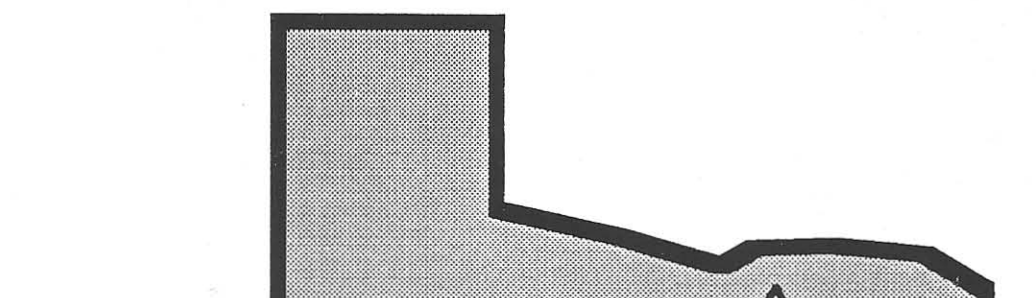
PROCEEDINGS OF THE 4TH ANNUAL AMSAT SPACE SYMPOSIUM DALLAS, TEXAS



NOVEMBER 8, 1986

AMSAT

SPACE SYMPOSIUM

AND

ANNUAL MEETING

GRAPEVINE, TEXAS

NOVEMBER 7, 8, 9 1986

ORGANIZATIONAL COMMITTEE

Al Brinckerhoff WB5PMR	Chairman
Rusty Reeve KT5U	Reservations
Ray Hoad WA5QGD	Prizes
Bill Reed WD0ETZ	Promotions
Keith Pugh W5IU	Accomidations
Darrell Crimmins KG5E	Communications
Bob Stricklin N5BRG	Speakers & Proceedings

****

1986 Annual Meeting Prize List

Prize Category	Prize	Donor
Grand Prize	ICOM IC-1271A 1.3 GHz Xcvr	ICOM America, Bellevue, W
Banquet Digital	AEA Model AMT-1 AMTOR/RTTY	AEA, Lynwood, WA
Banquet Deluxe	Yaesu FT-727R 2m/70cm HT	Yaesu USA, Cerritos, CA
Early Registrant	ALINCO ALM-203T 2 meter HT	Alinco, Reno, NV
Banquet Dish	Continental Satellite 10' Dish	Cont. Sat., Clackamas, OR
Banquet GaAs	Landwehr 2 m mastmount GaAsFET	Henry Radio, Los Angeles
Banquet GaAs	THL HRA-2 2 m mm GaAsFET	Encomm, Plano, TX
Banquet GaAs	ARR SP432VDG 2 m mm GaAsFET	ARR, Burlington, CT
Banquet GaAs	Lunar PAG432 GaAsFET	Lunar, San Diego, CA
Banquet Alum	Cushcraft 416-TB 70 cm X-yagi	Cushcraft, Manchester, NH
Banquet Alum	F9FT 1.3 GHz X-yagi	PX Shack, Bellemead, NJ
Banquet Alum	KLM 1.2-44LBX 1.3 GHz yagi	KLM/Mirage,Morgan Hill,CA
Banquet Alum	23-45LY 1.3 GHz loop yagi	Downeast Microwave, ME
Banquet Special	Daiwa NS-663A/N SWR/PWR meter	Hardin Elect, Ft Worth, T
Banquet Special	Pair of 3CX100A5 tubes	Eimac, Dallas, TX
Banquet Special	Welz SP-15M SWR/PWR meter	ECI, Dallas, TX
Banquet Special	100' Belden 9913 w/connect.	ECI, Dallas, TX
Banquet Special	$50 gift certificate	Nortex, Ft Worth, TX
Banquet Special	Free room for 2 nights	DFW Hilton Hotel
Banquet Software	GRAFTRAK and Silicon Ephemeris	Silicon Solution, Houston

* *

TABLE OF CONTENTS

Friday:

08:00	Depart Hilton Hotel	Grapevine
08:30-9:45	Rockwell Collins	Richardson
10:15-11:30	Crying Charlies or Xerox Surplus Store	Dallas Addison
12:00-12:15	Hilton Hotel	Grapevine
12:30-13:45	Lunch	Fort Worth
14:15-15:30	Nortex	Fort Worth
17:00-18:30	Happy Hour	Hilton Hotel

Hilton Hotel Patio or International Ballroom 3 & 4

18:30-??:?? Barbecue

Saturday:

<u>International Ballroom 3 & 4</u>

06:30-08:00 Breakfast

<u>Commerce Room (Main Auditorium)</u>

08:00-08:10	Vern Riportella WA2LQQ	Welcome Remarks
08:10-08:40	Harry Yoneda JA1ANG	FO12
08:45-09:15	Tom Clark W3IWI	FO12 Modems
09:20-09:45	Hans Van De Groenendaal ZS6AKV Hennie Rheeder ZS6ALN	Mode S Antennas
09:45-10:10	Break	
10:10-10:30	Phil Karn KA9Q	Automatic Frequency Control using IC271/471 and a PC
10:35-10:50	James Miller G3RUH	Satellite Attitude Determination
10:55-11:25	Bob Mc Gwier N4HY	New Molniya Orbit Options
11:30-12:00	James Eagleson WB6JNN	Amplitude Compandored SSB

<u>International Ballroom 3 & 4</u>

12:00-13:00 Lunch

Commerce Room (Main Auditorium)

13:00-13:25	Gerry Creager WB5FIV	Houston Satellite Efforts
13:30-14:00	Bob Dearsing N5AHD	UOSAT Telemetry Tracking
14:00-14:30	Jan King W3GEY	Phase IV
14:30-15:00	Martin Sweeting G3YJO	UOSAT Status and Future Projects
15:00-15:15	Break	
15:15-15:45	Bill Tynan W3XO Lou Mc Faddin W5DID Dick Fenner W5AVI	Maned Space Opportunities
15:45-16:15	Ralph Wallio W0RPK	Oscar 10 Status and Engineering Report
16:15-16:45	Paul Rinaldo W4RI	Digital Communications and Satellites
17:00-18:45	Social Hour	

Indoor Pool Area

19:00-20:20	Banquet	Marty Davidoff K2UBC Keynote Speaker Annual Awards Banquet Prizes

Indoor Pool Area

20:30-22:00	General Meeting	Vern Riportella, WA2LQQ President's Report

Sunday:

International Ballroom 3 & 4

06:30-08:00	Breakfast	

Options Rooms 1,2, & 3

08:00-11:30	Richard Fogle WA5TNY	Pre-amp Measurements
08:00-09:30 09:30-11:00 11:00-11:30	2 M 70 CM 23 CM	
07:30-09:00	Jan King	Phase IV Technical Review (Open Meeting)

09:00-10:0	Harold D. Reasoner K5SXK	Antenna System Design
10:00-11:30	Al Ward WB5LUA	Operating above 1 GHz

Merger Room

09:00-10:00	Jan King	Pase IV Technical Review Cont. (Comittee menbers only)
10:00-??:??	Board of Directors	Board Meeting

Monday

Merger Room

08:00-??:??	Board of Directors	Board Meeting

1200 BAUD PSK MODEMS FOR USE WITH FO-12

Dr. Thomas A. Clark, W3IWI

This paper will report on activities to develop reliable 1200 baud PSK modems for use with the FO-12 satellite. In particular, we will discuss a practical implementation of the JARL/JAMSAT Costas Loop design (see F. Yamashita, "A PSK Demodulator for the JAS-1 Satellite", QEX, August 1986, pp 3-6). To the basic design described in QEX have been added modulators optimized for the 'Manchester FM' FO-12 uplink and for terrestrial PSK use. Also added to the basic design has been a digital AFC circuit for automatically tracking Doppler shifts with unmodified commercial 'all-mode' VHF/UHF radios.

In addition to the design published in QEX, a simpler modem has been made available by James Miller, G3RUH. This design has similar features to those described above. A comparison between the two designs will be discussed.

The modem-to-radio interface will be discussed, with particular emphasis given towards 'eye-pattern' testing. Preliminary results on tests with several commercial radios to evaluate performance degradation arising from assymetric receiver IF bandpass filters will be presented. We plan to show the QEX-style modem in operation and will demonstrate many of these points with actual hardware.

Controlling ICOM Radios with an IBM-PC

By Phil Karn KA9Q

This article consists of two parts. Part 1 documents how I connected my ICOM IC-271A and IC-471A radios to the parallel printer port on my MIT (Made-in-Taiwan) PC clone. Part 2 consists of C source to subroutines that can be called by programs running on the PC.

Before you warm up your soldering iron, I highly recommend that you get and read a copy of the article "Computer Control of Icom R71, 271, 471 and 751 Radios" by Richard Bisbey, NG6Q, that appeared in the April 1986 Ham Radio on page 47. In it he describes how to install the EX-309 computer interface and how it operates. Richard has clearly been probing around the innards of ICOM radios for some time and has discovered some useful "tricks" that circumvent various misfeatures in the radio. I found the article to be extremely useful; the skimpy documentation provided by ICOM would have required much more trial-and-error experimentation.

Reading the Printer

Just about everybody with an IBM-PC has more parallel printer ports than they need. They're simple, so manufacturers of add-on multifunction cards like to toss them in "for free". Since the ICOM EX-309 computer interface requires a parallel connection, it seems like those extra printer ports ought to be useful for something. They are, but there's a glitch.

A PC printer port is output only (who needs to read data from a printer?) You *can* control an ICOM radio with an output-only port, but you can't read information back from the radio.

Fortunately, it is very easy to modify a garden-variety PC printer port (both clones and Real IBM) to allow both input and output, and the modification shouldn't even affect normal operation. You only need to cut one trace and to add one jumper. The secret to this easy mod is that 1) the standard printer interface uses a 74LS374 to drive the output connector, and 2) an input buffer to read back the state of the output pins is already provided. (Why the designer thought a programmer would want to read back the state of a write-only printer data port is beyond me, but I'm happy just the same that they put it in. Perhaps it was only meant for testing purposes).

According to the IBM Options and Adapters Technical Reference, the '374 is U41 on the monochrome/printer adapter, U18 on the AT Serial/Parallel adapter and U4 on the plain Printer Adapter. (Check your schematics if you have a clone). It's an 8-bit latch with tri-state outputs. In the original design, OE/ (pin 1) is grounded, always enabling the outputs. If you liberate this pin from ground and connect it instead to a spare output bit that just happens to be available on the 74LS174 hex D latch that drives the miscellaneous printer control lines, you can disable the '374 by setting this bit. This keeps it from interfering when you read data back from the radio. The '174 is U39 on the monochrome board, U4 on the AT Serial/Parallel card, and U7 on the plain Printer Adapter. Note that the '174 pin numbering may be different from board to board, but the pin you want is the one that latches BD5 from the data bus. On the monochrome card and "plain" printer adapter this is pin 15, while it's pin 10 on the AT Serial/Parallel card. Note also that while on the IBM cards the input to this unused latch is already connected, it is left unconnected on some clone cards (such as mine). It must be jumpered to BD5 on the data bus.

As long as software leaves this control bit alone, the printer port will still function normally. I.e., the default power-up state of the data port is "output" mode.

Once you've modified your printer port (and verified that it still works) the more tedious part of the job must be done. The problem is that there's no standard connector pinout for parallel ports (analogous to RS-232 for serial ports), so you need to build an adapter plug that shuffles the pins between the ICOM and the PC. The connector on the PC is a DB-25, the same plug used for RS-232. Various computer accessory suppliers (such as Inmac) supply solderless "wire-your-own-null-modem" RS232 adapter kits that make this very convenient. You get male and female DB25 connector shells, a plastic case that snaps together, and a supply of wires with male and female pins that snap into the connector shells. You can thus easily permute the pins any way you want. There's only one proper way to connect the 8 data bits (unless you like shuffling bits around in software) but the connections for the various strobe and ack signals are somewhat arbitrary. However, you're probably best off using the assignment I chose, since that will allow you to run my software without having to modify it.

Adapter Wiring

Here's the wiring I used in my adapter. I assume that you'll use a male DB-25 on the computer end of the 24-pin ribbon cable going to the EX-309 connectors. Note that the EX-309 uses a 24-pin GPIB-style connector, so make sure you install the DB-25 on the ICOM bus cable correctly; pin 1 of the DB-25 should connect to pin 1 on the EX-309's connector. Note also that because of the different pin layouts on the two connectors, pins 1-12 on the DB-25 correspond to pins 1-12 on the EX-309, BUT pins 14-25 on the DB-25 correspond to pins 13-24 on the EX-309. Pin 13 on the DB-25 is unused.

Printer Pin	Printer Function	Icom DB25 pin	Icom Function
2	Data bit 0	1	Data bit 0
3	Data bit 1	2	Data bit 1
4	Data bit 2	3	Data bit 2
5	Data bit 3	4	Data bit 3
6	Data bit 4	5	Data bit 4
7	Data bit 5	6	Data bit 5
8	Data bit 6	7	Data bit 6
9	Data bit 7	8	Data bit 7
17	SLCTIN	9	RP
1	STROBE	10	SRQ/
14	AUTO FDXT	22 (21 at radio)	WP
10	ACK	23 (22 at radio)	DAV/
18-25(any)	GND	25 (24 at radio)	GND

Programming Info

Once you've wired the adapter, the various ICOM signals appear as follows.

(This assumes the base addressing used for the monochrome adapter/printer port; adjust if your port is at a different address). Note that some of the ICOM bus lines are negative true, and others are positive true. Some (but not all) of the printer port's control and status lines are inverted as well. This has already been taken into account here. (The choice of bit assignments was in part made so that the radios would see an idle interface when the printer port is left in its uninitialized, power-up state).

3BCH (read/write): the 8-bit data bus. The direction of data flow is controlled by bit 5 in port 3BEH.

3BDH (read only):
Bit 6 (i.e., mask 40h) is the DAV bit, active low (a zero bit corresponds to the ICOM saying that Data is AVailable).

3BEH (write only):

Bit 0 (01H) controls the SRQ line to the radio, active high (setting this bit to a one tells the radio that Service is ReQuested).

Bit 1 (02H) is the WP (Write Pulse), active low. Note that this bit should be kept high when the interface is idle, although it will not have any effect as long as SRQ is inactive.

Bit 3 (08H) is the RP (Read Pulse), active low. This bit should also be kept high when the interface is idle.

Bit 4 (10H) is the IRQ (Interrupt ReQuest enable) bit that allows the ACK input pin to cause an interrupt. Since DAV is connected to the ACK input, this makes it possible to make the computer-to-radio protocol interrupt driven. This isn't usually worth it, though.

Bit 5 (20H) controls the direction (input/output) of the 8-bit data port. (This was the bit we had to wire up on the interface card). Clearing this bit puts the data port in output (computer -> radio) mode; setting it allows the computer to read data from the radio.

Here's the source code I wrote for controlling the ICOM radios through my PC clone's printer port. Note that all frequencies are represented in hertz, using longs; this makes things more consistent since different radio functions require different precision.

```
/* icom.c
 * Library functions for driving the ICOM computer interface
 * Copyright 1986 by Phil Karn, KA9Q
 * Permission granted for free noncommercial copying and use by
 * licensed radio amateurs.
 */
#include "icom.h"

char *modes[] = {
"LSB",  /* 0 */
```

```
"USB",   /* 1 */
"AM",    /* 2 */
"CW",    /* 3 */
"RTTY", /* 4 */
"FM",    /* 5 */
"CW Narrow",     /* 6 */
"RTTY Narrow",   /* 7 */
"lsb",   /* 8 */
"usb",   /* 9 */
"am",    /* a */
"cw narrow",     /* b */
"rtty narrow",   /* c */
"fm",    /* d */
"0xe",   /* e */
"0xf"    /* f */
};

/* Read band */
int
read_band(freq,lower,upper)
long freq;                  /* Used just to select the radio */
long *lower,*upper;         /* Band limits returned through here */
{
        register int i;

        start_cmd();
        if(send_byte(BAND | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        *upper = 0;
        read_byte();                    /* Toss opening delim */
        for(i=0;i<6;i++)
                *upper = *upper * 10 + (read_byte() & 0xf);
        read_byte();                    /* Toss closing delim */
        *upper *= 10000;                /* Convert to hertz */

        *lower = 0;
        read_byte();                    /* Toss second opening delim */
        for(i=0;i<6;i++)
                *lower = *lower * 10 + (read_byte() & 0xf);
        read_byte();                    /* Toss second closing delim */
        *lower *= 10000;                /* Convert to hertz */
        end_cmd();
        return 0;
}
/* Set frequency; the proper radio is automatically selected */
int
set_freq(freq)
long freq;      /* Frequency, hertz */
{
        register int i;
        char fstr[15];

        start_cmd();
```

```
        if(send_byte(FREQ | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        send_byte(FREQ | 0xd);
        sprintf(fstr,"%091d",freq/10);
        for(i=0;i<9;i++)
                send_byte(FREQ | (fstr[i] - '0'));
        send_byte(FREQ | 0xe);
        end_cmd();
        return 0;
}

/* Read frequency */
long
read_freq(freq)
long freq;      /* For band selection only */
{
        register int i;

        start_cmd();
        if(send_byte(FREQ | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        if(read_byte() < 0)     /* Discard opening delimiter */
                return -1;
        freq = 0;
        for(i=0;i<9;i++){
                freq = freq * 10 + (read_byte() & 0xf);
        }
        read_byte();            /* Discard closing delimiter */
        freq *= 10;
        end_cmd();
        return freq;
}
/* set mode */
int
set_mode(freq,mode)
long freq;              /* For radio selection */
int mode;               /* Desired operating mode */
{
        start_cmd();
        if(send_byte(MODE |and(freq)) < 0){
                end_cmd();
                return -1;
        }
        send_byte(MODE | 0xd);
        send_byte(MODE | mode);
        send_byte(MODE | 0xe);
        end_cmd();
        return 0;
}
/* Return current mode */
int
```

```
read_mode(freq)
long freq;                  /* For radio selection */
{
        int c;

        start_cmd();
        if(send_byte(MODE | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        read_byte();
        c = read_byte();
        read_byte();
        end_cmd();
        return c & 0xf;
}
/* Set offset */
int
set_offset(freq,offset)
long freq;          /* For radio selection */
long offset;        /* Offset, hertz */
{
        register int i;
        char fstr[15];

        start_cmd();
        if(send_byte(OFFSET | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        send_byte(OFFSET | 0xd);
        sprintf(fstr,"%09ld",freq/1000);
        for(i=0;i<9;i++)
                send_byte(OFFSET | (fstr[i] - '0'));
        send_byte(OFFSET | 0xe);
        end_cmd();
        return 0;
}

/* Read offset */
long
read_offset(freq)
long freq;          /* For radio selection */
{
        register int i;
        long offset;

        start_cmd();
        if(send_byte(OFFSET | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        read_byte();        /* Discard opening delimiter */
        offset = 0;
        for(i=0;i<9;i++)
```

```
                offset = offset * 10 + (read_byte() & 0xf);
        read_byte();    /* Discard closing delimiter */
        offset *= 1000;
        end_cmd();
        return offset;
}
/* Select memory channel or vfo */
int
set_mem(freq,val)
long freq;                  /* For radio selection */
int val;                    /* Desired VFO/channel number */
{
        start_cmd();
        if(send_byte(MEMVFO | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        send_byte(MEMVFO | 0xd);
        send_byte(MEMVFO | ((val >> 4) & 0xf)); /* tens digit */
        send_byte(MEMVFO | (val & 0xf));        /* units digit */
        send_byte(MEMVFO | 0xe);
        end_cmd();
        return 0;
}
/* Transfer between VFO and memory */
int
transfer(freq,dir)
long freq;                  /* For radio selection */
int dir;                    /* Desired direction of transfer */
{
        start_cmd();
        if(send_byte(MEMRW | band(freq)) < 0){
                end_cmd();
                return -1;
        }
        send_byte(MEMRW | 0xd);
        send_byte(MEMRW | dir);
        send_byte(MEMRW | 0xe);
        end_cmd();
        return 0;
}
/* Set band
 * Uses the hack by NG6Q in April 1986 Ham Radio
 * Warning: untested (I don't have a 751).
 */
int
set_band(freq,b)
long freq;                  /* For radio selection */
int b;                      /* Desired band */
{
        long funny;

        set_mem(freq,38);       /* Select channel 38 */
        funny = (freq/1000000) * 1000000;       /* Truncate to Mhz */
        funny += 100000 * b;            /* Desired band goes in 100khz digi
```

```
        set_freq(funny);
        transfer(freq,WRITE);                /* Store in memory */
        set_mem(freq,0);                     /* Go back to VFO */
        transfer(freq,READ);                 /* Get the funny value */
        set_freq(freq);                      /* Put in the one we really want */
        return 0;
}

/* The following are internal subroutines that perform the low-level
 * parts of the host/radio protocol. These can be "static" if you wish.
 */

/* Send individual byte of a message */
int
send_byte(c)
char c;
{
        register int i;

        outportb(I_DATA,c);

        /* Turn on WP and output mode in addition to SRQ */
        outportb(I_CTL,CTL_POL^(SRQ_CMD|WP_CMD|OUTPUT_MODE));

        /* Wait for DAV to go active low */
        for(i=TIMEOUT;i != 0;i--){
                if((inportb(I_DAV) & DAV_STAT) == 0)
                        break;
        }
        if(i == 0){
                outportb(I_CTL,CTL_POL);
                printf("sendbyte fail\n");
                return -1;
        }
        /* Drop WP and output mode, keeping SRQ active */
        outportb(I_CTL,CTL_POL^SRQ_CMD);

        /* Wait for DAV to go inactive high */
        for(i=TIMEOUT;i != 0;i--){
                if((inportb(I_DAV) & DAV_STAT) != 0)
                        break;
        }
        if(i == 0){
                outportb(I_CTL,CTL_POL);
                printf("sendbyte fail 2\n");
                return -2;
        }
        return 0;
}

/* Read individual byte within a message */
int
read_byte()
{
        register int i;
```

```
        register int c;

        /* Configure for input */
        outportb(I_CTL,CTL_POL^(RP_CMD|SRQ_CMD));

        /* Wait for DAV to go active low */
        for(i=TIMEOUT;i != 0;i--){
                if((inportb(I_DAV) & DAV_STAT) == 0)
                        break;
        }
        if(i == 0){
                outportb(I_CTL,CTL_POL);
                printf("read fail\n");
                return -1;
        }
        /* Read data byte from bus */
        c = inportb(I_DATA);

        /* Drop RP, keeping SRQ active */
        outportb(I_CTL,CTL_POL^SRQ_CMD);

        /* Wait for DAV to go inactive high */
        for(i=TIMEOUT;i != 0;i--){
                if((inportb(I_DAV) & DAV_STAT) != 0)
                        break;
        }
        if(i == 0){
                outportb(I_CTL,CTL_POL);
                printf("rreturn MHZ_144;
        } else if(freq >= 50000000){
                return MHZ_50;
        } else
                return HF;
}
/* Begin a message */
start_cmd()
{
        /* Assert SRQ */
        outportb(I_CTL,CTL_POL^SRQ_CMD);
}
/* End a message */
end_cmd()
{
        register int i;

        /* Wait a little bit */
        for(i=WAIT;i != 0;i--)
                ;
        /* Deactivate SRQ */
        outportb(I_CTL,CTL_POL);
}
-----------------
/* icom.h
 * Definitions for the ICOM library functions
 * 21 Aug 1986
```

```
 * Phil Karn, KA9Q
 */

/* System-dependent constants; edit to taste */

/* Port addresses */
#define I_DATA            0x3bc    /* Data I/O port */
#define I_CTL             0x3be    /* Control port (output) */
#define I_DAV             0x3bd    /* Data available port (input) */

/* Bits within I_DAV */
#define DAV_STAT          0x40
#define DAV_POL           0x40     /* DAV is negative polarity */

/* Bits within I_CTL */
#define OUTPUT_MODE       0x20
#define RP_CMD            0x8
#define WP_CMD            0x2
#define SRQ_CMD           0x1
/* Specify any bits in I_CTL which are negative logic.
 * Output mode, RP and WP are negative logic; SRQ is positive
 */
#define CTL_POL (OUTPUT_MODE|RP_CMD|WP_CMD)

/* These two values were found experimentally to work on an 8-MHz 8088
 * Increase WAIT if you get frequent timeouts or protocol lockups
 */
#define TIMEOUT 65535   /* Timeout on a read/write operation */
#define WAIT    1100    /* Delay at end of sequence */

/* The following definitions are fixed by the ICOM design; they should not
 * have to be changed.
 */

/* Commands */
#define BAND              0x10
#define FREQ              0x20
#define MODE              0x30
#define OFFSET            0x40
#define MEMVFO            0x50
#define MEMRW             0x60

/* Addresses */
#define HF                0x1      /* IC-71 or IC-751 */
#define MHZ_50            0x2
#define MHZ_144           0x3      /* IC-271 */
#define MHZ_220           0x4
#define MHZ_430           0x5      /* IC-471 */
#define MHZ_1200          0x6      /* IC-1271 */

/* Modes */
#define LSB     0
#define USB     1
#define AM      2
#define CW      3
```

```
#define RTTY     4
#define FM       5
#define CWN      6
#define RTTYN    7

#define WRITE    1          /* VFO to memory */
#define READ     2          /* Memory to VFO */

long read_freq();
```

End of code

OSCAR-10 ATTITUDE DETERMINATION

by James Miller G3RUH

Introduction

Oscar-10 attitude has to be actively controlled for two reasons. Firstly, to ensure that the solar panels always receive sufficient sunlight to maintain a healthy battery charge as well as operate transponders, computer etc. Second, for sensible communications, the antennas need to point earthwards as much as possible.

