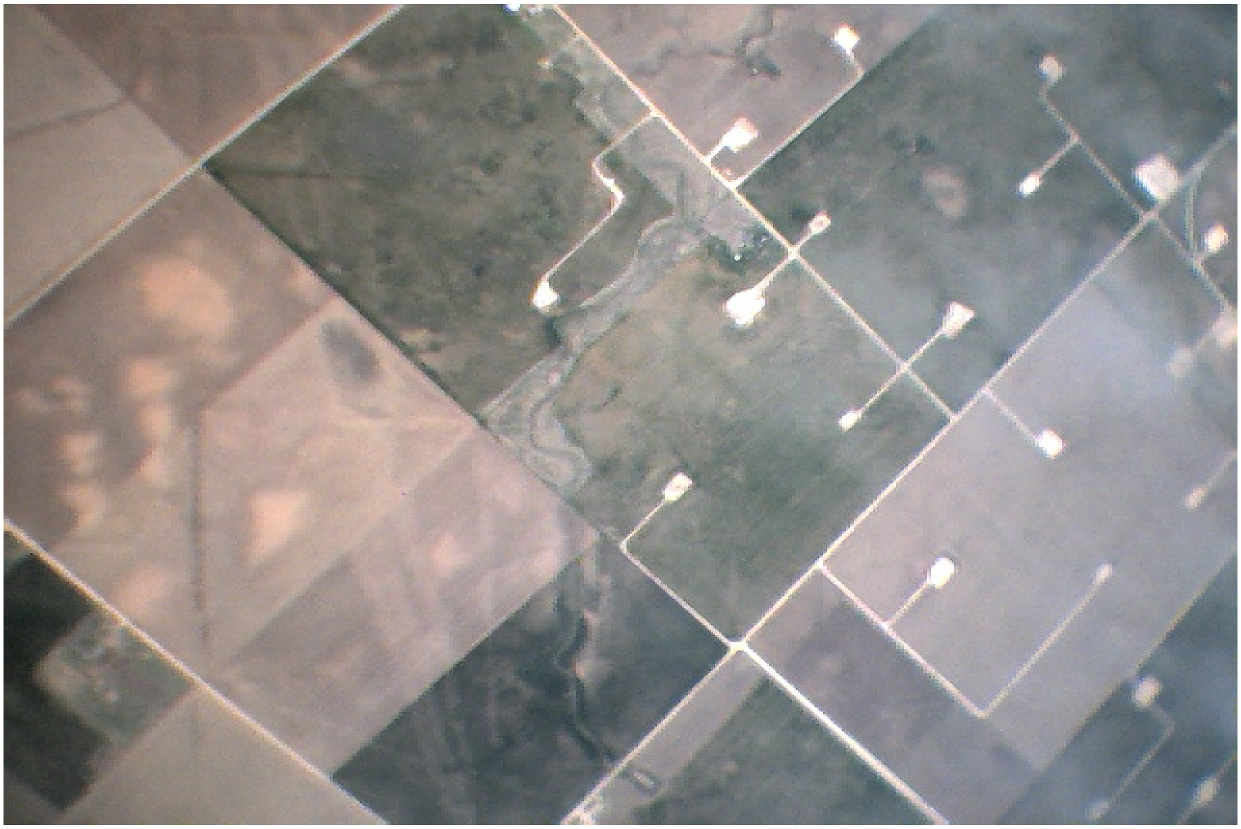


Photo taken by the small digital camera at about 3,000 feet, showing oil field locations and caliche roads, as well as a streambed and soil features.

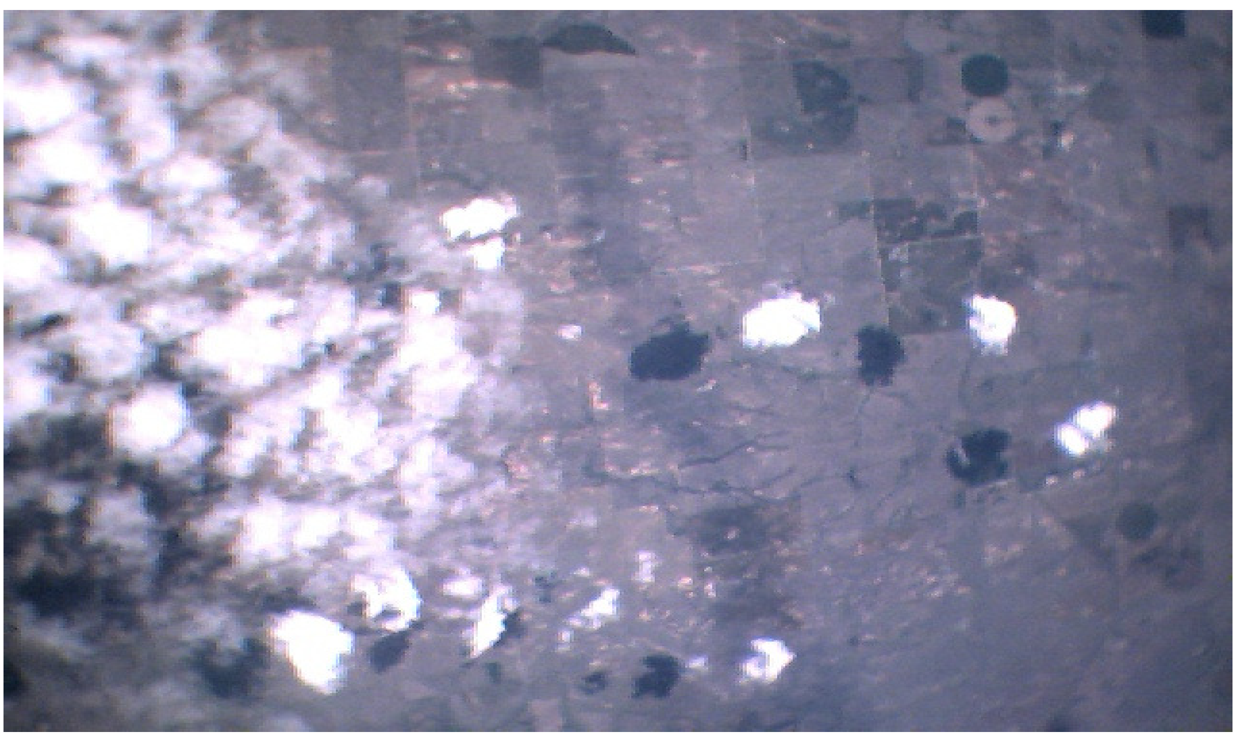


Photo from about 50,000 feet, showing round irrigated fields, 1/2 mile wide, and cloud shadows

Additional photos from this flight can be found at http://almostangels.org/balloons/