Solar illumination is always changing because the Sun moves steadily about 1 degree/day across the heavens. And the satellite orientation appears to change about 1 degree a week because the orbit plane drifts - witness steady changes in Argument of Perigee and Right Ascension of Ascending Node, RAAN.

However, before you try to change a satellite's attitude first you have to measure it! In addition you need to know what values change it to for best results. I have developed several attitude finding methods and planning tools for Oscar-10, which are in regular use by the active AO-10 Ground Control Stations, and this paper outlines some of them.

Attitude Definition

Oscar-10 is spin stabilised; this means that it spins about the motor/antenna axis of symmetry, at a rate of some 30 r.p.m. Most importantly, the spin axis points to a fixed point in space, called "the attitude" - unless the spacecraft is deliberately moved by ground station command.

The spin axis direction is specified by two numbers called attitude longitude (ALON) and attitude latitude (ALAT), and they are measured in the orbit plane. Longitude is measured round from perigee, in degrees 0-360, in the same sense as the satellite's motion. Latitude is specified up (+) or down (-) from the orbit plane.

The nominal attitude for Oscar-10 is ALON = 180 degrees, ALAT = 0 degrees, (conventionally written 180/0) when the antennas would be pointing at the Earth's centre with the spacecraft at apogee. Attitude 190/0 gives Earth centre pointing just after apogee, 170/0 just before. A positive value for ALAT means the antennas are pointing down towards the Southern hemisphere.

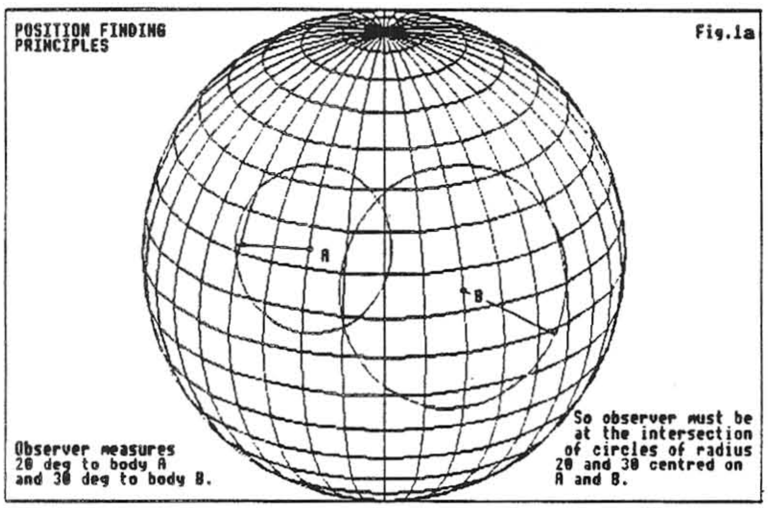
ALON typically ranges from 140 to 220 degrees, and ALAT between -30 and +30 degrees.

The value of ALON slowly reduces at a rate of 1 degree/week because the orbit plane is moving at that rate. Nonetheless, the attitude IS fixed with respect to the stars: the attitude's celestial coordinates, Right Ascension (RA) and declination (DEC) are invariant - but are not very convenient for popular use.

Finding the Attitude

The art of position finding is centuries old. The principles are much the same whether you are surveying the backyard or aiming a satellite. All you need is two or three objects whose position IS known. You make an observation about each of them. Then you calculate or plot your position - it being the only place on the map that could give rise to those observations.

A simple analogy. You have a map of a room; you are somewhere in the middle, and want to plot your position on the map. You measure the distance to one corner (RA), and then the distance to another (RB). Draw in two arcs of the measured radii from each corner - and your position must lie at the intersection - see Fig 1. Of course, two circles intersect in two places, and you must resolve this. Possibly the second intersection lies outside the room, which is absurd; if not, then you could measure the distance to a third corner.



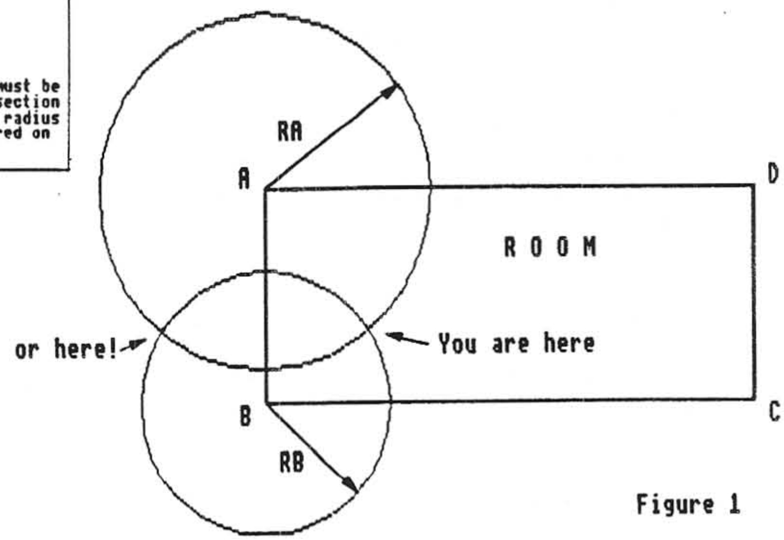


Figure 1

Its just the same with a satellite. You have a map of the sky; you are on board the satellite and want to plot the spin axis direction on the map. You measure the angle between the spin axis and a couple of known points, such as a star, or the Sun, draw in the stars and then two arcs, and the attitude direction must lie at their intersection. The ambiguity is resolved with a the help of a third body or some reasonableness criterion.

Implementation

There are several ways of mechanising this process, depending on what data is available, and how accurate you want the answers to be. At one end of the spectrum, a simple look-up table method is available (ref 2) that anyone can use.

However the job is more powerfully handled by computer and there are graphical methods and numerical methods. The simplest numerical methods take just 2 measurements (observations) and compute the 2 attitude coordinates, ALON and ALAT. These are fast and easy to use, but of course any small error (noise) on an observation leads directly to undetectable small errors in the solution.

So for added security, one "overdetermines" the problem by making as many observations as possible, and computing the attitude which is in some sense the best given those observations. This gives increased confidence in the answer, and also allows you to weed out defective observations.

Some idea of the range of tools used can be gathered from a brief list of the software developed:

Program Outline Description

-- EASIFIX

Attitude from 1 Sun, and two equal Earth sensor observations (ref2) SENSOLV

Attitude from one Sun and one Earth Sensor

SUNFIT Attitude from multiple Sun observations

ESSFIT Attitude from multiple Sun and multiple Earth obseravations

ATTPLOT Graphical suite; draws Sun measurements, Earth, eclipses and related phenomena on celestial sphere.

ILLPLAN Solar panel illumination and Sun Angle chart generator

ATTHIST Predicts future attitude given present position

AO10NOW Real time AO-10 antenna tracking for automatic data capture

TLM10-3 PSK Telemetry full engineering display

K10FIT Smoothed Keplerian elements generator from 1 year's keps

ECLIPSE AO-10 Eclipse prediction

Choice of Bodies

What objects are available for AO-10 to measure? For a near Earth satellite the obvious choices are the Sun, which is an extremely bright approximately point source of light, and the Earth which is very big and appears to move about as the satellite moves round the orbit. The Moon could be used too, but with simple sensors would too easily be confused with the Earth. The stars are abundant but faint, and suitable sensors are of a complexity beyond that which Oscar-10 needs.

So, AO-10 carries a Sun Sensor and an Earth sensor. They are mounted in the end of arm 2, and look out radially onto what is called the spacecraft's equator. So the sensors scan the equatorial belt once per revolution, about 30 times a minute.

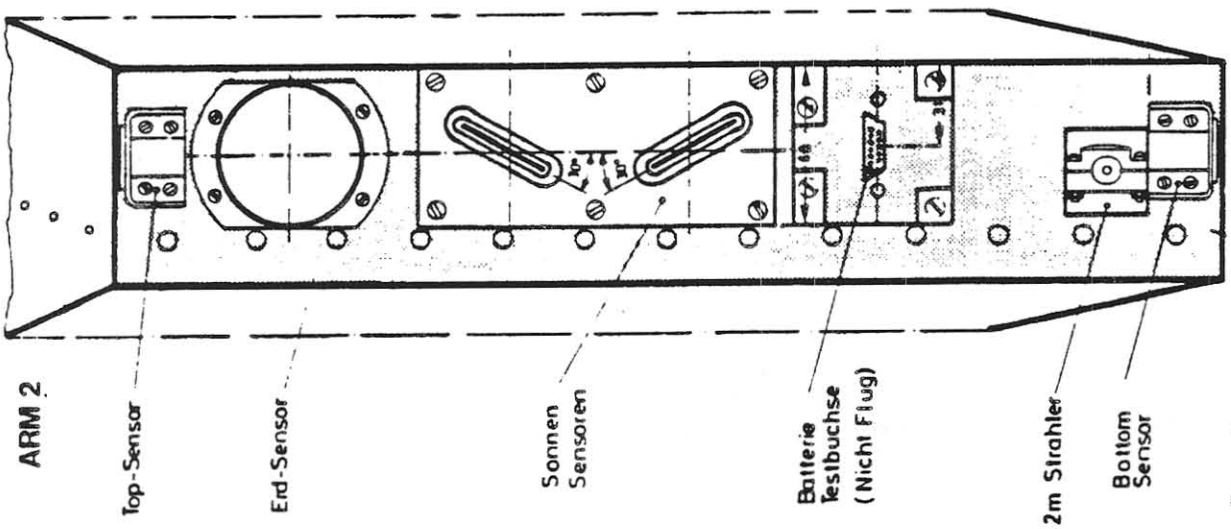


Figure 2 is an end view of sensors, reproduced from PHASE IIIb drawing number 3076A. The circular Earth sensor has a lens and a projecting shade. The Sun sensor actually comprises two identical units mounted as shown.

Oscar-10 carries two other sensors, solar cells 20mm x 20mm facing top and bottom. These give instant qualitative indications as to whether the Sun is above, below or on the spacecraft equator. Their main function is as a safety stop; the on board computer will automatically turn off the transponders and magnetorquers if for any reason the Sun comes too far (50 degrees) above the S/C equator.

Sun Sensors

The Sun sensor is a most elegant yet simple optical instrument. It consists of nothing more than a slit, behind which is a photo-diode.

On Oscar-10 this slit is 33 mm x 0.6 mm, with the BPX48 diode 5 mm behind.

Allowing for obstructions, this gives the diode a field of view of about +- 50 degrees up and down the slit.

As the satellite spins the Sun flashes past the slit each revolution, giving a 'pip' or pulse from the photodiode electronics at the precise moment the Sun passes through the field of view.

From 'Pips' to Angles

Both Sun sensors give pips, but you can see from figure 2 that each is inclined 30 degrees to the spin axis. So the pulses occur at slightly different times. It is this difference which provides the measurement of 'Sun Angle', defined as the angle between the Sun and the satellite's equatorial plane. Figure 3 shows how.

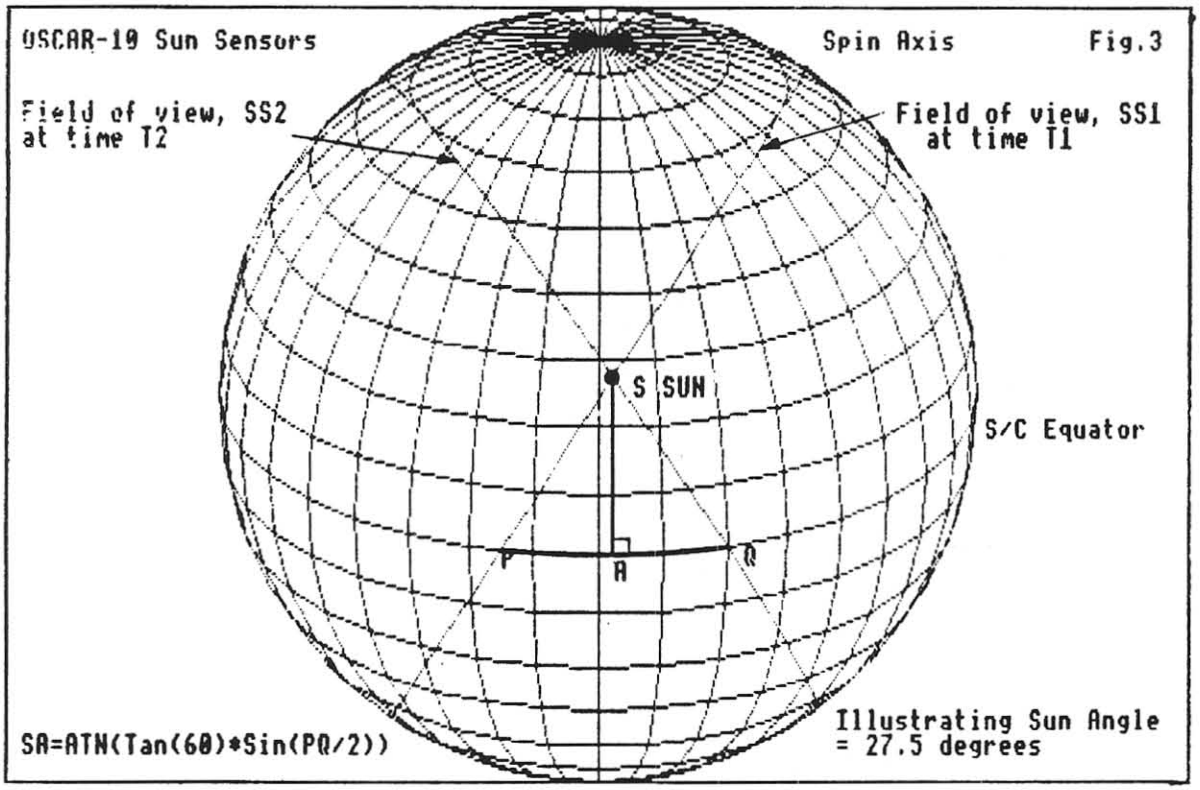


Fig. 3 is the local view from Oscar-10. You must imagine the satellite is a the sphere's centre, the spin axis runs from top to bottom, the spacecraft equator runs around the middle and in this diagram the sensors scan from left to right. The point marked S marks the Sun's (fixed) position, and we want to find SA, the Sun Angle.

Suppose at instant T1 the upper sensor SS1 pips; its field of view must be arc SP. Moments later at T2 the lower sensor pips, and its arc is SQ. We know the baseline angle PQ = (T2-T1) x spinrate. As each arc is inclined at 60 degrees, we can solve for the triangle for Sun Angle SA, viz:

$$SA = ATN(Tan(60) \times Sin(PQ/2))$$

Sun Sensor Electronics

I've just described the method, but to implement it we need a mechanism for determining T1 and T2 - and hence the baseline arc PQ. In Oscar-10 the sensor electronics unit (SEU) takes care of this function.

In outline it consists of an oscillator which is phase locked to the upper beam (SS1) pips. The oscillator runs at 256x the pip rate and drives an 8-bit counter such that the counter reads 0 when SS1 pips. When the lower beam (SS2) pips the counter state is read into the on-board computer's telemetry buffer.

In this way the equator is divided into 256 parts and the arc PQ is now 360 x SS2Count/256 degrees, making the Sun Angle conversion equation:

$$SA = ATN(Tan(60) \times Sin(180 \times SS2count/256)),$$ all in degrees.

Counts exceeding 127 represent a negative value of PQ, i.e. use SS2count-256. 1 count is equivalent to about 1.2 degrees. The spin counter is also read when SS1 pips; if the system is properly synchronized, SS1 will read 0 or 255, because the PLL dithers.

Attitude Determination by Sun Angles

Figure 3 illustrated one measurement of Sun angle (SA). Now we need to derive spacecraft attitude from this, which is illustrated graphically, Fig 4.

If the Sun is angle SA up from spacecraft equator, then it means the satellite spin axis must be lie somewhere along a circle radius 90-SA centred on the Sun's position; the latter's position is found from the Astronomical Almanac (ref 3) or as described in reference 1).

However one observation will not give us a 2-D attitude fix; we need two or more. Well, the second object could just as well be the Sun again, but several days days later. This is because it will have moved a little, and in this context is another object. So here for example are 3 sample measurements made at 14 day intervals:

Sun Sensor 2   Sun Angle

Date	Counts	Deg
1984 Jan 01	46	42.8
1984 Jan 15	47	43.4
1984 Jan 29	42	40.5

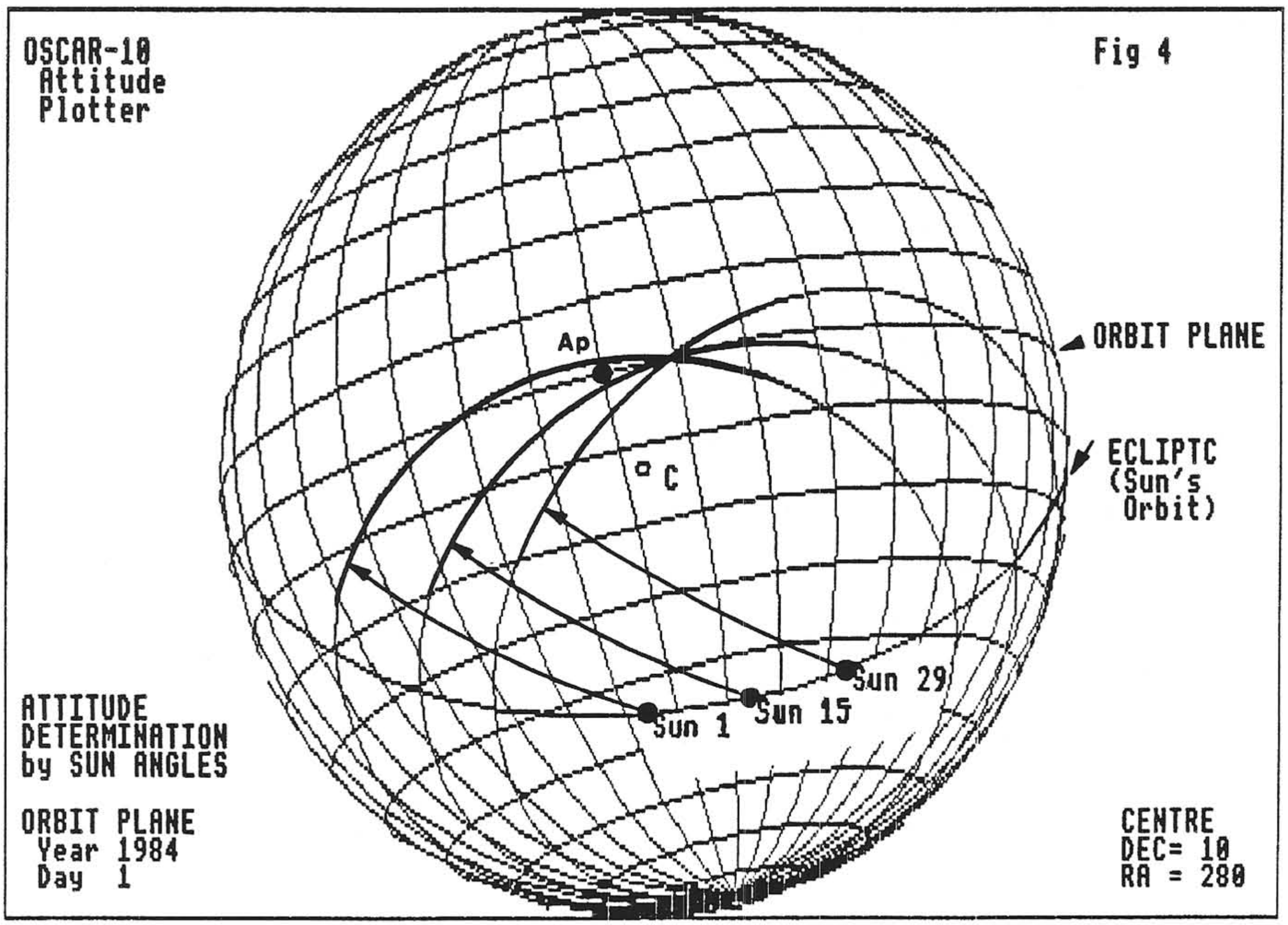


FIG 4

Fig 4 represents the Oscar-10's view of the celestial sphere, and was created using program ATTPLOT. The grid though is in orbit plane coordinates, with the orbit plane passing though apogee direction marked "Ap", at coordinates ALON = 180, ALAT = 0. In the illustration longitude increases rightwards, latitude increases upwards. Oscar-10 is in the centre of the globe; its antenna axis points roughly at perigee, the spin (motor) axis generally towards the apogee direction shown.

Measurement Arcs

The first Sun angle measurement illustrated is drawn as an arc of 90-42.8 degrees centred on the Sun for Jan 01, and the second arc of 90-43.4 degrees is centred on Jan 15, and the third on the Sun for Jan 29.

The arcs intersect at two potential attitude solutions, equispaced across the Sun's plane or Ecliptic. The intersection at ALON=190 ALAT=0 is clearly the most likely one; the other obscured at the pole is almost normal to the plane. Though possible, it would indicate some fairly heroic attitude mismanagement!

Sun Sensor Fix - Numerical Method

The three observations can also be processed numerically; they are simply entered into program SUNFIT, which has a typical output like this:

```
              OSCAR-10 ATTITUDE DETERMINATION by SUN ANGLES
              ---------------------------------------------
Initialising Constants .. Reading Data .. Starting solution at 180/0 ..

 Pass: 1.00  LON = 191.18      LAT =  2.96

 Pass: 2.00  LON = 189.44      LAT = -0.08

 .. converged .. results:

          Solution Date: 1984 Jan 1 [Sunday]       AMSAT DAY 2191

                     Orbit Coordinates        Celestial Coords
          Solution     ALON        ALAT         DEC        RA
         -------------------------------------------------------
          Soln. 1     189.44      -0.08        23.95     284.05
          Soln. 2      53.78     -85.76       -67.60     305.62
         -------------------------------------------------------

      95% Confidence Ellipse:  MAJOR = 1.23 deg   MINOR = 0.01 deg
```

Potential Accuracy Limitations - SUNFIT

This method has one slight drawback. The angle of intersection of the arcs is often very fine, so any slight measurement errors are grossly magnified by the "scissors" effect, giving quite a large fix uncertainty in one direction. In practice you have to take many more than 2 measurements, and validate them carefully. The intersection angle is also increased by taking data over a longer interval - BUT it means you cannot get an instant attitude solution when you need one quickly, particularly when reorienting the spacecraft.

Sometimes the Sun arcs don't actually intersect at all. When the attitude position lies on the Ecliptic (Sun's orbit), the arcs all "kiss" each other, which causes SUNFIT numerical difficulties best studied with a graphical run of

ATTPLOT.

However, the proper solution to this is to use another body altogether - the Earth.

Earth Sensors

The Sun sensor is simple - two slits and two photodiodes - because the Sun is extremely bright, and virtually a point source of light. On the other hand the Earth is rather dim, and its size seen from Oscar-10 ranges from 17 degrees diameter seen from apogee to 75 degrees at perigee. So the instrument needs a lens to gather light and to focus an image of the Earth onto a light detector.

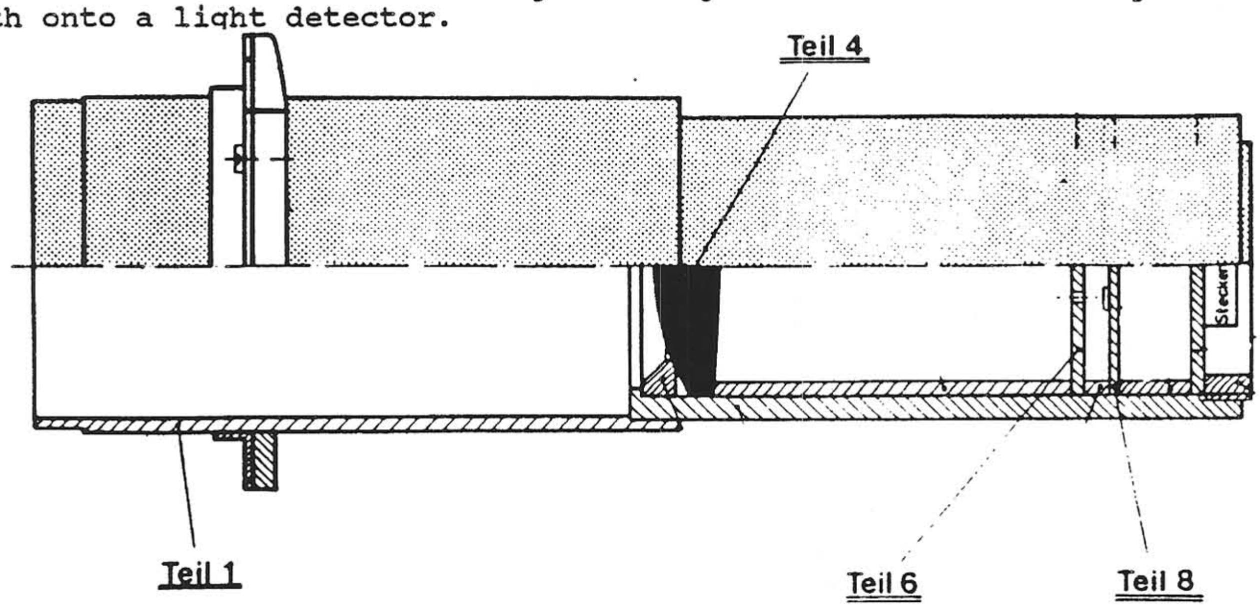


FIGURE 5 is a cross section of OSCAR-10's Earth sensor optics, and is reproduced from AMSAT Phase 3b drawing number 6003. Light enters from the left via an anti-glare shield (1) and the radiation-resistant lens (4), which has a focal length of about 65mm. Two photodiodes are mounted at the focus on plate (8), and just in front of the diodes is a disc (6) with two 2mm holes in front of the diodes, 5mm above and below the centre. This creates two Earth sensors, in one package. Each has a beamwidth of 2 degrees, and they look 4.4 degrees above and below the main axis. The field of view is limited by the shield, and is about +-13 degrees.

The instrument, like the Sun sensor is mounted looking out of arm 2. As Oscar-10 moves around its orbit, shortly before perigee Earth will come into the sensors' view, and an image of the Earth sweeps across the photodiodes. One or both photodiodes will give out a signal, commencing at horizon-in, and ceasing at horizon-out. The time of start (or finish) of this signal gives us the measurement we need. Gradually the Earth comes into full view, then leaves. Shortly after perigee, depending on the exact orientation of the spacecraft, Earth once more comes into view, giving a second series of measurements.

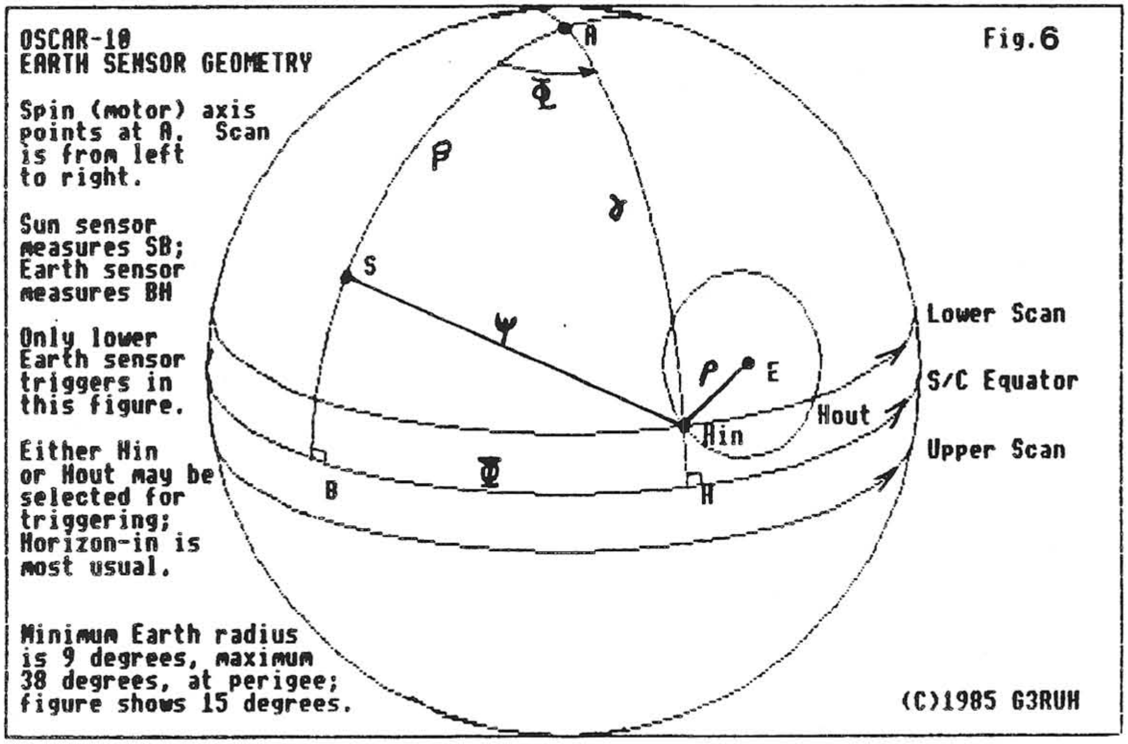


Figure 6 shows the various angular relationships. Oscar-10 is at the centre of this sphere, its spin axis vertical, with the motor pointing out at 'A'. Both Sun and Earth sensors look out onto the equatorial belt, scanning round from left to right as Oscar-10 spins. The Earth's disc is shown centred at 'E', and the lower (motor) Earth sensor beam is shown intercepting the horizon at Hin, leaving at Hout. The upper sensor (antenna side) will not be triggering. Also shown is the position of the Sun, at 'S'. During an encounter the Earth moves essentially up or down this figure.

Earth Sensor Measurements

The Earth sensor signal is also processed by the Sensor Electronic Unit (SEU). Recall the Sun sensor system contains an oscillator phased-locked to the Sun pulses, in such a way that a datum is established corresponding to point 'B' in figure 6, and providing a clock at 256x the spin rate, effectively dividing the spacecraft's equator into 256 parts.

The same clock is used by the Earth sensor electronics; a register is clocked with the instantaneous spin count at either Hin or Hout, depending on the setting of the ground-controlled Edge Select Flag (usualy Hin). So the Earth sensor measurement is simply the angle 'BH', expressed in 256ths of a revolution. In the jargon this is known as a 'rotation angle' measurement; while the Sun sensor provides an 'arc-length' measure. (Ref 5).

As there are two Earth sensors, so two values are telemetered; a flag also says whether the ES measurement has just been updated or not. The flag is reset as the spin counter goes through zero on each revolution. Also telemetred are the mean anomalies (Z count) corresponding to each measurement. This effectively time-tags the data.

In summary, the Earth sensor sub-system provides ESL, MAL, FLL and ESU, MAU and FLU (sensor count, mean anomaly, flags; lower/upper).

Attitude Fixing With the Earth Sensors

We start off with two measurements (observations) S-B and B-H in figure 6, and we have also four known constants, 'S' the Sun's position, 'E' the Earth's location, Earth's radius angle rho (ρ) or E-Hin, and the Earth sensor alignment angle gamma (γ) or 90-(Hin-H). We need to compute the location of 'A' from this data.

Lets work backwards from the solution. 'A' is at the intersection of two arcs of known length, beta (β) and gamma (γ), though we don't yet know where point Hin, the end of gamma (γ) is. Hin lies at the intersection of two known arcs rho (ρ) and psi (ψ), but we first need to know the length of psi (ψ).

However, the latter is the third side of triangle S-A-Hin, for which we already know angles S-A, A-Hin and the included angle phi (Φ), which is the same as B-H, the Earth sensor measurement.

This is a purely geometric problem, and takes no account of whether the Earth was actually illuminated at the time, or whether the sensor trigger could have been a terminator crossing, so additional checks are applied to the potential solution to ensure that the answer is reasonable. In fact geometrically there are two solutions per sensor, one usually an unreasonable value that can be discarded.

Program SENSOLV - Example of Earth-Sun Solution

On 1985 Sep 12 Oscar-10 popped up briefly during a perigee fly-past, the sensor values were entered into program SENSOLV which mechanises the geometry just described, with the following results:

```
OSCAR-10 ATTITUDE DETERMINATION  - EARTH/SUN
---------------------------------------------
Which Earth Sensor; [U/L] ?   LOWER
                              -----
```

```
YEAR 1985 DAY 255   ORBIT 1691
SS1  0    SS2  217
ESL  158  ESU  169      Earth's appearance - Full
MAL  253  MAU  250      Solution condition - OK. Horizon wholly lit
```

Soln	Dec	RA	ALAT	ALON	Horiz
1	-55.4	355.4	-32.0	203.2	Hin
2	1.0	41.7	26.7	238.8	Hout

```
Which Earth Sensor; [U/L] ?   UPPER
                              -----
YEAR 1985 DAY 255   ORBIT 1691
SS1  0    SS2  217
ESL  158  ESU  169      Earth's appearance - Gibbous
MAL  253  MAU  250      Solution condition - OK. Horizon crossing lit
```

Soln	Dec	RA	ALAT	ALON	Horiz
1	-55.5	347.1	-33.6	197.9	Hin
2	-29.9	37.6	-3.8	232.3	Hout

We would deduce that Oscar-10's attitude was ALON 200, ALAT -33 degrees, since the two solutions No. 2 both disagree, and would corrspond to an horizon out trigger.

Ultimate Weapon - Program ESSFIT

This program processes a whole series of Earth measurements, from both upper and lower sensors, from any number of days, plus as many Sun sensor measurements as desired, and calculates an unambiguous attitude fix.

The super-abundance of data makes it very accurate - so accurate that it is also able to calculate the mounting angles of the Earth sensor.

As with the other numerical methods, it seeks the "least squares" solution which is the one that minimises the sum of the squares of the difference between the actual observations and their expected values given that potential solution.

Support Programs

Attitude determination is but one aspect of satellite management. Other questions to be answered are typically:

* Given the present attitude, what will it appear like in the coming months?

* What is the optimum attitude profile for the next 2 years?

* When do eclipses occur, and for how long?

* NASA keplerian elements are notoriously "noisy" - not at all what is needed for precision calculations: what's the cure?

Solutions to these kind of questions are provided by support programs such as ATTHIST, ILLPLAN, ECLIPSE and K1OFIT without which no modern Phase 3 commander is properly equipped!

Program ATTHIST

Lets follow the very first example (ALON=190, ALAT=0) through a few months using program ATTHIST:

```
OSCAR-10 ATTITUDE FUTURE BEHAVIOUR DUE TO PRECESSION
----------------------------------------------------
Please enter initial attitude (in-plane, deg) and year/day
ALON ,ALAT, YEAR, DAY ?  190, 0, 1984, 1
```

DATE	SUN ANGLE deg	ALON deg	ALAT deg	SS2 counts
1984 Jan 01 [Sun]	42.6	190.0	0.0	47
1984 Jan 29 [Sun]	40.6	186.5	-0.7	42
1984 Feb 26 [Sun]	28.0	183.0	-1.3	25
1984 Mar 25 [Sun]	10.3	179.6	-1.7	9
1984 Apr 22 [Sun]	-8.5	176.1	-2.0	249
1984 May 20 [Sun]	-26.0	172.7	-2.1	233
etc				

Notice the effect of orbit plane prescession on the attitude coordinates. In the example, no attitude change would be required for many months to come because of the favourable Sun angle and good attitude prospect.

Program ILLPLAN

This program generates a chart every week of Sun Angle achieved for all attitude choices around the nominal 180/0. Longitude decreases from right to left and Latitude is shown increasing downwards. Thus, if the satellite is at APOGEE, the Earth may be visualised as being at the centre of the numbers, so movement around the table is in the same sense as antenna aim. The "***" indicates the no-go zone near the Sun, where the Sun angle exceeds 45 degrees. This particular chart can be studied in conjunction with figure 4.

1984 Jan 1 [Sun] AMSAT DAY 2191 Sun Elev = -45.2 Sun AZ = 173.5

LA\LO	240	230	220	210	200	190	180	170	160	150	140	130	120
-40	42	***	***	***	***	***	***	***	***	***	***	***	***
-30	37	44	***	***	***	***	***	***	***	***	***	***	***
-20	30	37	44	***	***	***	***	***	***	***	***	***	40

-10	24	30	37	43	***	***	***	***	***	***	45	39	32
0	16	23	29	35	39	43	45	45	43	40	36	31	25
10	9	15	21	26	30	33	35	35	34	31	27	22	17
20	1	7	12	17	21	23	25	25	24	22	18	14	9
30	-6	-1	4	8	11	13	15	15	14	12	9	5	1
40	-14	-9	-5	-1	2	4	5	5	4	2	0	-4	-8

OSCAR-10 SUN ANGLE ANALYSIS CHART - Example

This is only one chart of a continuous series, and allows the Ground stations to look forward for the optimum attitude strategy, one that avoids the *** areas, keeps ALAT as near to zero as possible, and avoids the need for too much attitude changing. Manouevres are both disruptive for the transponder users and time consuming to effect.

During Oscar-10's early life its RAAN was around 180 degrees, which meant that AO-10's orbit plane and the Sun's orbit plane (the Ecliptic, which has an RAAN = 0 by definition) were maximally different. So the Sun Angle was almost always favourable, and few attitude changes were needed. As we approach 1987 the two planes align, differing in inclination by only 3 degrees. Frequent attitude changes will be needed to maintain a favourable Sun angle, and as there will be an Eclipse every orbit, expect regular transponder schedule changes. Analysis of these problems is made simple with ILLPLAN charts.

Program K10FIT

It's unwise to rely on an isolated NASA keplerian element set; all those decimal places may look reassuring, but in fact Argument of Perigee, RAAN and Mean Anomaly precision is rarely better than 0.3 degrees! Program K10FIT generates a smoothed keplerian ephemeris from a year's worth of individual sets. When it runs the "noisy" data is very apparent, and poor values can be quickly eliminated. The ephemerides generated are then used for six months or so both in the attitude determination programs, as well as in the Ground Control Station computers, and the spacecraft on-board computer. They are also distributed to all AMSAT groups via the usual channels.

Acknowledgements

Particular thanks must go to AO-10 commander Ian Ashley ZL1AOX for enthusiastic adoption of these methods from the outset, and for immediate provision of historical data for testing and comparison. Special thanks to Phase 3c commander-in-training Graham Ratcliff VK5AGR for a similar commitment. I also thank AMSAT Australia and AMSAT-UK for financially supporting this work over its 2 year gestation.

References

1. "Sun's Up, Parts 1,2 and 3", J.R. Miller G3RUH, OSCAR NEWS Nos. 50,51 and 52, Dec 1984, Feb 1985, Apr 1985. (Via AMSAT-UK, London E12 5EQ, England.)

2. "Do-It-Yourself OSCAR-10 Attitude Fix", J.R. Miller, OSCAR NEWS No. 57, Feb 1986.

3. "The Astronomical Almanac 1984", (Section C). US Nautical Almanac Office & UK - H.M.N.A.O., US Government Printing Office, Washington/Her Majesty's Stationary Office, ISBN 0-11-8869191-1

4. "Sensorship - A Question of Attitude, Parts 1 & 2", J.R. Miller, OSCAR NEWS Nos. 54 and 55, Aug 1985, Oct 1985.

5. "Spacecraft Attitude Determination and Control", Ed. James R. Wertz, D.Reidel Publishing Co. 1984 ISBN 90-277-1204-2.

HOUSTON SATELLITE PLANS
A PROPOSED SERIES OF SATELLITES FOR DIGITAL MESSAGING

By G. Creager

ABSTRACT:

Explosive growth in Amateur Radio's use of digital communications has occurred since the implementation of AX.25, an adaptation of the CCITT X.25 switched packet network protocol. We propose a series of orbiting satellites dedicated to digital communications. Central to our concept are the following: To maximize the user base by designing the system for use by a prototypical Mode B station; and minimize the amount of modification expected on otherwise usable Packet radio equipment by adhering to the existing AX.25 protocol implementations regarding data encoding, data rates and modem access. A minimum of two satellites are planned. The first phase of the experiment proposes launch of a subset of the final system hardware and software from a Shuttle (STS) Getaway Special into a low-earth orbit, with final orbital insertion accomplished using a thermal-expansion (Freon 114) based perigee kick motor. The second phase of the experiment proposes one or more satellites in a higher orbit, with the advantages of longer window, more access area and less doppler. Both phases will share some commonality: an orbiting digital packet repeater, a single channel device, with input and output on the chosen satellite beacon frequency; and a store-and-forward messaging system. The digital hardware will be designed by the Houston group. Spaceframe design and fabrication will be undertaken by the Phase III- C group in Boulder, CO. Radio frequency components will be designed and fabricated by the Motorola Amateur Radio Club in Fort Lauderdale Florida. Design and implementation of the Packet Technology Satellite Experiment is expected to require at least three years.

Packet Radio (Packet) has enjoyed a marked enthusiasm since it was introduced several years ago. Packet arose as an outgrowth of the computer communications revolution. An adaptation of the CCITT X.25 switched packet network protocol, known in the Packet world as AX.25, allowed incorporation of entire Amateur Radio callsigns as well as intermediate path information (digital repeaters or "digipeaters") in the address field. Initially, the Tuscon Amateur Packet Radio Corporation (TAPR) designed the first commercially available terminal node controllers (TNC). Several manufacturers offered equipment including licensed TAPR designs, and alternatives. An entire redesign effort by TAPR resulted in enhanced operation using the newer TNC-2. Recent additions to the state of the art include IBM-PC plug-in TNC's, controllers specifically for the Apple MacIntosh, hardware-software combinations for the Commodore 64 and 128, and specialty devices which allow use of several of the digital modes including Packet, AMTOR, RTTY, and CW. One manufacturer estimates over 20,000 TNC's have been sold to date overall.

Several groups have proposed and implemented digital communications experiments for orbiting Amateur satellites. These include the digital communications experiment on UoSAT OSCAR-11, the Phase III-B (OSCAR- 10) message system, the RUDAK store and forward system for Phase III-C and the digital transponder and messaging system on JAS-1. The Houston-based Packet Technology Satellite Experiment (PTSE) has proposed a series of orbiting satellites designed for Amateur Packet communications. The considerations which led to this proposal are discussed below.

Of primary concern in the design of the PTSE was maximization of the user base and minimization of modifications to standard Packet hardware. Therefore, we decided that a narrow-band frequency modulated signal, utilizing audio frequency shift keying (AFSK) would be employed for both uplink and downlink. Standard TNC modem tones will be used to allow use of the TNC in non-satellite applications. The system is being designed to serve the typical Mode B station for Phase 1 implementation (100 watts EIRP, 14 dBi transmitter antenna gain).

Two hardware objectives were considered in development of the Packet Technology Satellite Experiment. These included an orbiting digipeater, and a store-and-forward message system. Both of these concepts have been adequately proven in terrestrial applications. The orbiting digipeater will function similarly to a terrestrial digipeater: If a station chooses to include the orbiting digipeater in its connect or unprotocol communications path, it will receive and subsequently retransmit the digital signal on the same frequency that it received it. In addition, the digipeater output will serve as a beacon output, transmitting information related to spacecraft status and condition. The store-and-forward, or messaging, system will perform a function similar to a terrestrial Packet Bulletin Board System (PBBS). The user will have the option of sending a message, reading one left for him, and killing any messages where he was either the sender or addressee. The messaging system will allow run-string input of information, or else will prompt the user for required information. Messages will be constrained to one 80 by 25 screen of data, or approximately 2000 bytes.

Hardware specifications are currently being developed. Current requirements include the use of complementary metal oxide-silicon (CMOS) technology for all integrated circuits to reduce power requirements, static random access memory (RAM) to eliminate the requirement for periodic memory refresh, a large, addressable memory space to accommodate store-and-forward user messages, and error detection and correction hardware and algorithms to detect and correct single bit errors and simply detect and flag multiple, sequential bit errors. Additionally, a large array of memory allows removal of a block in the event of hard failure.

Software specifications are under development, pending finalization of the hardware design. Software requirements, to include user interface, store-and-forward functionality, spacecraft housekeeping functions and digipeater operations are being included in the specifications design. In brief,. the spacecraft software is expected to provide as user simple (not necessarily friendly) an interface to the messaging system as possible. Commands common to the WORLI system will be incorporated, if feasible, to allow the user a comfortable mode to operate in. However, the satellite is NOT a bulletin board; it merely provides one of the functions thereof.

Testing of the Phase 2 spacecraft systems will begin with the Phase 1 deployment. Phase 1 will be a scaled version of hardware and software scheduled for Phase 2. In Phase 2, the basic craft is planned to include a 145 MHz digipeater and 5 Mode B-type (435 MHz uplink, 145 MHz downlink) or Mode L-type (1.2 GHZ uplink, 435 MHz downlink) store and forward channels. The messaging system channels will be segregated by functionality. Two uplink channels will be dedicated to uplinking of messages; three uplink channels will be dedicated to message retrieval. Two downlink channels will be used: Both will be controlled by the onboard computer to promote better channel utilization; one will be dedicated to message uploading, and one to retrieval. The digipeater transmitter channel will function as the spacecraft telemetry beacon. Detection of a known command station call sign will result in a dump of current spacecraft status data. We anticipate developing software to promote distributed command stations transmitting telemetry back to Houston for archiving and analysis. Phase 1 will incorporate a smaller model of the Phase 2 computer system, and program code will be commented out to accommodate the fact that only two store-and-forward channels will fly on it. The digipeater is common to both spacecraft.

The orbit proposed for Phase 1 is approximately 800 kilometers (500 statute miles), circular. We propose to utilize the Freon-114 perigee kick technology developed for UoSAT/PAKSAT to propel the PTSE satellite from a 300 km Shuttle Transportation System (Shuttle) orbit to 800 km. To date, no Shuttle Getaway Special has been approved for launch with a propulsion system in place. A stable circular orbit of this altitude will have an orbital period of approximately 95 minutes and an overhead pass acquisition window of over 10 minutes. The orbits being discussed for the second phase of the project will require a different propulsion system because of the increased mass, and the higher velocity vector required to place an object in a higher orbit. NASA is currently investigating the possibility of a low-cost, small payload package, in the "scout-class" range capable of lifting a 200- 400 kg payload to geosynchronous orbit. It is our considered opinion that the benefits of a high orbit realized in long acquisition window, ease of tracking and small doppler shift will adequately counter the problems of deployment and power considerations.

Several groups have expressed an interest in working with the Houston group, or have been actively solicited. The Motorola Amateur Radio Club, Fort Lauderdale, Florida, who provided the communications handitalkies for W5LFL and W0ORE has expressed and interest in designing and qualifying the spacecraft RF components. The Phase III-C group from Boulder Colorado has been recruited to provide their expertise in spaceframe design and power buss design to our effort. Rick Fleeter, designer of the PAKSAT propulsion system, has been approached to act as propulsion engineer and consultant for the PTSE. In general, an outpouring of support has indicated that all pertinent areas for design consideration have been addressed either within the Houston group or by outside experience.

Funding for the Packet Technology Satellite experiment has not been resolved. Initial plas call for submission of an unsolicited grant request to NASA for a Young Investigators' Award, to provide funding and a laboratory on site at the Johnson Space Center for project work. We further intend to solicit funds from major aerospace manufacturers, in conjunction with AMSAT, in an attempt to gain renewed support from the private sector for Amateur Radio satellite projects.

We anticipate a minimum of three years will be required to bring the two phase project to a conclusion. Much of the reason for the extended time line is due to the grounding of the Shuttle fleet following the Challenger accident. Additionally, the need to develop new computer designs specific for this project as well as mating software, may prove time intensive. Component selection, subsystem assembly and troubleshooting, and extensive ground testing will also impose extensive time requirements. The current short term goal, nonetheless, is to complete a prototype hardware system within six months to allow software implementation and realtime testing of the hardware and software.

CONCLUSION:

We have proposed the design, development, fabrication and deployment of a series of satellites designed for digital communications relay. Specific design criteria include planning for use by a standard OSCAR earth-station and utilization of current AX.25 technology (to preclude the modification of otherwise useful packet equipment). The spacecraft will provide message forwarding functions as well as a digipeater to relay Packet radio signals. The first phase of our project proposes deployment of a subset of the Phase 2 spacecraft into an 800 km circular orbit to provide an early implementation of the satellite for general use as well as to provide a test system for continues Phase 2 development. We anticipate the project will require significant effort on the order of three years to complete.

MICROCOMPUTER SYSTEMS FOR UoSAT TRACKING AND DATA ACQUISITION

by
Robert J. Diersing, N5AHD
Associate Professor of Computer Science
Corpus Christi State University
6300 Ocean Drive
Corpus Christi, Texas 78412
(512)-991-6810-X476
September, 1986

ABSTRACT

This article describes two microcomputer systems used for low-earth-orbit satellite tracking and data acquisition. The systems were developed for use with UoSAT spacecraft operated in the Amateur Satellite Service. One of the systems uses a single computer while the other is a two-computer system. The article concludes with the plans for continued development of the systems to perform new functions such as a gateway to the FO-12 store-and-forward packet radio satellite. The details of the single-computer system were given at the 1984 AMSAT Space Symposium but since no proceedings were published they are repeated in this paper. The details of the two-computer system have not previously been presented or published in an Amateur Radio publication.

INTRODUCTION

In 1981, UoSAT-OSCAR-9, designed and constructed by the University of Surrey (England) Electrical Engineering Department, was launched. UoSAT-OSCAR-9 was the first amateur radio spacecraft to be dedicated to applied research in cost-effective spacecraft engineering and scientific experiments. It was also the first amateur radio spacecraft to carry onboard microprocessors as part of its command, control, and telemetry systems. Data is telemetered to the ground in ASCII at 1200 bauds and is thus easily processable by a microcomputer system with the proper software. UoSAT- OSCAR-9 carries no communications transponder. The University of Surrey's second satellite, UoSAT-OSCAR-11, was launched in March, 1984. UoSAT-OSCAR-9 and UoSAT-OSCAR-11 have come to be called UoSAT-1 and UoSAT-2 and will be referred to as such in this article.

After some additional background information, this article will describe two microcomputer systems designed to automatically track and collect data from amateur radio spacecraft, particularly the UoSATs. The additional background is needed to provide insight into the motivation for the development of the systems. The article will conclude with an evaluation of the systems and the plans for changing and expanding the functions of the systems. Since this article is intended to present the hardware-related aspects of the systems, software will not be discussed in great detail.

Spacecraft In Operation

UoSAT-1 and UoSAT-2---These spacecraft have already been mentioned. They are both in polar, sun-synchronous orbits. UoSAT-1 has an apogee of approximately 500 km. and is usually accessable during two orbits occurring in the early morning hours (3:00 to 6:00 A.M.) and two orbits occurring in the middle afternoon hours (3:00 to 6:00 P.M.). UoSAT-2 has an apogee of approximately 700 km. and has roughly the same number of accessable orbits per day except that they occur during the late evening (8:00 to 11:00 P.M.) and late morning (9:00 A.M. to 12:00 noon) hours. The access time will vary up to a maximum of about 18 minutes. Local times are given in Central Standard Time. The obvious inconvenience of some of these times is one motivation for the development of an automated system.

The operating system software in these spacecraft is now quite sophisticated and various types of data will be captured even within a single access period. A typical combination might be plain text bulletins, telemetered data from spacecraft systems and experiments, whole-orbit telemetry surveys, onboard computer status, and for UoSAT-2, the message headers resulting from messages stored in the Data Communications Experiment, DCE. Examples of these five data types can be found in Figures 1A through 1E.

FO-12---The first amateur radio satellite with a free access store-and-forward digital communications transponder is called FO-12 for Fuji-OSCAR-12. It is a product of Japanese origin where the transponders were built by Japanese radio amateurs and the spaceframe was built by NEC. It was sucessfully launched in August, 1986 by NASDA (the Japanese equivalent of NASA). A properly equipped automated ground station could serve as a gateway to/from terrestrial packet radio networks and FO-12.

Orbit Prediction

The prediction of the satellite access times for a given point on the earth is a computation-intensive task. Yet, an automated system must have this data for every satellite it is to track. The algorithms used to generate this data for the systems described here were developed by Dr. Thomas A. Clark, W3IWI, and were first published in 1980 [1].

Hardware Selection

The final topic before presenting the two hardware configurations is that of hardware selection. The reader may wonder why the systems have been implemented on S-100 bus Z- 80 computers. There are several reasons. First, amateur radio operators are always at the forefront of experimentation. For this reason many started their experimentation with microprocessors at a time when the S-100 bus was much more popular. Second, in any amateur radio project there is the very practical tendency to use the equipment one has available to minimize costs. Finally, it is now easy and inexpensive to acquire 8-bit microcomputers which are adequate for dedicated systems such as described here due to the trend to upgrade to newer 16- and 32-bit systems.

SINGLE-COMPUTER CONTROL SYSTEM

The first automated system developed is shown in Figures 2 and 3. Figure 2 concentrates on equipment external to the computer while Figure 3 provides additional detail about the internal computer system components. As can be seen, the system provides for control of antenna position during satellite access times, control of antenna circularity (polarization), control of radio receiver frequency to compensate for Doppler effect, and control of the tape recorder for both data capture and recording of the satellite/orbit/date/time stamp from the speech synthesizer. All of the above items were conceived in the initial system design with the exception of the speech synthesizer for voice identification of the recorded tapes. This was added as an afterthought. The pertinent details of the method of implementation of these features follow.

Antenna Positioning

The antenna position is updated during a satellite pass at a time interval corresponding to the one used when the orbital predictions were made. Several system components are involved.

First, a new set of azimuth and elevation headings are acquired at the start of a new time step. Next, from parameters known by the program, these headings are converted to the corresponding position indicating voltages to be read from the rotator control boxes by the analog-to-digital converter channels. Third, the current position voltages are read. By comparing the current and target voltages the required direction of movement is found. Fourth, movement in the proper direction is initiated by setting the proper bit of the latched parallel output port going to the rotator control interface. Finally, the motion is stopped when the position voltage read from the A-to-D, which is being read continuously, matches the target voltage.

Depending on the A-to-D used, rescaling of the input may be required so that the input range of the A-to-D is consistent with that produced by the rotator position indicator. Also, in some cases additional voltage regulation may be required for the power supply providing the position indication voltage. With a little work a combination can been found that allows the antennas to be positioned to within one unit on the analog position indicator. This is usually 5 degrees for typical azimuth rotators and 3 degrees for elevation rotators. This level of accuracy is adequate for most antennas found at amateur radio stations.

Antenna Polarization Switching

The signal as originated from the satellite is either right- or left-circular polarized. However, due to spacecraft orientation, spacecraft motion, propagation effects, and other factors, the signal-to-noise ratio may sometimes be improved by switching to the opposite polarization sense. This is especially true when the fade is deep and prolonged and not caused by local man-made noise.

To attempt to accomodate these fades, the ciruclarity switch mounted at the antenna is wired to one of the relays on the 4PIO isolated interface. When there is no other function to perform the system constantly monitors the signal strength as indicated by the receiver S-meter. As long as the level stays above some threshold set in software nothing is changed. If the level does fall below the cutoff point nothing is done immediately but the system continues mon- itoring to see if the trend is either consistently downward or prolonged according to other software counters. If it is a consistent downward trend a switch is made to the opposite polarization.

Frequency Correction For Doppler Shift

As is the case with any transmitting source in motion with respect to the observer, there is Doppler shift observed when receiving the signal from the satellite. Although it is not considerable at the usual receiving frequency of 145.825 MHz., the ability to automatically compensate for it was thought to be a desirable feature.

The implementation of this feature requires a custom- built interface between the S-100 bus and the microprocessor in the ICOM IC-251A receiver. The requirement is to decode a Z-80 port address and provide the data to the microprocessor in the radio at CMOS levels over a 4-bit data bus. There are also control signals for data transfer and other status indications such as signal/no signal being received. Thus, data must also be read from the receiver through a Z-80 port. The interface in use was designed by Kurt Terwilliger, KI6J, of Cromemco Inc. [4].

During a satellite pass, the receiver frequency is updated at each time step after antenna positioning. The frequency is first set using the Doppler computed during the orbit prediction phase. This is used as an initial guess after which the frequency is moved in the required direction in 100 Hz. steps while monitoring the center frequency (discriminator) meter output. Before the zeroing process is started, the metering circuit must be switched from signal strength to center frequency. It is returned to signal strength monitoring after the frequency is set.

Tape Logging and Control

The audio tape recorder used to capture the data is turned on and off by a relay on the 4PIO interface. It was soon learned that it would be much better if there was some sort of marker recorded on the tape between each data set.

The solution to this problem was another custom-built board interfacing the National Semiconductor Digitalker speech synthesizer chip set to the system. The circuit was designed by Dr. Aaron Brown and is documented in [3].

The control scheme was modified slightly such that at the beginning of a satellite pass the audio input to the tape recorder is switched to the Digitalker interface. Then, a voice label is placed on the tape consisting of the satellite identifier, orbit number, date, and time under program control. After the label has been generated, the input to the tape recorder is switched back to the receiver audio.

Software Issues

All of the previously described functions are controlled by a single computer program written in BASIC. The version of BASIC used was Cromemco 32K Structured BASIC. This dialect of BASIC is particularly powerful in that it provides all of the necessary structured programming features including procedures. This allowed easy development of a fairly complicated control system. There were no time- critical functions beyond the capabilities of an interpretive language.

Results of Actual System Operation

The single-computer control system has been in operation since October of 1983. As might be expected, various deficiencies were found and other desirable features were conceived. Some of these items would require software solutions while others would require a different hardware configuratiuon.

The most serious deficiency of the system was choosing to tape record the data rather than capturing it directly on disk. Soon, large stacks of tapes accumulated which still had to be demodulated before the data could be inspected and processed. With two spacecraft operational providing, on the average, eight visible passes per day it is easy to see that one could spend days processing an accumulation of tapes. Clearly, this had to be changed.

Another problem was the inability to prioritize the tracking function among satellites. The desirability of this feature is best illustrated by an example. AMSAT-OSCAR-10 in its elliptical orbit may have a visibility time as long as 12 hours. In the mean time, one or more shorter duration passes of polar, sun-synchronous satellites such as UoSAT-1 and UoSAT-2 may have occurred and their data will have been lost. Even though OSCAR-10 does not carry scientific experiments, it is desirable to monitor its telemetry from time to time to see the status of the various spacecraft systems.

A minor fault of the system was noticed during the Space Shuttle missions which included amateur radio operations. The first of these was by Dr. Owen Garriot from Columbia in 1983. The problem arose due to the azimuth and elevation positioning being done serially rather than in parallel. The low altitude of the Space Shuttle orbit causes it to be moving very fast with respect to the ground station. On high-elevation passes the system had a hard time keeping up with the Space Shuttle.

Finally, some of the functions implemented could have been omitted without serious consequences. One of these was the Doppler shift correction function. Although it is still thought desirable it could be limited to using only the computed value to set the receive frequency. The zeroing to the on-the-air signal could be eliminated. This is satisfactory on the two meter downlink frequency which is used the majority of the time. It would probably not be satisfactory when monitoring higher frequency downlinks. Another justification for the elimination of this feature is a present trend in modem design to allow the modem to control the receiver frequency directly. This is possible because almost all digital frequency control receivers have facilities for controlling the VFO from an external source.

Another feature that did not work well was the antenna polarization switching. Using the software approach described earlier, it was very difficult to decide when a switch would be beneficial. Frequently the switch would be made just when it would have been better to leave things as they were. The solution to this problem used by the University of Surrey groundstation (at least at one point in time) was have two identical receiving systems with one connected to an antenna of RHCP and the other connected to an antenna of LHCP. The error rate is then monitored on both receive channels simultaneously and the system producing the lowest error rate is selected for data capture. For the systems described here, this approach would have been cost- prohibitive due to the duplication of equipment required.

This section has described the shortcomings of the single-computer system as observed through two years of actual operation. The experience gained provided the basis for development of the dual-computer system described next.

DUAL-COMPUTER CONTROL SYSTEM

The author is employed at Corpus Christi State University and due to the phase-out of Z-80 single-user systems, several donations of such equipment were made to the university. This turn of events coupled with the desire to remove the deficiencies of the original system and also have a station in operation at the university caused the construction of a new system to begin in late 1985. The configuration to be described next was placed online on February 1, 1986 and has been in continuous operation since that time.

Two computers are employed in the new configuration. One of them is used for station control functions such as antenna positioning, radio control, and so forth while the other is used for data capture. All data is held in memory until the satellite is no longer visible after which it is saved on disk. The station control computer sends commands to the data capture computer. Figure 4 shows equipment external to the two computers while Figure 5 provides additional detail about the internal computer system components.

Station Control System

The major changes in the station control system are software changes and will be discussed later. The antenna positioning function is handled in the same manner as the single-computer system. The system clock/calendar is an external rather than internal device. Frequency control of the radio receiver, a Yaseu FRG-9600, is accomplished through a serial port provided on the receiver as standard equipment. However, this port operates at TTL rather than RS-232 levels. There is no attempt to zero the radio frequency to the actual received signal and there is no switching of antenna polarization. Finally, the two systems are connected via an 8-bit bi-directional parallel port for communication purposes.

Data Capture System

The major changes to the overall system come as a result of the addition of the second computer. As mentioned earlier, all of the captured data is held in memory until the spacecraft is no longer visible and then it is stored on disk. Since the Z-80 can only accomodate a 16-bit address bus and it is likely that more data than this will be captured on a single pass, bank switched memory is used.

Bank-Switched Memory---The data capture system has 3 banks of 32K bytes each for data storage. The bank switching is done by assigning one of the Z-80 I/O ports (40h) for this purpose. When a bank of memory fills the program can issue an OUT instruction to the bank-select port with the desired new bank number specified in the accumulator. The memory boards then decode this I/O instruction and those with a bank number matching the one specified are connected to the bus while all others are disconnected. If a memory board should remain connected to the bus at all times, it is wired to appear in all eight possible banks.

In the data capture system, addresses 0000 to 3FFFh are not switched since the data capture program resides there. Likewise, addresses C000 to FFFFh are not switched because the operating system resides in high memory. It is the 32K bytes occupying addresses 4000 to BFFFh that is bank switched during data capture operations.

While, bank switching could be eliminated entirely by using a newer microprocessor with a larger linear address space, one must consider the cost of the computer system in this case--zero. The bank-switched memory carried a similar price tag.

Multiple Modems---Since the data is now being demod- ulated in real time, there is a requirement to switch modems according to the modulation scheme used in the received data. This turns out to be one of the major assets of the new system both now and in the future. All satellites now being tracked use different modulation schemes. Furthermore, those already built and awaiting launch also use varying schemes. In some cases, the modulation scheme used on the uplink is different than the modulation used on the downlink.

Any required modems can be connected to the data capture computer subject only to the availability of serial interface cards. The proper modem is selected at data capture time by command sent from the station control computer according to specifications made by the operator for the particular satellite.

Software Support---Software running in the data capture computer is written in Z-80 assembly language. The program is one that evolved from one used previously for the separate demodulation and storage of the recorded data tapes. The program was modified so that it can be operated in both local and remote command mode. Remote command being the mode in which it will accept commands from the station control computer. The station control computer can issue commands to select the desired receive port, and thus the correct modem, to start and stop data capture, and write the captured data to disk with the proper file name.

There are also several other new software features. One of them allows threshold values to be set for starting and suspending data capture. The start threshold requires that a certain number of consecutive error-free characters be received before data capture is started. The suspend threshold causes a certain number of consecutive character errors to stop data capture. Capture is resumed again when the start threshold criteria is fulfilled. This feature has the effect of eliminating the capture of many erroneous characters particularly when signal strength is poor such as when the satellite is near the horizon at the beginning and end of a pass. Finally, the operator may specify the memory bank numbers and addresses to be used in the banked-memory capture process.

EXTENSIONS TO CURRENT SYSTEMS

Both of the systems described in this article are operational. The dual-computer system has proven entirely satisfactory from a hardware viewpoint. The single-computer system is used mostly for backup and experimentation. This is primarily due to the university location of the dual- computer system being a much more RF-noise-free environment. Also, the operation of the university system as the primary system serves to expose students to computer applications in the space sciences. This section briefly details some changes and extensions planned for both systems.

Single-Computer System

The hardware will be expanded to support the two antenna systems already in place. This will allow the tracking function for some satellites to be assigned to one antenna system and other satellites to a different antenna system. The control system software will be converted from BASIC to a compiled language, probably PL/I. In the diagram shown in Figure 3, the SDI graphics interface can be seen. This is not currently used but the plan is to utilize the graphics system to provide a real-time ground track display for the satellites being tracked.

Dual-Computer System

This system may also be expanded to support control of dual antenna systems but since the antenna systems are not already in place this has not been decided. However, the control program will be converted to a compiled language as well. At the same time a few minor problems will be fixed. The most significant change to this system will involve the integration of additional hardware and software so that it can serve as a gateway to the FO-12 satellite.

The FO-12 satellite was mentioned in the background section and was successfully launched during preparation of this article. For a description of the FO-12 satellite systems see [5]. Complete details of the issues involved in integrating the gateway function are beyond the scope of this article. Briefly, though, the work will involve the integration of a typical terrestrial packet radio mailbox system such that it can communicate with the data-capture system. Messages from terrestrial packet radio system that are marked for uploading to the spacecraft would have to be fetched by the data capture computer and transmitted during a FO-12 pass. The reverse process would also have to be done-- retrieving data from FO-12 destined for the local area network.

CONCLUSION

The design, development, and implementation of the systems described here has shown that it is indeed possible to construct a sophisticated microcomputer-based system for low-earth-orbit satellite tracking and data collection. It remains to be seen if system functions can be expanded to include that of a packet radio satellite gateway for use with the JAS-1 satellite. The outcome of that endeavor will be reported in a future article.

ACKNOWLEDGEMENTS

The author would like to thank those individuals who contributed in various ways to the development of the systems described in this article. Mr. Carl Crownover, President of Jordan Laboratories, donated some of the hardware used in the station control computer of the dual-computer system. Dr. F. Michael Speed, President of Speedman Oil Company, donated the data capture computer system. Finally, thanks to Dr. Ruth Bakke, Dean of the College of Science and Technology, Corpus Christi State University, for providing the additional laboratory space for that part of the development work done at the university.

REFERENCES

1. Clark, Thomas A., "BASIC Orbits", ORBIT Magazine No. 6, AMSAT-USA, March, 1980, Page 6.
2. ________, "Microcomputer Processing of UoSAT-OSCAR-9 Telemetry", QST, August, 1984, Page 23.
3. ________, Microcomputer Applications in Station Control and Processing for UoSAT-OSCAR-9 and UoSAT-OSCAR-11, AMSAT-UK, July, 1985.
4. Terwilliger, Curt, "Computer Control of the IC-255A", QST, May, 1981, Page 30.
5. Yamashita, Fugio, "Outline of Satellite JAS-1", Proceedings of the ARRL Amateur Radio 5th Computer Networking Conference, Orlando, Florida, March 9, 1986, Page 122.

```
00015203515221 21E7
```

```
000152035152212 1E7
```

```
UOSAT-2              8608063171422
002727015 68A02238B03469804054505040106026207054608048409037D
105051113 4521200031306371412241544 8C16383F17531118522C19547E
204701211 85F22659A230001240017250007260 97A27527528545E295187
305134310 36732286D335746340007352646363161374462384861395168
407641411 21742634743062344165245000146000247505348515D494823
505563511 1155266705367345466765500005600035751245850805 95108
6082A6615 FD0621F4E63334164440265 1E0C6647ED67700668000E69000F
```

```
UOSAT-2              8608063171437
002673015598022437035125040545050401060262070546080484 09037D
1050731134521200031306261412171544 8C16383F17532218524A19547E
20508F21185F22659A230001240017250007260 97A27526428543829518 7
3047553103673228 6D335775340007352631363152374462384861395168
4076504112174263474306014416524500014600024750534851 5D494823
5056245111155266615367255466235500005600035751175850805 95108
6082A6615FD0621F4E633341644402651E0C665A87677006 68000E69000F
```

```
UOSAT-2              8608063171441
00279C0155230224510352510405450504010602620705460804840 9037D
10507311345212000313063714101515449D16383F17532218524A19547E
20508F21185F22659A230001240017250007260 97A27526428542929518 7
30429C3103673228 6D335746340007352646363161374462384861395168
407650411217426347430654441652450001460002475053485 15D494823
5057165111155266705367345466765500005600035751175850805 95108
6082A6615FD0621F4E63334164440265 1E0C66544567700668000E69000F
```

```
UOSAT-2              8608063171446
00297C01 54220224730353630405450504010602620705460804840 9037D
10508C11 345212000313063714104015448C16383F17532218525B19547E
20507021 189322659A230001240017250007260 97A27526428542929518 7
30387F31 0367322 86D33579B340007352657363170374462384861395168
40765041 1217426347430645441652450001460002475053485 15D494823
50576151 11155266 9E53675254667655000056000357512458508 0595108
6082A661 5FD0621F4E63334164440265 1E0C66520767700668000E69000F
```

Figure 1C --- Standard telemetry data as transmitted by UoSAT-2. The duration of transmission is controlled by the OBC. UoSAT-1 transmits standard telemetry in a similar format.

```
***UOSAT 2 COMPUTER STATUS INFORMATION***
COMMAND DIARY V3.2 IN OPERATION
UNIVERSAL TIME IS 17:18:11
DATE 06/08/86
AUTO MODE IS SELECTED
SPACECRAFT SPIN PERIOD IS -0095H SECONDS
LAST CMD SENT BY COMPUTER WAS 40H TO 1
LAST CMD RECD BY COMPUTER WAS 48H TO 1 WITH DATA 00H
CURRENT WOD COMMENCED AT 00:00:00
DATE 06/08/86
SURVEY INCLUDES CHANS 02,03,30,41,

***UOSAT 2 COMPUTER STATUS INFORMATION***
COMMAND DIARY V3.2 IN OPERATION
UNIVERSAL TIME IS 17:18:15
DATE 06/08/86
AUTO MODE IS SELECTED
SPACECRAFT SPIN PERIOD IS -0095H SECONDS
LAST CMD SENT BY COMPUTER WAS 40H TO 1
LAST CMD RECD BY COMPUTER WAS 48H TO 1 WITH DATA 00H
CURRENT WOD COMMENCED AT 00:00:00
DATE 06/08/86
SURVEY INCLUDES CHANS 02,03,30,41,

***UOSAT 2 COMPUTER STATUS INFORMATION***
COMMAND DIARY V3.2 IN OPERATION
UNIVERSAL TIME IS 17:18:19
DATE 06/08/86
AUTO MODE IS SELECTED
SPACECRAFT SPIN PERIOD IS -0095H SECONDS
LAST CMD SENT BY COMPUTER WAS 40H TO 1
LAST CMD RECD BY COMPUTER WAS 48H TO 1 WITH DATA 00H
CURRENT WOD COMMENCED AT 00:00:00
DATE 06/08/86
SURVEY INCLUDES CHANS 02,03,30,41,
```

Figure 1D --- UoSAT-2 OBC status is transmitted periodically. The UoSAT-1 OBC produces a similar status message. Note that the OBC status shows which channels are included in the whole orbit telemetry survey and the date and time of the survey. The channels included in the survey can be retrieved from the actual data but the date and time can only be found in the OBC status message.

UoSAT-OSCAR-11   Bulletin-047   31 July 1986
**************   ************   ************

UoSAT Spacecraft Control Centre,
University of Surrey, England.

** UO-9 OPERATIONS **

A Spacecraft Operations Review was hedd at UoS last week to plan UO-9 & 11 orbital operations for the next three months. In view of the difficulties generally experienced whilst loading the weekly Bulletin and DIARY schedule into UO-9 causing the s/c to be switched OFF at least one day per week, it is proposed to reload the DIARY schedule once per month and to retain only a short Bulletin on UO-9 for operations schedules and non-time-critical information only. Thus the weekly 'news' items will be carried only by UO-11, which is far easier to reload and possesses sufficient on-board memory to support both a long Surveys simultaneously. The consequent reduction of workload on the groundstation & staff will allow us to maintain a more up-to-date news service on UO-11 and devote more time to other underdeveloped experiments.

A more detailed description of the planned operations will be carried in a future Bulletin, however if any UoSAT experimenters have any suggestions that they wish to submit or feel that the above operations plan would seriously jeopardise their activities - please write to UoS immediately so that views may be considered.

** UO-11 OPERATIONS **

** WOD CHECKSUM CHANGE **

As mentioned in previous bulletins, the UO-2 WOD checksum is changing from the current value of AA hex to the new sum of BB hex. This change will be effective from 07/08/86.

* UoSAT SLIDES/BOOKLETS *

Thanks for the many requests for the above and the accompanying donations to cover costs - these are most welcome! Please, however, do not send cheques in non-UK currency as these generally cost more than their face value to process! 'Foreign' currency notes are OK.

We still have over 50 sets of 40 slides left for those who would like to 'see' the design, construction, test & launch of UO-11.

** JAS-1 LAUNCH **

The launch of the Japanese Amateur Radio Satellite JAS-1 is still scheduled for 7 August at 2030 UTC. Amateur Satellite Report indicates that daily advisories will be filed by Haruo Yonida (JA1ANG) beginning on 5 August. These advisories should be available at UoS for inclusion in UO-11 newsflashes. In North America, a special 75-meter (3857 kHz) AMSAT net cycle will be held on Wednesday 6 August.

The AMSAT Launch Information Service will provide realtime coverage on launch day starting at 1930 UTC. Teleconference linkingof all net stations will begin at 2000 UTC. Nets will be active on 20 and 40 meters. Frequencies planned for use include 14282, 14295, 7185 and, if 15 meters is open, 21390 kHz. JA1ANG in Japan will be included in the teleconference to provide a first-hand description of launch and boost phases. This net will continue with separation and first beacon reports from South America at 2132 UTC. These reports and a wrap-up of events will conclude the realtime coverage at 2200 UTC.

Prie3 will be genreated by JA1ANG on 8 and 9 August, and AMSAT-NA will hold special 75 meter AMSAT net sessions on Thursday and Friday evenings to distribute Keplerian elements and other up-to-date information.

** RS SATELLITE TRANSPONDER SCHEDULE **

A new operating schedule for the RS satellites is in effect. RS-5 will be on from 0900 to 1400 UTC daily except Wednesdays Moscow time (2100 to 2100 Tuesday UTC). RS-7 will be turned on from 1400 to 2100 UTC daily except Wednesdays Moscow time. Since the satellites don't have working batteries, they tur. off when entering eclipse. Thus, for this shcedule to be implemented, the satellites must be turned on on each orbit by the Moscow control station. The cycle of eclipses ends on 10 August, and the satellites may then be found on for longer periods.

(Via ASR)

Figure 1E --- A sample of the general news bulletin messages transmitted by both UoSAT-1 and UoSAT-2. This is a very up-to-date news source in which information may appear well before it is published in other forms.

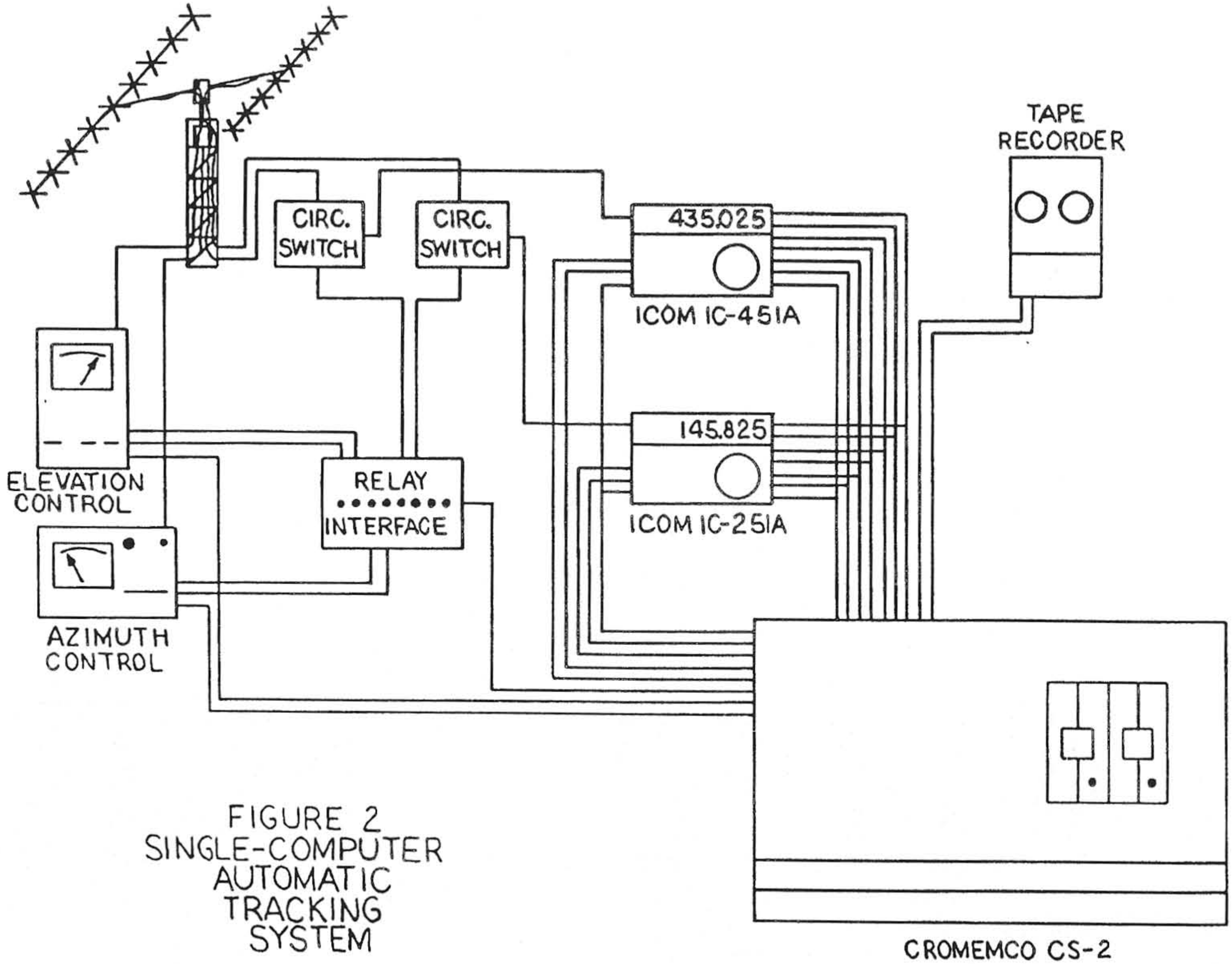


FIGURE 2
SINGLE-COMPUTER
AUTOMATIC
TRACKING
SYSTEM

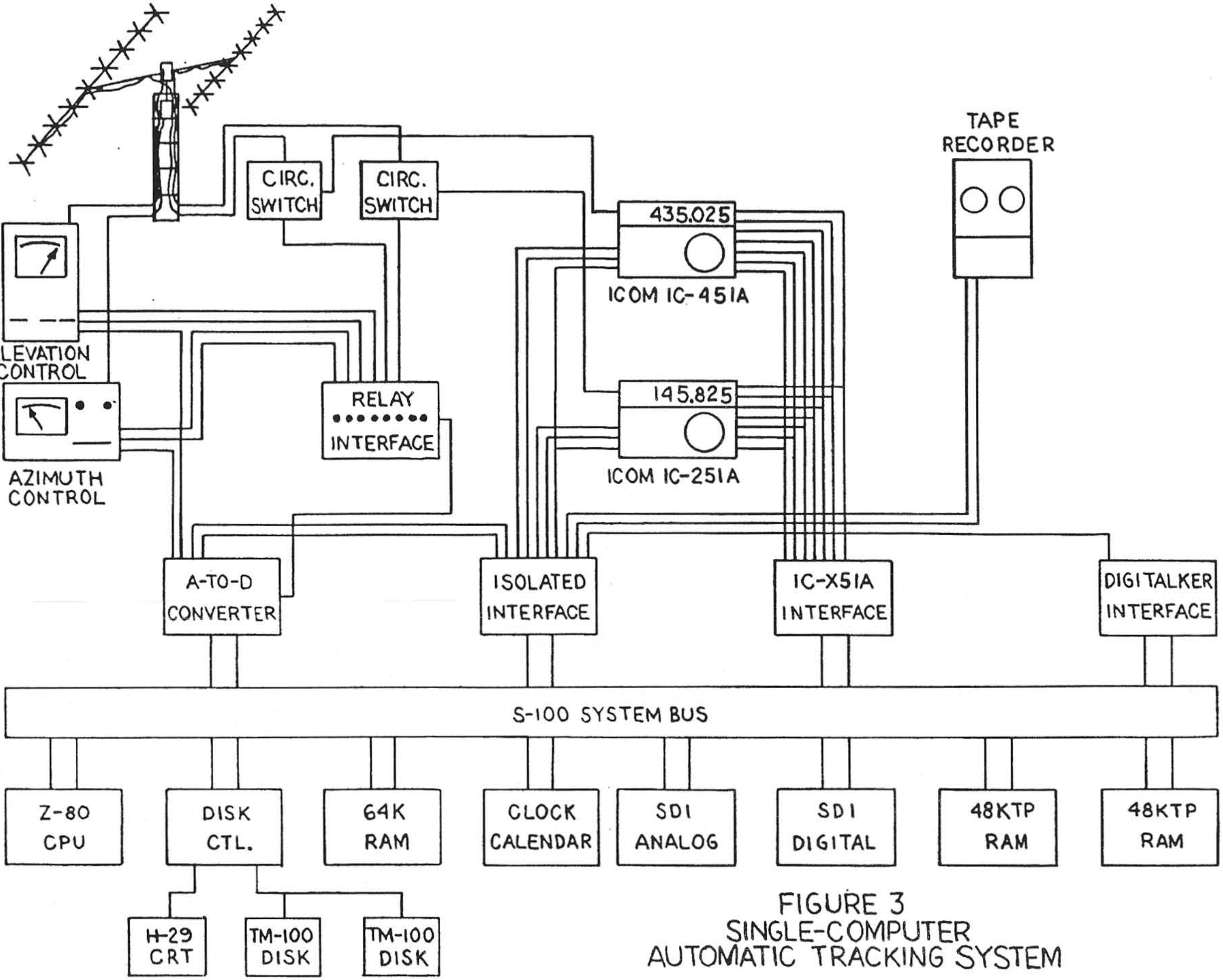


FIGURE 3
SINGLE-COMPUTER
AUTOMATIC TRACKING SYSTEM

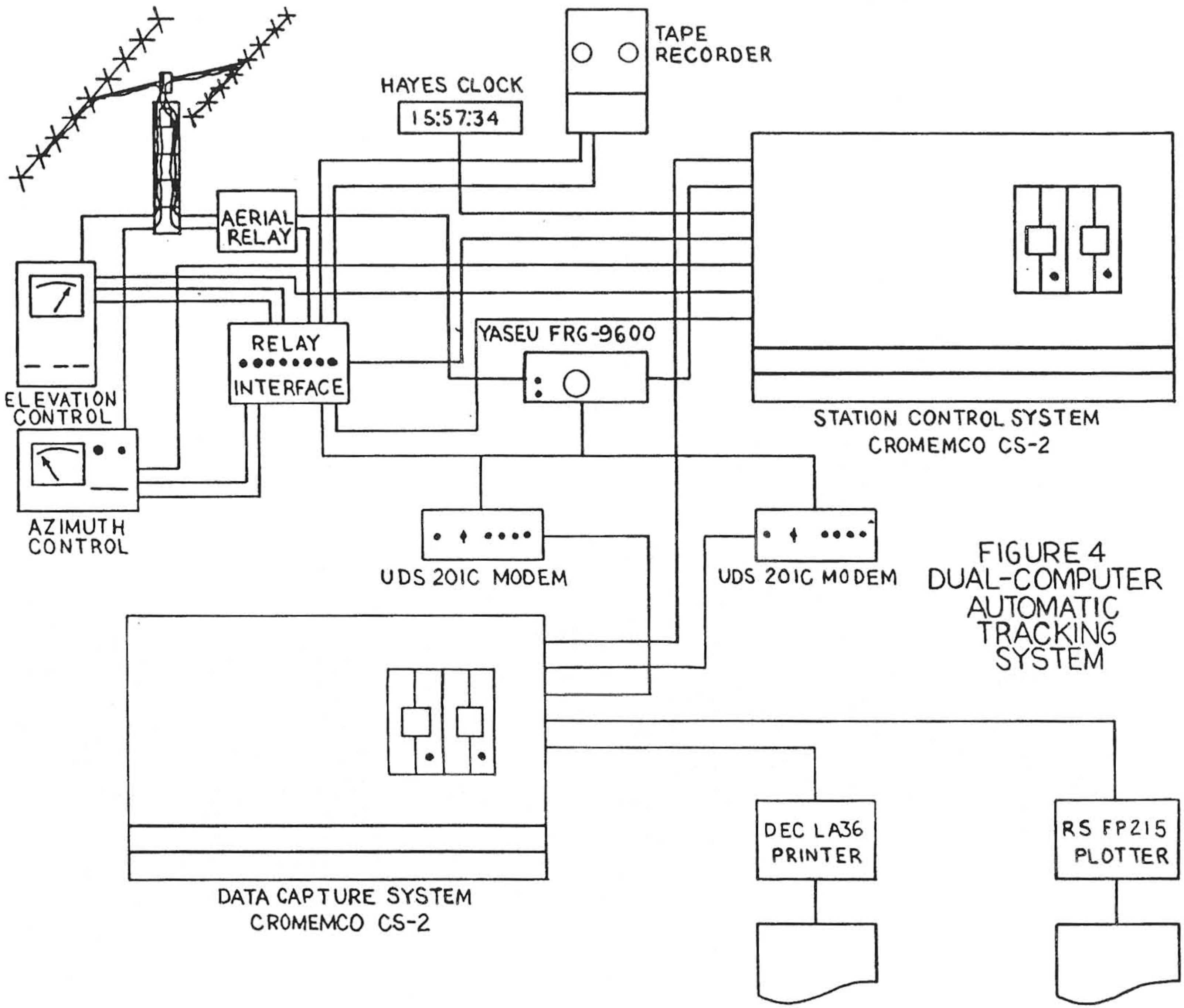


FIGURE 4
DUAL-COMPUTER AUTOMATIC TRACKING SYSTEM

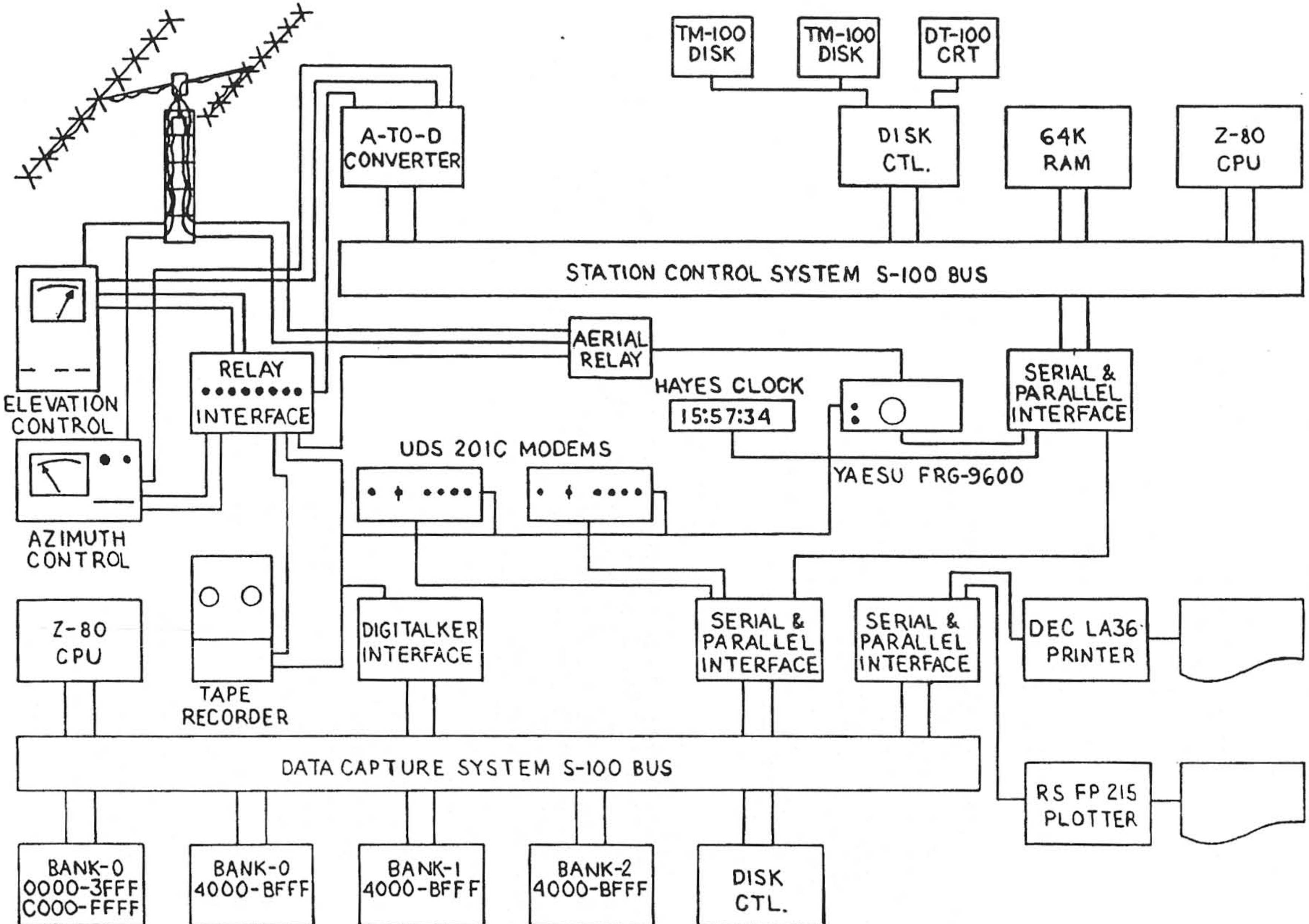


FIGURE 5
DUAL-COMPUTER
AUTOMATIC TRACKING SYSTEM

PROCESSING UoSAT WHOLE-ORBIT TELEMETRY DATA

by
Robert J. Diersing, N5AHD
Associate Professor of Computer Science
Corpus Christi State University
6300 Ocean Drive
Corpus Christi, TX 78412
(512)-991-6810-X476

September, 1986

ABSTRACT

This article will familiarize the reader with the whole- orbit telemetry data surveys currently being transmitted by both UoSAT-1 and UoSAT-2 and the requirements for processing this data type. An overview of both standard and whole-orbit telemetry data transmissions will be given. This will be followed by a detailed description of the whole-orbit surveys. Considerations for the development of a comprehensive set of computer programs for processing WOD are included. The article concludes with a description of an actual WOD processing system, operational experience with that system, and a brief presentation of the hardware environment in which it is used.

INTRODUCTION

The transmission of whole-orbit telemetry surveys began quite some time ago with UoSAT-1 (UoSAT-OSCAR-9). At that time two different formats were used on two different days of the week. One form consisted of a transmission of seven telemetry channel readings that were stored in the onboard computer (OBC) memory at fixed time intervals for the duration of one orbit. The other form consisted of eight telemetry channel readings with radiation counter data interspersed in the transmitted data stream. Whole-orbit telemetry was also transmitted by UoSAT-2 (UoSAT-OSCAR-11) after its recovery in May, 1984. The format was similar to that used with UoSAT-1.

Toward the end of 1985 and beginning of 1986, both spacecraft began to operate under the control of a diary program stored in the OBC. This control program allowed much more flexibility in scheduling the activities of the OBC and data types transmitted on the downlinks. Consequently, whole-orbit telemetry surveys are transmitted very frequently from both spacecraft. The increased frequency of transmissions of WOD make it more desirable to be able to decode and analyze this data. The amateur satellite enthusiast can thus observe the measurements made by onboard sensors when the spacecraft is not within range of the groundstation.

Little has been published on the subject of whole-orbit telemetry data processing in the United States. Information is available from the University of Surrey in the form of the UoSAT Spacecraft Data Booklet [4]. There have also been a number of articles written by Harold Meerza carried in the AMSAT-UK OSCAR News. This paper will serve to consolidate the available information while presenting additional details about the processing of WOD. Even though a number of actual examples of WOD plots will be included, no time will be spent here on analyzing the data. That will be left for another paper.

The remainder of this paper contains three major parts. The first will present a brief overview of the standard and whole-orbit telemetry transmitted by both UoSAT-1 and UoSAT- 2. This has been done so that readers who have not monitored these spacecraft will be familiar with the telemetry system in general. A more detailed study of the WOD surveys will be done in the second part. This will include such things as the method for validating the received data, interleaved transmission scheme, and procedures for combining data from several successive orbits to form a completely error-free data file. The third part will describe the programs used to process the WOD files from which the sample plots included with this article were made.

Two shorter sections have also been included. One of them describes the operational experience gained from the system and the plans for future changes to the system. The other provides a brief description of the hardware and software used for WOD processing.

OVERVIEW OF STANDARD AND WHOLE-ORBIT TELEMETRY

This section contains a brief description of the standard and whole-orbit telemetry formats. It is important to understand the standard format since the whole-orbit data is merely an extraction from the standard telemetry channels that has been stored in the OBC memory. The data is later transmitted on the downlink at time intervals determined by the OBC.

The UoSAT spacecraft transmits telemetry data in ASCII, usually at 1200 bauds, but other rates may be used. The data describes the status of the spacecraft systems and also contains telemetered values from the spacecraft housekeeping systems and onboard experiments. Typical standard telemetry frames from UoSAT-1 and UoSAT-2 follow.

```
UOSAT-1              8609070115234 COMPUTER GENERATED TELEMETRY
000909010302027O8D0300030400040540100633 8E07272008414909490 4
```

```
4076724112174263 8B430610441661450001460002475024485 13B494832
```

The two previous examples are actual telemetry frames captured while this article was being prepared. For both UoSAT-1 and UoSAT-2, the lines beginning with 00 through 50 contain the actual measurements being telemetered. Each of these lines consists of ten sets of a two-digit channel number followed by a three-digit value followed by a check digit. The check digit validation scheme is the same for both UoSAT-1 and UoSAT-2. However, this validation scheme will not be covered here since we are primarily interested in whole-orbit data.

The header line is similar in both frames and contains the date, day of week, and UTC time of transmission. In the UoSAT-2 frame, the last line contains the status of all of the onboard systems. For example, which systems are active and which are inactive, downlink data rate, downlink modulation type and so forth. Currently, there is no similar indication of systems status in the UoSAT-1 frame.

No matter which data format is being processed, the values from the channels of interest must be converted to engineering units. This is done by substituting the value from the telemetry into a calibration equation. Some channels use the same equations while others are different. For the system described in this article the conversion to engineering units is done by program WODPLOT to be discussed later. A few examples of conversions of telemetered values to engineering units for UoSAT-1 follow.

Consider one of the least complicated equations.

Channel Number Telemetered Value

50120

I = 3 * N mA = +10 V Line Current

I = 3 * 120 = 360 mA

Some equations are more complicated.

Channel No. 27 = I of Telecommand Receiver

27307

I = 0.125 * (N - 16) * 0.952 mA

I = 0.125 * (307 - 16) * 0.952 = 34.629 mA

Other equations may require values from two channels.

Channel No. 05 = Magnetometer Experiment HXC
Channel No. 15 = Magnetometer Experiment HXF

05401 15337

$$Bx = (129 * NXC - 64324) - 18.05 * (NXF - 511)\ nT$$
$$Bx = (129 * 401 - 64324) - 18.05 * (337 - 511)\ nT$$

$$Bx = -9454\ nT$$

These are merely a few examples, but they do represent the range of complexity that will be encountered. A complete list of calibration equations for both satellites can be found in [4].

As has already been mentioned, the WOD surveys are done by saving the values from certain selected channels in the the OBC memory for a period of time. The amount of OBC memory available for data storage is about 8K for UoSAT-1 and 32K for UoSAT-2. The duration of the survey is under control of the OBC as loaded by the UoS command station. If whole-orbit data is being transmitted, the status message transmitted by the command diary will give the date and time of collection and the channels that are included in the survey. Samples of the status message and WOD surveys from both spacecraft follow.

```
***UOSAT1 COMPUTER STATUS INFORMATION***

COMMAND DIARY V0.4 IN OPERATION
UNIVERSAL TIME IS 11:49:24
DATE 07/09/86
AUTO MODE IS SELECTED
LAST CMD SENT BY COMPUTER WAS XXH TO 0
LAST CMD RECD BY COMPUTER WAS 7DH TO 0 WITH DATA 34H
CURRENT WOD COMMENCED AT 00:00:00
DATE 06/09/86
SURVEY INCLUDES CHANS 53,54,55,

0000053054055AE
000808677637626
001008678038307
00180867854027A
002008679140761
002808679741446
0030086803427BE
00380868094399E
.....
     .....
          .....
04C022061063573
04C823560563561

***UOSAT 2 COMPUTER STATUS INFORMATION***
```

```
COMMAND DIARY V3.4 IN OPERATION
UNIVERSAL TIME IS 17:52:51
DATE 07/09/86
AUTO MODE IS SELECTED
SPACECRAFT SPIN PERIOD IS -00D2H SECONDS
LAST CMD SENT BY COMPUTER WAS 40H TO 1
LAST CMD RECD BY COMPUTER WAS 6DH TO 0 WITH DATA 00H
CURRENT WOD COMMENCED AT 00:00:00
DATE 07/09/86
SURVEY INCLUDES CHANS 11,37,38,39,

                 000001103703803902
                 00083454394815139l
                 00103444394815138A
                 001834443948151382
                 00203444394815137A
                 002834443948151372
                 00303434394805136C
                 003834343948051364
                 ......
                 0FD0332440474510D6
                 0FD8332440474510CE
```

We will now look at the WOD telemetry format in more detail.

A CLOSER LOOK AT WHOLE-ORBIT TELEMETRY

Header Lines and Line Serial Numbers

There are some important observations to be made about the sample WOD surveys in the previous section. First, each line consists of a four-digit line serial number followed by from one to eight three-digit telemetry channel values followed by a two-digit checksum. The only exception is the first line, serial number 0000h. In this line the telemetry channel value positions contain the channel numbers of the channels included in the survey. An inspection of the UoSAT- 2 sample will verify this. Spaces have been inserted for readability.

0000 011 037 038 039 02

It should be noted that this is consistent with the information contained in the status message. It is also important to note that the date and time of collection can only be obtained from the status message and is not contained in the survey data itself.

The time span between successive lines is determined by multiplying the line serial number increment by the time required to digitize and transmit a standard telemetry frame at the current downlink data rate. Considering a downlink data rate of 1200 bauds, the digitize-and-transmit time for UoSAT-1 is 5.28 seconds and for UoSAT-2 it is 4.84 seconds. Thus, the time between lines 0008h and 0010h in the UoSAT-1 example is

(0010h - 0008h) * 5.28 and (0010h-0008h) * 4.84 for the same lines in the UoSAT-2 example. The duration of a WOD survey can thus be determined by multiplying the highest line serial number by the same factors of 5.28 and 4.84. Various maximum line serial numbers that have been observed recently are shown in the table below. Both the time between measurements (lines) and the duration must, of course, be considered by the plotting program WODPLOT.

OBSERVED HIGHEST LINE SERIAL NUMBERS IN WOD SURVEYS

Number of WOD Channels	UoSAT-1 High Serial	UoSAT-2 High Serial
1	0E48	
2	0720	
3	04C0	
4		07E8
8		0FD8

Interleaved Transmission Scheme

The previous examples were only short extractions from an actual WOD survey. Their intent was to show the general format for WOD and that a typical survey from UoSAT-1 might consist of lines 0000h through 04C8h while one from UoSAT-2 could have lines 0000h through 0FD8h. The larger number of lines from UoSAT-2 is a result of the larger amount of memory available in which to store the survey. In actual practice, however, multiple sets of lines are transmitted as shown in the following example from UoSAT-2.

```
000001103703803902
000834543948151391
00103444394815138A
001834443948151382
00203444394815137A
002834443948151372
00303434394805136C
003834343948051364
......
0FD0332440474510D6
0FD8332440474510CE

000134543948151398
000934543948151390
001134443948151389
002934443948151371
00313434394805136B
003934343948051363
00413434394805135B
004934243948051354
......
0FD1332440474510D6
0FD9332440474510CE
```

The data set with serial numbers 0001h through 0FD9h is transmitted following the data set with serial numbers 0000h through 0FD8h. There may also be a 0002h through 0FDAh set. The previous discussion of time between measurements still holds. That is the time between lines 0008h and 0009h is 4.84 seconds since the difference between serial numbers is one. The data is downlinked in this interleaved fashion so that burst errors during downlink reception can be repaired with the following set of "nearby" data points. Although the system described in this article does not make use of this feature it is particularly useful when observing the WOD in real time as is done at the UoS command station.

Checksum Validation

In order to verify the checksum, each pair of ASCII characters is taken as a hex byte value and summed. Using modulus 256 arithmetic, the summation should produce a constant result. In the case of UoSAT-1 whole orbit telemetry, the constant value is AAh, which is 170 decimal. For UoSAT-2 the value is BBh, which is 187 decimal. The validation scheme is the same for both UoSAT-1 and UoSAT-2 except for the production of a different constant result. An example of the checksum validation procedure follows. It was taken from the UoSAT Spacecraft Data Booklet [4].

Consider the WOD telemetry line:

    0088511449621693FF

Take this line and add a zero ('0') in front of each three-digit telemetry value to get:

    00 88 05 11 04 49 06 21 06 93 FF

Add together the first digit from each pair (remembering A=10,B=11, etc.) and multiply by 16:

    16*(0+8+0+1+0+4+0+2+0+9+F) = 624

Add together the second digit from each pair:

    0+8+5+1+4+9+6+1+6+3+F = 58

Add these two previous results together, divide by 256, and note the remainder.

    (624+58)/256 = 2 with remainder 170

Lines producing the correct result when subjected to the validation procedure should represent correct data. The UoSAT-2 WOD should produce a remainder of 187 (BBh). This validation procedure is done by the program TLMEDIT.

Merging Data from Multiple Orbits

If data from the UoSATs is collected often, it will be noted that rarely can a complete WOD survey be captured in a single pass. This is usually due to a combination of two factors. The first is marginal reception due to low elevation passes and/or local interference with the downlink signal. The second is the switching of the WOD on and off the downlink by the OBC resulting in insufficient data being captured.

The solution to this problem lies in the merging of data from orbits where the same WOD survey has been transmitted. Care must be taken that the WOD is from the same survey as indicated by the OBC status message. The following table shows a group of orbits collected at the author's station location.

UoSAT-1 and UoSAT-2 DATA COLLECTED AT 27.48N, 97.24W

UoSAT-1 Data			UoSAT-2 Data		
Orbit No.	Date	High Serial	Orbit No.	Date	High Serial
27162	08/25/86	049A	12089	06/07/86	090A
27163	08/26/86	0242	12090	06/07/86	0D99
27170	08/26/86	0722	12096	06/07/86	0FD0
27171	08/26/86	0722	12097	06/07/86	0FD9
			12098	06/07/86	0FD8

UoSAT-2---For the author's station location, a new WOD collection has already begun for the UTC day prior to the first visible pass. This can be seen by referring to the UoSAT-2 data in the preceding table. Note that the highest line serial number for orbit no. 12089 is 090Ah and for orbit no. 12090 it is 0D99h. This is because WOD collection was in progress when the data was captured. When monitoring the downlink in real time, "WHOLE ORBIT DATA COLLECTION IN PROGRESS" will be seen in the OBC status messages until the survey has been completed. For listeners in the United States, the best orbits for WOD collection will be the morning passes since the survey will have been completed by then. Occasionally, a new WOD survey will be stated around noon UTC but this is not common.

UoSAT-1---The same comments apply to UoSAT-1 as given for UoSAT-2 with one notable exception. The difference is that frequently, a new WOD survey is initiated between passes visible in the U.S. since this is when UTC midnight occurs. This can be seen in the preceding table since orbit no. 27162 occurs on 08/25/86 while orbit no. 27163 occurs on 08/26/86. The highest line serial number is again lower on orbit no. 27163 indicating a WOD survey is in progress.

AN OPERATIONAL SOFTWARE SYSTEM

Overview of Processing Programs and Examples

This section describes an operational software system for processing WOD surveys from the UoSATs. The system consists of six programs--TLMEDIT, TLMWHOLE, ORBITS00, ORBITS01, WOD1PLOT, and WOD2PLOT. TLMEDIT does the first phase editing for all types of UoSAT data. TLMWHOLE performs completeness checks on edited WOD files and merges WOD from different orbits to produce complete WOD files for plotting. ORBITS01 is used to generate subsatellite point data for use by the plotting program. ORBITS00 maintains the element set data base used by ORBITS01. WOD1PLOT and WOD2PLOT are used to plot the WOD surveys from UoSAT-1 and UoSAT-2 respectively.

Video display output and operator responses for each of the programs follow. The use of TLMWHOLE for WOD completeness checking and file merging will be shown by using two different groups of orbits from UoSAT-2. These groups are shown in the table below and represent two extremes one can encounter when processing WOD with respect to processing steps required. Figure 1A shows a processing flowchart for the worst-case example and Figure 1B depicts the best-case example. Most cases in actual practice lie somewhere in between these two extremes. It is often possible to construct a complete WOD survey from data from two orbits.

UoSAT-2 WOD FILES USED IN PROCESSING EXAMPLES

Orbits from 06/07/86		Orbits from 06/21/86	
File Name	File Size	File Name	File Size
U2W12089.DAT	20,758	U2W12294.DAT	16,138
U2W12090.DAT	16,758	U2W12295.DAT	17,618
U2W12096.DAT	8,958	U2W12301.DAT	25,038
U2W12097.DAT	36,998	U2W12302.DAT	24,418
U2W12098.DAT	10,718		

Phase 1 Editing --- TLMEDIT

All types of telemetry data transmitted by the UoSATs are processed by TLMEDIT. In this case it is used to extract WOD from a raw data file as captured from the satellite. It is this program that performs the checksum computations that were described earlier. TLMEDIT will also process all of the older type UoSAT formats. This is necessary because there is a backlog of raw data that has yet to be processed.

```
Terse prompts desired?  (Y,[N])
Display output file while processing? (Y,[N])
Enter input telemetry file name U2T13441.RAW
Enter output telemetry file name U2W13441.DAT

Telemetry formats that can be processed.
     1 = Standard UoSAT-1, old style
     2 = Standard UoSAT-1, new style
     3 = Checksummed UoSAT-1, old style
     4 = Checksummed UoSAT-1, new style
     5 = Whole orbit type 1 UoSAT-1, old style
     6 = Whole orbit type 2 UoSAT-1, old style
     7 = Standard UoSAT-2
     8 = Checksummed  UoSAT-2
     9 = Whole orbit UoSAT-2 and UoSAT-1 new style
```

```
Enter telemetry type code 9

Enter number of channels in line [4]
Enter checksum for line in decimal [170] 187

Processing U2W13441.RAW, please wait.......................

 1886 Records in input file.
  610 Records in output file.
The input file was 44.8% WOD.
0FD8 was the high serial number.
000001103703803902 was the channel ID line.
```

Phase 2 Editing and File Merge --- TLMWHOLE

TLMWHOLE has two functions--it can check a WOD file for completeness and it can merge WOD files from different orbits together in an attempt to produce a 100% complete WOD survey. The two examples below depict the complete range of possible cases for completeness of WOD survey files.

The first example shows the complete run for checking file U2W12089.DAT and producing a file that can be later merged with WOD from the same survey but collected on different orbits. Only the file status output from the next four runs are shown. These runs show U2W12090.DAT, U2W12096.DAT, U2W12097.DAT, and U2W12098.DAT to be 67.7, 7.1, 99.4, and 28.9 percent complete respectively. This example represents one of the worst possible cases that could happen. U2W12097.DAT is 99.4% complete and only needs lines 0378h, 0DB8h, and 0E80h. However, a quick inspection of the status of the other files shows that neither 0DB8h nor 0E80h is in any of the other four files. Thus, with WOD from the same survey available from five different orbits, a complete file cannot be constructed.

Only one example of operation of TLMWHOLE in merge mode is shown. Multiple merge runs would be required as shown in Figure 1A. After all merges are complete the file is 99.6% complete. Nevertheless, it has been included in the plotting examples as if it were 100% complete.

Contrast this example with that of U2W12301.DAT. Here the best possible outcome is realized--a 100% complete file in a single run. Probably one rule of thumb should be to try the largest U2W*.DAT file first. This would be especially true if the orbit was a morning (local U.S. time) pass since a WOD survey would have been completed by that time.

```
Terse prompts desired? (Y,[N])
Telemetry formats that can be processed:
     1 = Whole orbit type 1 UoSAT-1 (old style)
     2 = Whole orbit type 2 UoSAT-1 (old style)
    W2 = Whole orbit UoSAT-2 and UoSAT-1 (new style)
Enter telemetry type code W2

Processing options:
```

```
     C = Check status
     M = Merge files
Enter processing type C

Enter input telemetry file name U2W12089.DAT
Enter UoSAT WOD first line serial 0000
Enter UoSAT WOD last line serial 0FD8
Enter UoSAT WOD line serial increment 8
Enter number of channels in line 4
Display file contents during status check? (Y,[N])
Produce sorted output file for merge? (Y,[N]) Y

Generating serial number list...
Checking U2W12089.DAT...................................

Status of file U2W12089.DAT
0000        Missing              02F0 - 0508 Missing
0018        Missing              0520 - 0570 Missing
0050        Missing              05A0        Missing
0070        Missing              05C0 - 05D8 Missing
00D8        Missing              0688 - 06A0 Missing
00F8        Missing              06D0 - 06E8 Missing
0128 - 0130 Missing              0720 - 0728 Missing
0150        Missing              07C8        Missing
0168        Missing              0810        Missing
01A0        Missing              0840 - 0850 Missing
01C0        Missing              0898        Missing
0298        Missing              08B0        Missing
02D0 - 02D8 Missing              08F8 - 0FD8 Missing
                                 The output file is 33.7% complete.

Reading input file U2W12089.WRK.............................
Sorting input file U2W12089.WRK.
Writing output file U2W12089.SRT.........................

End of job.

--------------------------------------------------------------

Status of file U2W12090.DAT      Status of file U2W12096.DAT
0400        Missing              0000 - 0A58 Missing
07C8 - 07D0 Missing              0A68 - 0AA8 Missing
0870 - 0888 Missing              0AB8 - 0C40 Missing
08B0 - 08C0 Missing              0C50 - 0D20 Missing
08D0        Missing              0D38 - 0D68 Missing
08E0 - 0908 Missing              0DA8 - 0E30 Missing
0920 - 0928 Missing              0E40 - 0E58 Missing
0948        Missing              0E70 - 0E80 Missing
0960 - 0980 Missing              0EA0 - 0EA8 Missing
0990        Missing              0EF0 - 0EF8 Missing
09A0 - 09B8 Missing              0F18 - 0F60 Missing
09C8 - 09D8 Missing              0F80 - 0F88 Missing
09F0 - 09F8 Missing              0FA8 - 0FC8 Missing
0A08        Missing              0FD8        Missing
0A30 - 0A38 Missing              The output file is 7.1% complete.
```

```
0A68        Missing
0A78 - 0A88 Missing
0AC8        Missing
0AE0 - 0AE8 Missing
0B18 - 0B28 Missing
0C30        Missing
0C40        Missing
0C50 - 0FD8 Missing
The output file is 67.7% complete.

Status of file U2W12097.DAT
0378        Missing
0DB8        Missing
0E80        Missing
The output file is 99.4% complete.

Status of file U2W12098.DAT
0108 - 0110 Missing
0130        Missing
0140 - 0190 Missing
01A0 - 0200 Missing
0218        Missing
0238 - 02C8 Missing
02D8 - 0388 Missing
0398 - 03A8 Missing
03B8 - 0428 Missing
0448 - 0490 Missing
04A0 - 0508 Missing
0570 - 0580 Missing
0590        Missing
05A0 - 05C0 Missing
05F0        Missing
0608 - 0610 Missing
0650        Missing
0668        Missing
0678 - 0688 Missing
06C8        Missing
0710        Missing
0728        Missing
0768 - 0790 Missing
07A0 - 07A8 Missing
07B8 - 07C0 Missing
07D8        Missing
07F0 - 0828 Missing
0838 - 0878 Missing
0888 - 0898 Missing
08A8 - 0C60 Missing
0C78 - 0C88 Missing
0C98        Missing
0CC0        Missing
0CD0 - 0E08 Missing
0E18 - 0EA0 Missing
0EB0 - 0ED8 Missing
0F00 - 0F10 Missing
0F28 - 0F38 Missing
0F58        Missing
0F78 - 0F80 Missing
The output file is 28.9% complete.

-------------------------------------------------------------

Enter telemetry type code W2
Enter processing type code M
Enter input telemetry file name U2W12089.SRT
Enter telemetry file name to be merged U2W12090.SRT
Enter merged output file name U2W12090.MRG

Merge of UoSAT WOD files in progress, please wait...
Merge of UoSAT WOD files complete.
513 records read from input files.
355 records written to output file.

Status of file U2W12089.000
0DB8        Missing
0E80        Missing
The output file is 99.6% complete.

-------------------------------------------------------------

Enter telemetry type code W2
```

```
Enter processing type code C
Enter input telemetry file name U2W12301.DAT
Enter UoSAT WOD first line serial 0000
Enter UoSAT WOD last line serial 0FD8
Enter UoSAT WOD line serial increment 8
Enter number of channels in line 4
Produce sorted output file for merge? (Y,[N]) Y

Generating serial number list...
Checking U2W12301.DAT....................................

Status of file U2W12301.DAT
The output file is 100.0% complete.

Reading input file U2W12301.WRK.............................
Sorting input file U2W12301.WRK.............................
Writing output file U2W12301.SRT............................
End of job.
```

Subsatellite Point Computations --- ORBITS00 and ORBITS01

A slightly modified version of the W3IWI orbit prediction program [1] is used to produce a file of sub-satellite points that can be read by the plotting program WODPLOT. This file is used to provide information about the position of the spacecraft during the WOD survey. Since it is sometimes desirable to plot old data, a program was written to maintain a data base of element sets. ORBITS01 can then select the element set nearest to the time for which SSP data is needed.

Typical displays from both ORBITS00 and ORBITS01 follow. First, two displays from ORBITS00 are shown. The remainder of this section shows output and operator replies associated with ORBITS01.

```
KEY  SATELLITE  IDENTIFIER  YEAR  DAY    to  YEAR  DAY     COUNT
 1     UO-9      81-100B     84 352.4230      86 247.4544   107
 2     AO-10     83-058B     84 365.9529      86  35.6826    46
 3     UO-11     84-021B     84 355.2174      86 237.6459    62

              SATELLITE HEADER RECORD DISPLAY
               Satellite Name: UO-9
                Object Number: 12888
                   Identifier: 81-100B
       Beacon Frequency No. 1:  145.825
       Beacon Frequency No. 2:  435.025
       Beacon Frequency No. 3: 2401.5
       Beacon Frequency No. 4:    0.0
                   First Year:   84
                    First Day:  352.42296325
                    Last Year:   86
                     Last Day:  247.45443268
            Element Set Count:  107
```

Record Key: 1

```
Enter prediction output device.
V=video, P=printer, N=none ([V],P,N)
Do you wish to create SSP file? (Y,[N]) Y
Enter SSP file name UO11SSP.013

                    STATION SELECTION MENU
Number    Station   Longitude   Latitude     Height     Min  Elev

   1      N5AHD       97.24       27.48        0          -3.0
   2      N5AHD       97.24       27.48        0         -90.0
   3      G3YJO        0.20       51.10        0          -3.0
                    Enter station number 2

                   SATELLITE SELECTION MENU
Number     Satellite    Object    Identifier      Element Sets

   1       UO-9         12888      81-100B            107
   2       AO-10        14129      83-058B             46
   3       UO-11        14781      84-021B             62
                   Enter Satellite number 3

       ENTER START DATE/TIME, DURATION, AND TIME STEP
                   Start:       Year = 86
                               Month = 1
                                 Day = 20
                          Day Number = 20
                   Start:  UTC Hours = 0
                             Minutes = 0
                   Duration:   Hours = 24
                             Minutes = 0
                   Step:     Minutes = 1
       Calculation will be from 20.000000 to 21.000000
               Is above data correct? ([Y],N)

          Station = N5AHD located at 27.48N, 97.24W
          Orbital elements for UO-11
          Element set no. 112 issued 01/21/86 in use.
          Element set age in days = 2
          Reference epoch = 86 + 17.2069
          Starting epoch = 86 + 20.0000 = 86/01/20 at 00:00
```

PARAMETER	REFERENCE	STARTING
Orbit number	10030	10071
Mean anomaly	80.0770	20.7422
Inclination	98.1689	
Eccentricity	0.00122450	
Mean motion	14.6202	
Mean motion rate	0.00000073	
Semi-major axis	7064.7450	
Arg of perigee	279.9044	271.1695
R.A.A.N.	86.1471	88.9081

```
Beacon freq. in MHz.     145.825
 When ready to begin calculations press RETURN
   CALCULATIONS IN PROGRESS, PLEASE WAIT...
```

Plotting --- WOD1PLOT and WOD2PLOT

Programs WOD1PLOT and WOD2PLOT are used for plotting data from UoSAT-1 and UoSAT-2 respectively. Program prompts and operator responses for one plotting run are shown below. The program allows multiple channels to be plotted in the same run if the y-axis units are the same for the channels requested. The maximum number of plots allowed in one run is four. The program allows WOD input files containing any number of surveyed channels up to a maximum of ten.

Figure 2 shows the four plots from U2W12089.000 used in the previous example of TLMWHOLE operation. Figure 3 shows the plot from U2W12301.000 also from the previous discussion. The other figures contain plots from UoSAT-2 WOD surveys of other telemetry channels and have been included for reader interest.

```
Enter telemetry file name U2W12301.000
Enter WOD survey orbit number 12301
Enter WOD survey date 06/21/86
Enter WOD survey time 00:00:00
Enter number of channels 4
Enter time increment for X-axis in seconds  1800
Enter SSP file name U2SSP.061

Select channel numbers to be plotted.
Channel no. 1 is 002 = Nav Magnetometer Y-axis        Plot? Y
Channel no. 2 is 003 = Nav Magnetometer Z-axis        Plot? N
Channel no. 3 is 010 = Solar Array Current +Y         Plot? N
Channel no. 4 is 020 = Solar Array Current -X         Plot? N

Processing WOD file, please wait...
Insert BLUE pen.  Press RETURN/ENTER when ready.
Insert BLACK pen.  Press RETURN/ENTER when ready.
Processing complete.  Plot again from same file? (Y,[N]) N
```

RESULTS OF ACTUAL OPERATION

The reader can easily see that even though the system described here accomplishes the desired result, there can be an excessive number of processing steps with a correspondingly large amount of operator interaction. This has been caused by the continued modification of a system that was originally used to process, at most, around four orbits per week of WOD from a single spacecraft, UoSAT-1. In addition to the fewer transmissions of WOD by UoSAT-1, the entire downlink time was dedicated to WOD on the designated days. Thus, there were fewer merges required to obtain a complete survey. With the development of the diary software aboard both UoSATs, much more WOD is generated than can be conveniently handled. Another factor that influenced the system development was the CP/M-80 operating system operating on a computer with a 64K address space.

Work has already begun to improve the system. Some of the improvements will be realized by consolidating the functions of TLMEDIT and TLMWHOLE into a single program. Since all processing of WOD is now done on systems with UNIX- like operating systems, it is possible to make use of shell scripts and other operating system features such as built-in sort routines and redirection of program input and output to assist in processing the WOD. The result of these changes will be a less operator-intensive system.

HARDWARE AND SOFTWARE ENVIRONMENT

The data to be processed by the programs described here is automatically captured by a two-computer system. One system does station control functions such as antenna positioning while the other does the actual data capture. For a complete description of this system see [2]. Intermediate storage and processing of the data takes place on one or both of two Cromemco CS-2H computers running 68000 Cromix or 68000 Cromix-Plus. The CS-2Hs are also used to store the element set data base and generate the subsatellite point data files. The plots were done on a Radio Shack FP-215 flatbed plotter. The programs described here are written in PL/I-80 supplied by Digital Research.

CONCLUSION

One purpose of this paper has been to describe the whole-orbit telemetry data surveys transmitted by UoSAT-1 and UoSAT-2 as well as some of the considerations for processing that data. The details of an operational software system for processing WOD surveys have been included. The major purpose of the paper, however, is to create some curiosity and interest in UoSAT-1 and UoSAT-2 operations among amateur radio satellite enthusiasts. It is the opinion of this author that this can best be accomplished by providing a more complete description of data available and the requirements for its processing than has been widely available in the past.

ACKNOWLEDGEMENTS

The author would like to recognize the assistance of several others who played a part in the implementation of the system described in this article. Maureen Brown and Ruth Killins, computer science department secretaries, checked the more than two hundred element sets for accuracy after entry into the system. Ladell McFarlen and Mary Lynn McNair, graduate students in computer science, processed much of the backlog of WOD some of which was used as examples in this paper. Finally, thanks to Steve Holder of the University of Surrey for providing information about the WOD surveys prior to the publication of the latest UoSAT Spacecraft

Data Booklet.

TRADEMARKS USED IN THIS PAPER

The following trademarks have been used in this paper and are hereby acknowledged.

UNIX is a trademark of AT&T.

Cromix and Cromix-Plus are trademarks of Cromemco, Inc.

CP/M-80 and PL/I-80 are trademarks of Digital Research.

REFERENCES

1. Clark, Thomas A., "BASIC Orbits", ORBIT Magazine No. 6, AMSAT-USA, March, 1980, Page 6.

2. Diersing, Robert J., "Microcomputer Systems for Low-Earth-Orbit Satellite Tracking and Data Acquisition", Proceedings of the AMSAT 1986 Space Symposium, Dallas, Texas, November, 1986.

3. ________, Microcomputer Applications in Station Control and Processing for UoSAT-OSCAR-9 and UoSAT-OSCAR-11, AMSAT-UK, July, 1985.

4. Sweeting, M.N., et. al., UoSAT Spacecraft Data Booklet, Department of Electronic & Electrical Engineering, University of Surrey, May, 1986.

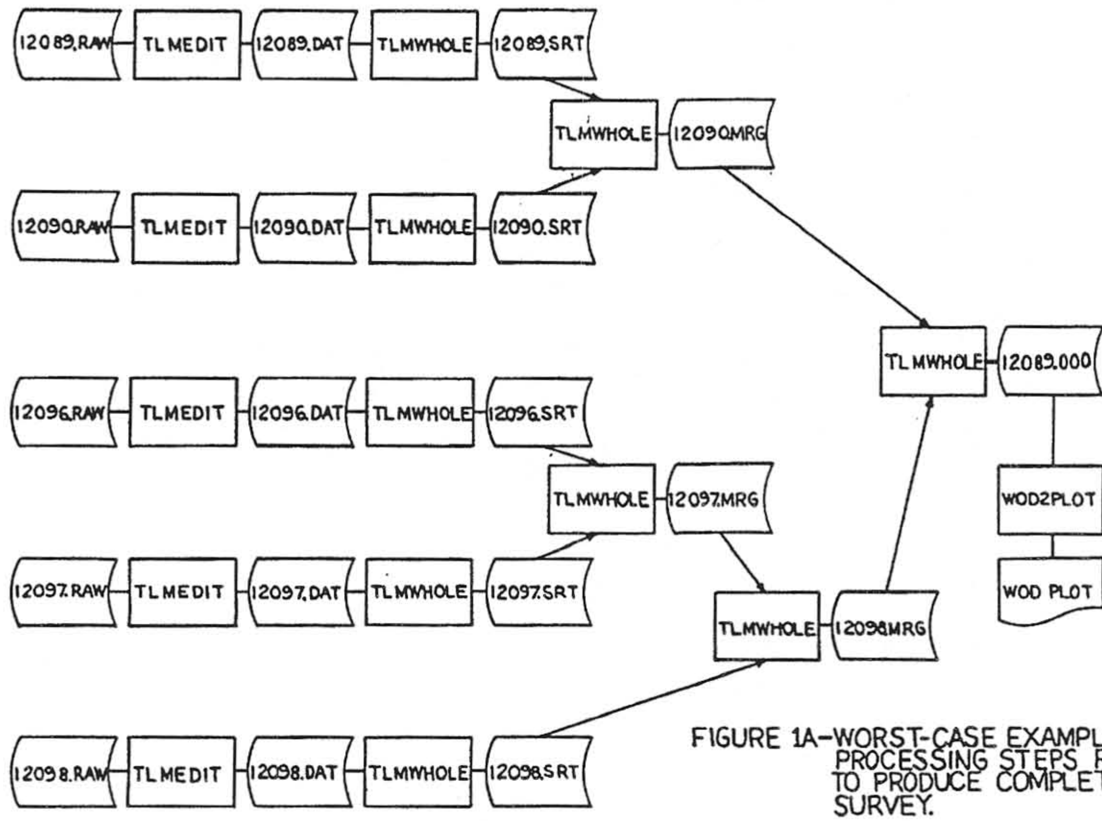


FIGURE 1A-WORST-CASE EXAMPLE OF PROCESSING STEPS REQUIRED TO PRODUCE COMPLETE WOD SURVEY.

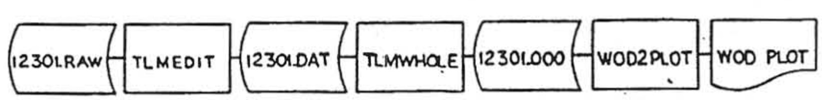
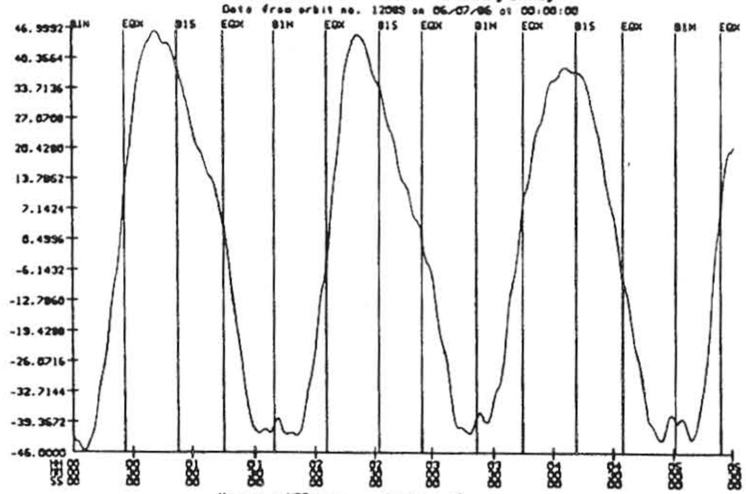


FIGURE 1B-BEST-CASE EXAMPLE OF PROCESSING STEPS REQUIRED TO PRODUCE COMPLETE WOD SURVEY.

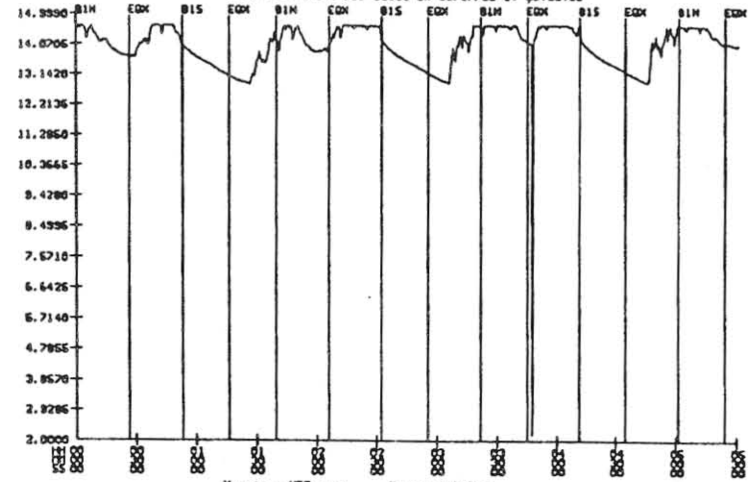
UOSAT-OSCAR-11 Whole-Orbit Telemetry Survey
Data from orbit no. 12083 on 06/07/86 at 00:00:00



X-axis = UTC time Y-axis = uT

RED = Channel no. 2 = Nav Magnetometer Z Axis

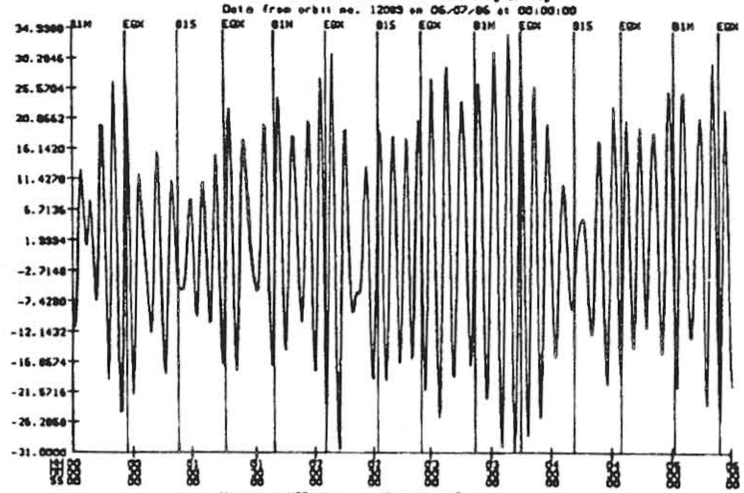
UOSAT-OSCAR-11 Whole-Orbit Telemetry Survey
Data from orbit no. 12083 on 06/07/86 at 00:00:00



X-axis = UTC time Y-axis = Volts

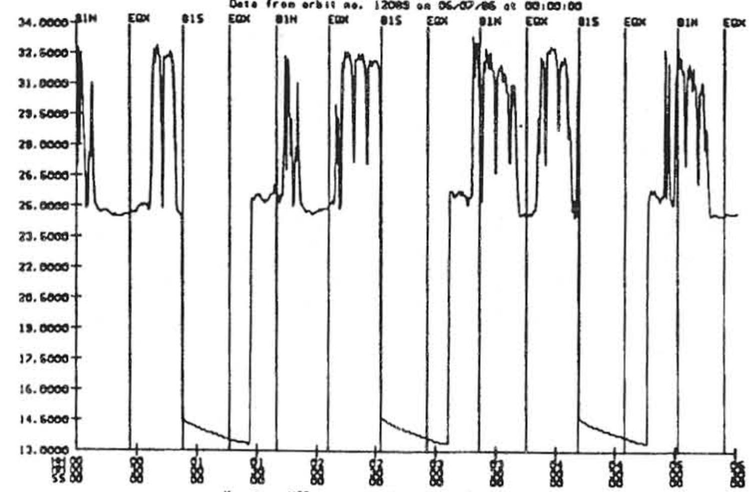
BLUE = Channel no. 52 = Battery Voltage (+14V)

UOSAT-OSCAR-11 Whole-Orbit Telemetry Survey
Data from orbit no. 12083 on 06/07/86 at 00:00:00



X-axis = UTC time Y-axis = uT
BLACK = Channel no. 1 = Nav Magnetometer X Axis

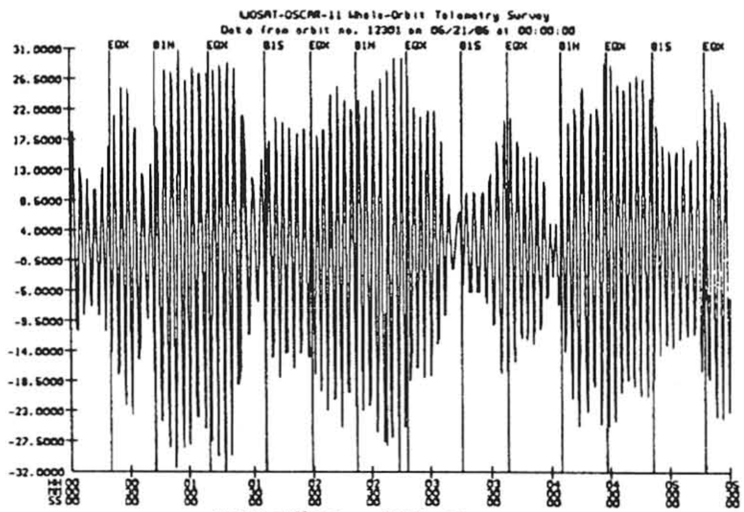
UOSAT-OSCAR-11 Whole-Orbit Telemetry Survey
Data from orbit no. 12083 on 06/07/86 at 00:00:00



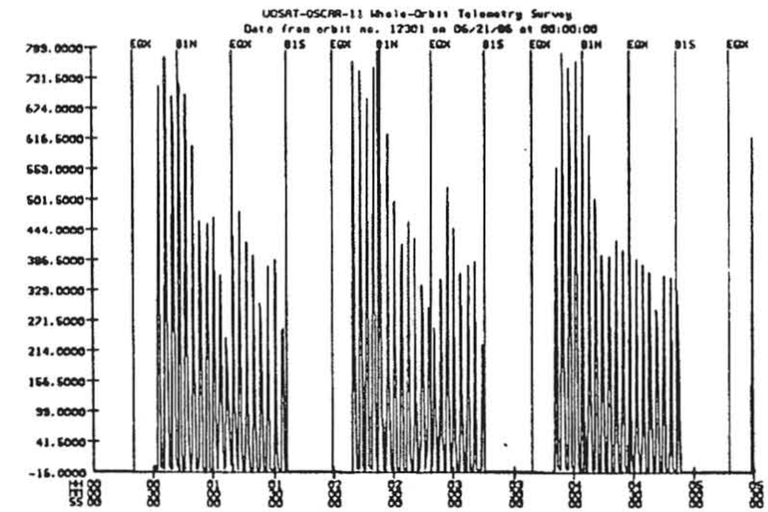
X-axis = UTC time Y-axis = Volts

GREEN = Channel no. 40 = Solar Array Voltage (+30V)

FIGURE 2 --- All channels from orbit 12083.

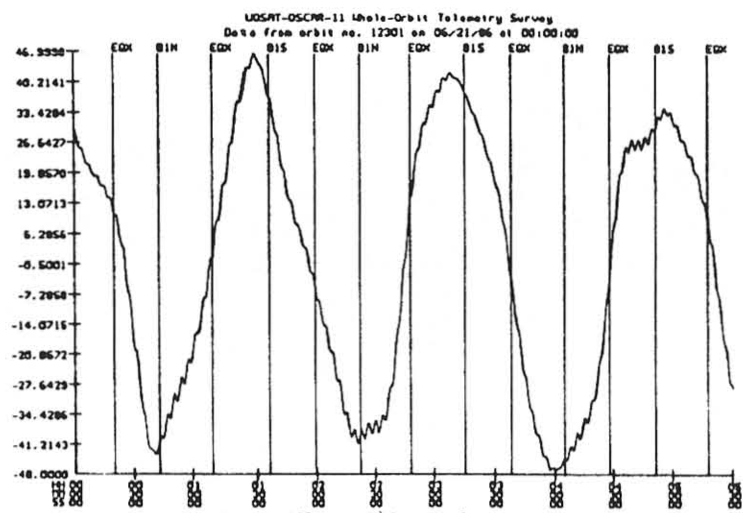


X-axis = UTC time Y-axis = uT
RED = Channel no. 3 = Nav Magnetometer Y Axis



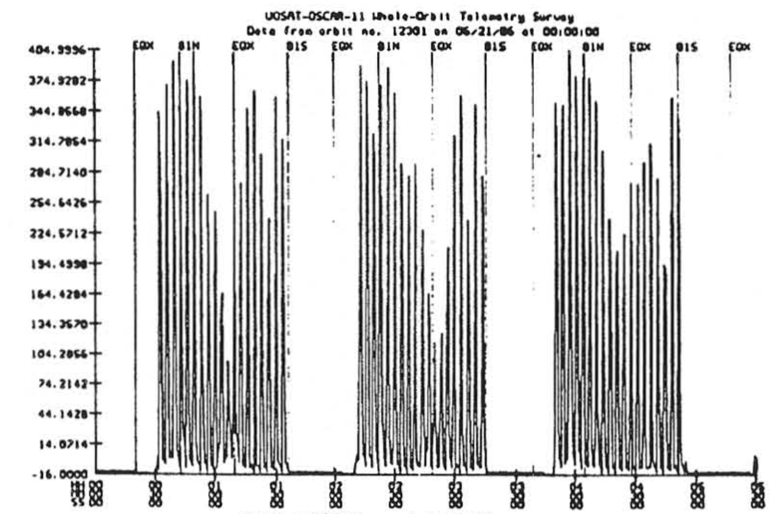
X-axis = UTC time Y-axis = mA

BLUE = Channel no. 20 = Solar Array Current -X



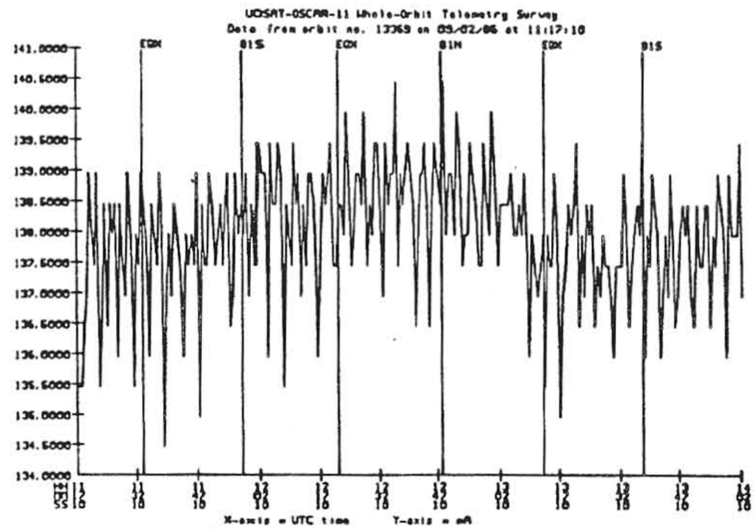
X-axis = UTC time Y-axis = uT
BLACK = Channel no. 2 = Nav Magnetometer Z Axis

FIGURE 3 --- All channels from orbit 12301.

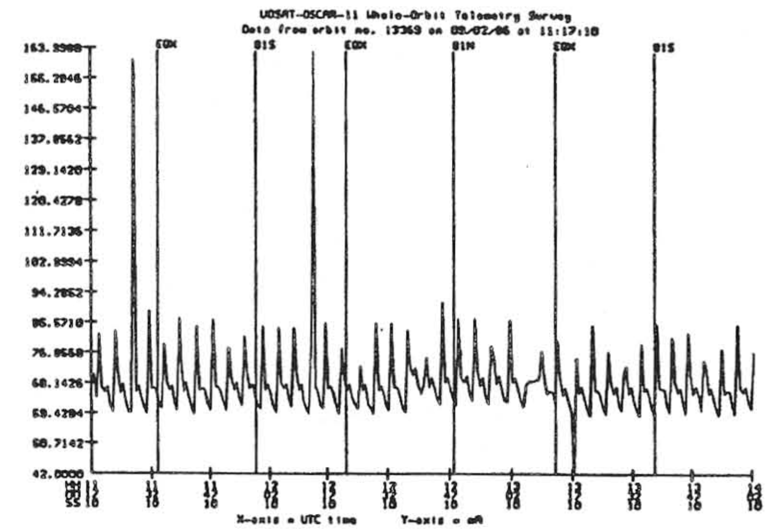


X-axis = UTC time Y-axis = mA

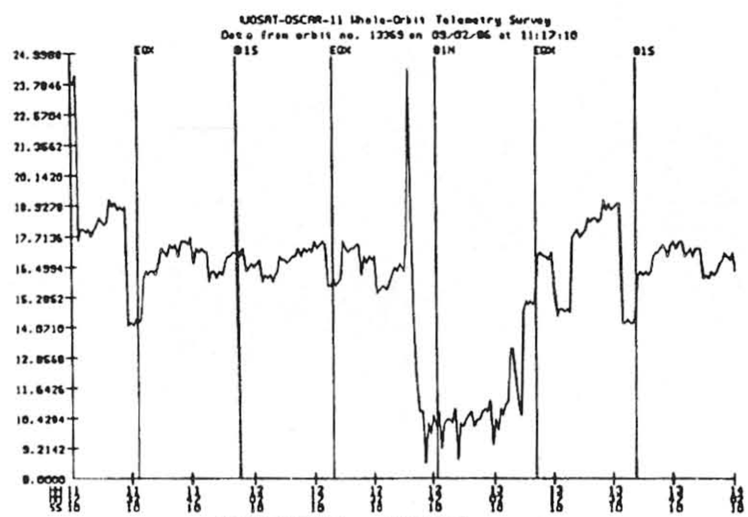
GREEN = Channel no. 10 = Solar Array Current +Y



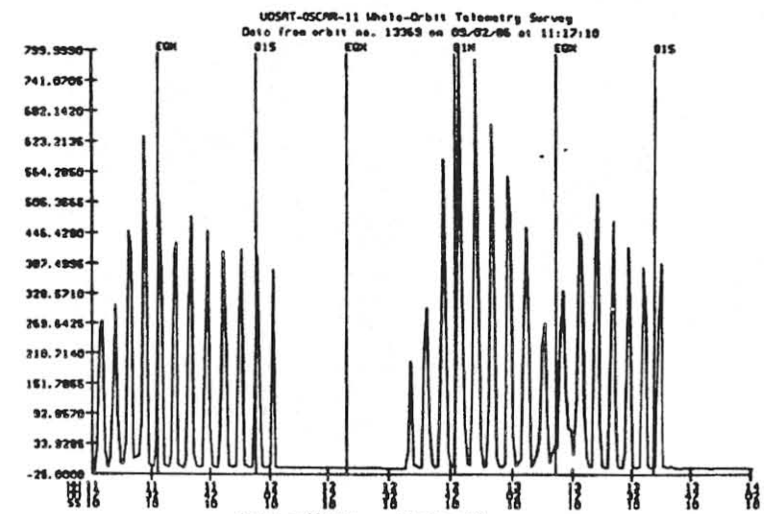
RED = Channel no. 15 = DCE CPU Current



GREEN = Channel no. 16 = DCE GMEM Current



BLACK = Channel no. 14 = DCE RAMUNIT Current



BLUE = Channel no. 20 = Solar Array Current -X

FIGURE 4 --- Channels 14, 15, 16, & 20 from orbit 13363.

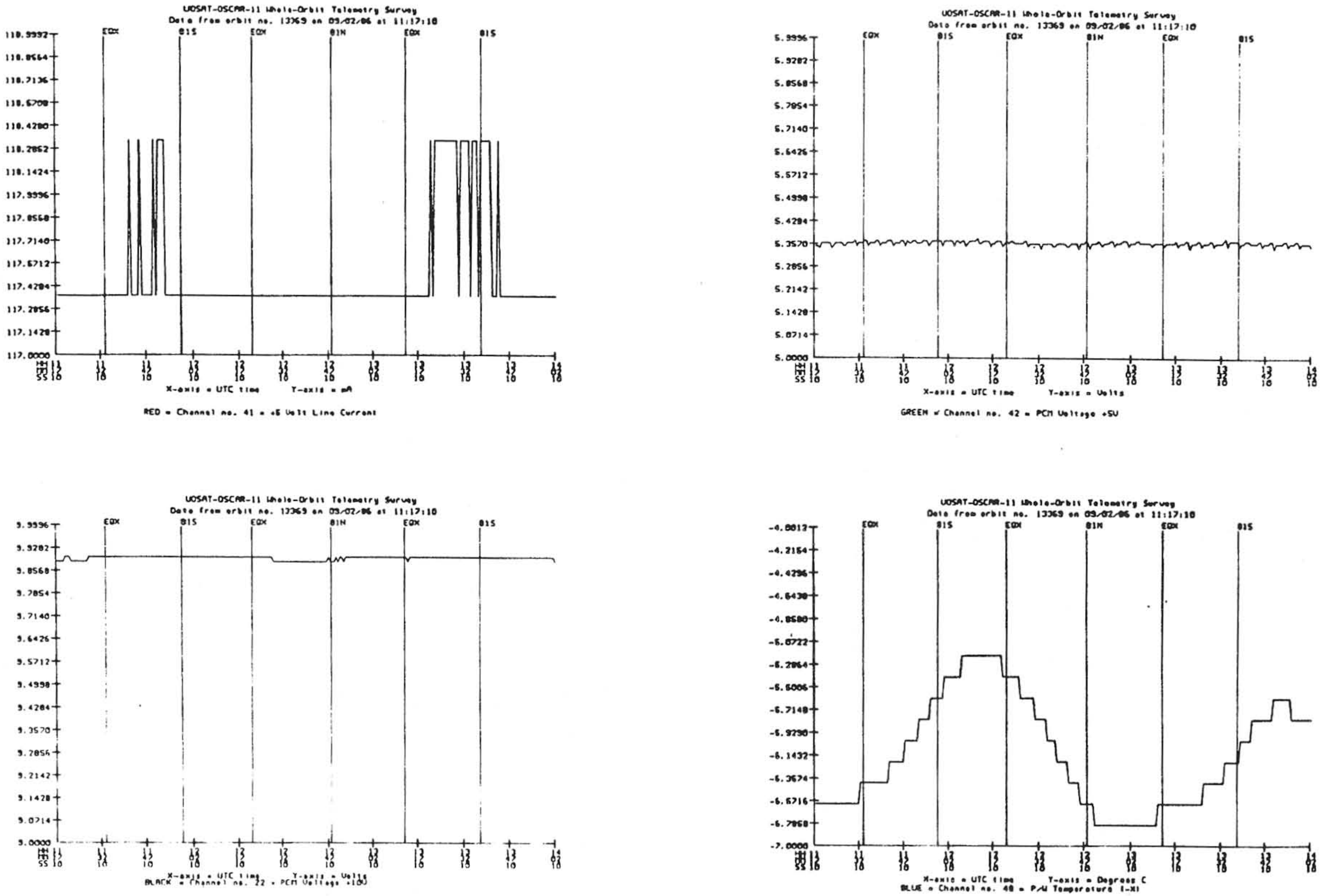


FIGURE 5 Channels 22, 41, 42, & 48 from orbit 13369.

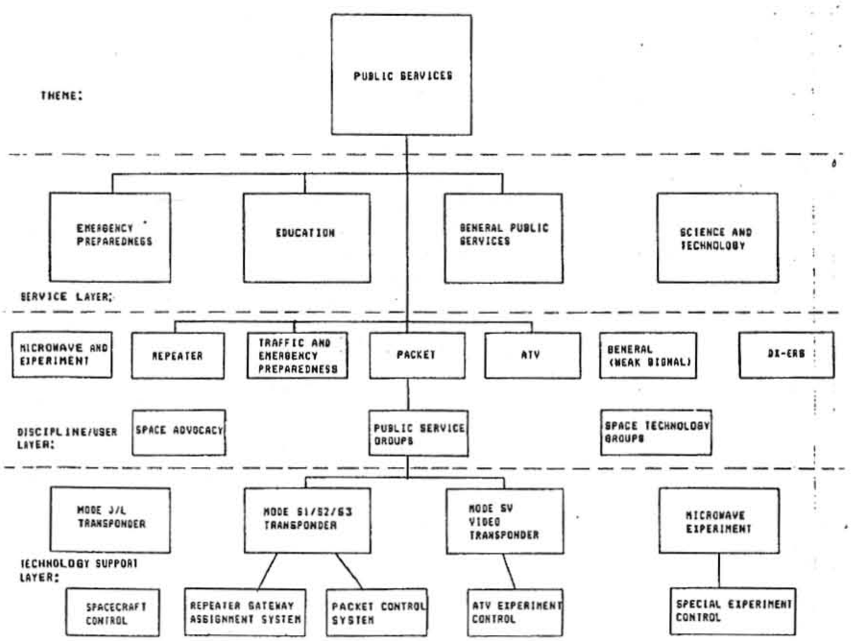
A Review of The Pase IV Project

BY

Jan King W3GEY

PHASE FOUR PROGRAM GOALS

- EXPAND FUNDING BASE
  (BY PARTICIPATION WITH)
  WIDER AMATEUR RADIO BASE
  SPACE ACTIVITY AND TECHNOLOGY GROUPS
  MORE AMATEUR EQUIPMENT VENDORS
  POSSIBLE CO-OP CORPORATE PARTNER(S)



PHASE FOUR PROGRAM GOALS

- SPECTRUM OCCUPANCY
  VHF
  UHF
  MICROWAVE BANDS
- PUBLIC BENEFIT
  EDUCATION
  EMERGENCY PREPAREDNESS
  INTERNATIONAL EXCHANGE

PHASE FOUR PROGRAM GOALS

- WIDER AMATEUR RADIO INVOLVEMENT
  NATIONAL TRAFFIC HANDLING COMMUNITY
  REPEATER COMMUNITY
  PACKET RADIO COMMUNITY
  ATV COMMUNITY
  MICROWAVE AND EXPERIMENTER COMMUNITY
  WEAK SIGNAL AND DX COMMUNITIES
  (TRADITIONAL OSCAR USERS)
- WIDER SPACE COMMUNITY INVOLVEMENT
  SPACE ADVOCACY GROUPS
  SPACE TECHNOLOGY GROUPS
  SELECTED UNIVERSITIES
  (STANFORD UNIVERSITY)
  (UNIVERSITY OF COLORADO)

EDUCATION

- CULTURAL EXCHANGE
- SCIENCE AND ENGINEERING
- AMATEUR RADIO TRAINING

SATELLITE APPLICATIONS:

- PROVISION OF EXCITING CULTURAL EXCHANGE PROGRAMS
- PROVISION OF MULTIMEDIA SCIENCE AND ENGINEERING TUTORIALS TO AMATEUR AND NON-AMATEUR GROUPS
- PROVISION OF NEW FORMS OF SATELLITE TECHNOLOGY DEMONSTRATIONS:
  - MODULATION AND CODING (ACSSB, DIGITAL VOICE)
  - ANTENNA DESIGN AND TECHNOLOGY
  - BASIC SATELLITE LINK PRINCIPLES
  - ORBIT MECHANICS OF GEOSTATIONARY ORBIT
- PROVISION OF BASIC AMATEUR RADIO TRAINING TUTORIALS

GENERAL PUBLIC SERVICES

- NTS
- ARRL BULLETINS
- OTHER THIRD PARTY SUPPORT SERVICES

SATELLITE APPLICATIONS:

- VERY POWERFUL BROADCAST CAPABILITY IN MULTIPLE MODES
  - VIA REPEATER GATEWAY CONNECTION
  - DIRECT BROADCAST VIA SATELLITE TRANSPONDER
  - VIA PACKET GATEWAY INTERCONNECTION
  - VIA DIGITAL VIDEO TELEVISION
- AUGMENTATION OF TRADITION PHONE PATCH AND TRAFFIC HANDLING SERVICES
- SUPPORT OF SHORT TERM SCIENTIFIC AND CULTURAL EXPEDITIONS TO REMOTE LOCATIONS WITH VOICE, DATA AND/OR VIDEO CAPABILITY
- POTENTIAL PROVISION OF THIRD PARTY SERVICES TO NON-AMATEUR GROUPS WITH SIMILAR GOALS AND OBJECTIVES

RESOURCES AND EXECUTION LAYER:

CORPORATE SUPPORT	UNIVERSITIES	AMATEUR RADIO COMMUNITY	SPACE ADVOCACY AND TECHNOLOGY COMMUNITY	PUBLIC SERVICE COMMUNITY

EMERGENCY PREPAREDNESS

- RACES
- AREC
- NATIONAL EMERGENCY SERVICE ORGANIZATIONS

SATELLITE APPLICATIONS:

- CONNECTIVITY BETWEEN "FORWARD" AND "REAR" NETWORK EMERGENCY SERVICE AREAS
- SUPPORT SIMULATED EMERGENCY TESTS RELATED TO LARGE NATURAL DISASTERS (e.g. EARTHQUAKES, FLOODS, HURRICANES)
- ENABLE "LONG HAUL" PACKET NETWORKS TO SUPPORT EMERGENCY SITUATIONS
- PROVISION OF DEDICATED HIGH PERFORMANCE LINKS (DATA AND VOICE) IN TIMES OF EMERGENCY
- ENABLE COMMUNICATIONS VIA PORTABLE PACKET, FM AND ATV GATEWAYS IN TIMES OF EMERGENCY

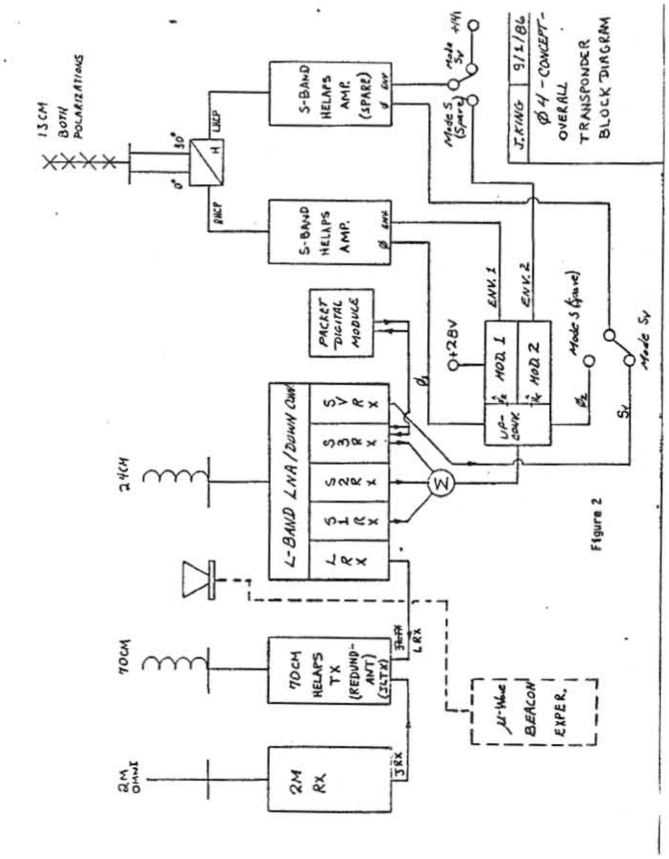


Figure 2

USER EQUIPMENT

Mode S-1 (General Linear Communications Transponder):

- o Single Antenna - 1.5 M Parabola w. Dual Freq Feed (50% Apature Efficiency)
- o RX Antenna Gain: 28.5 dBi
- o LNA Noise Figure: 1.0 dB
- o Pointing Loss: 1.0 dB
- o Feedline + Misc. Losses: 1.1 dB
- * System G/T: +4.7 dB/K
- o TX Antenna Gain: 23.0 dBi
- o Transmitter Power Output: 10W Average
- o Transmit Misc. Losses: 1.3 dB
- * EIRP: 30.0 dBW

Mode S-2 (Gateway Interconnect):

- o Same as S-1 Station Except:
  - o Feedline + Misc. RX Losses: 0.6 dB
  - o RX Noise Figure: 0.7 dB
  - * System G/T: 5.1 dB

Mode S-3 (Packet Gateway Interconnect - 19200 bps):

- o Same Station Equipment as S-2 Station

Mode S-4 (Gateway Interconnect - Broadcast Mode):

- o Same Station Equipment as S-2 Station

LINK PERFORMANCE

RESULTS

Mode:	Avg. D/L S/N:	Peak S/N SSB:	Eb/No:
J	10.5 dB	21.5 dB	12.0 dB
L	11.3 dB	22.3 dB	12.8 dB
S-1	13.4 dB	24.4 dB	14.9 dB
S-2	15.0 dB	33.0 dB*	16.5 dB
S-3	----	----	13.2 dB**
S-4	21.4 dB	39.4 dB*	12.3 dB***
S-v	----	----	12.0 dB #

* ACSSB assumed to be used (subjective improvement over SSB equal to +8dB).

** Projected improvements in satellite antenna gain allow an increase in data rate on the Packet Transponder to 19.2 K.B.P.S. This has been determined by means of link analysis, subsequent to the drafting of the "Guidelines" document.

*** Result obtained if S-4 mode was used as a dedicated packet link at 32 K.B.P.S.

\# At a data rate of 500 K.B.P.S.

TRANSPONDER SYSTEM

D.C. POWER REQUIREMENTS

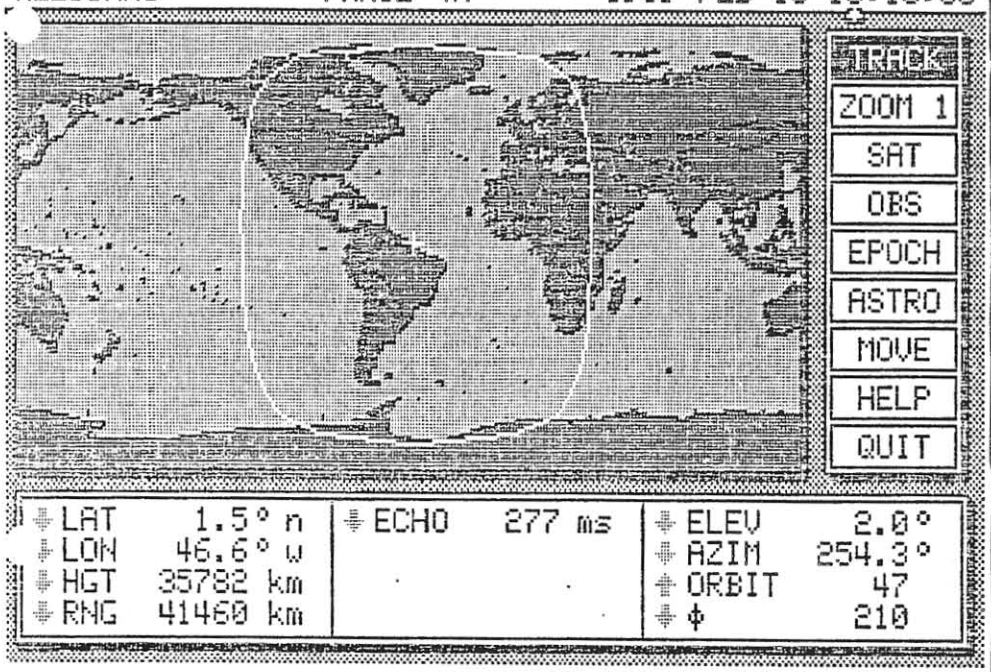
Mode J/L Transponder:

Mode:	Average RF Power:	D.C. Power:
J	10.0 W	31 W
L	19.6 W	60 W
Total	29.6 W	91 W

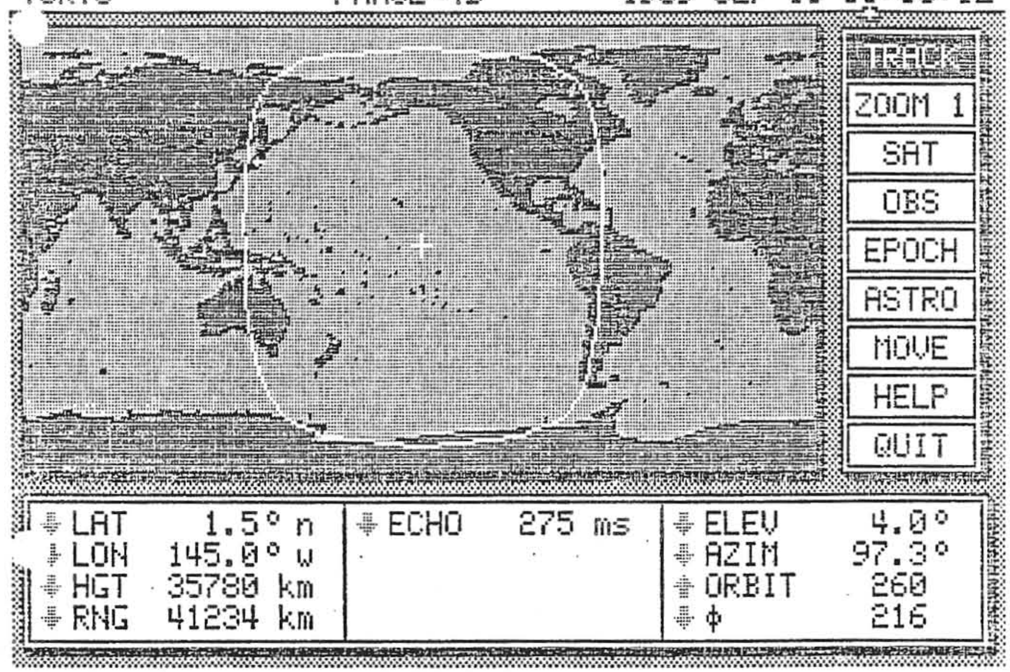
Mode S Transponder:

Mode:	Average RF Power:	D.C. Power:
S-1	5.4 W	25.0 W
S-2 (or S-4)	4.5 W	20.4 W
S-3	2.0 W	9.1 W
Total	11.9 W	54.5 W

Mode Sv Transponder:	10.0 W	40.0 W
Total Payload D.C. Power:		185.5 W


HELSINKI
PHASE-4A
1989 FEB 15 18:16:05
TRACK
ZOOM 1
SAT
OBS
EPOCH
ASTRO
MOVE
HELP
QUIT
LAT 1.5° n
LON 46.6° w
HGT 35782 km
RNG 41460 km
ECHO 277 ms
ELEV 2.0°
AZIM 254.3°
ORBIT 47
ϕ 210

6


TOKYO
PHASE-4B
1989 SEP 16 11:35:12
TRACK
ZOOM 1
SAT
OBS
EPOCH
ASTRO
MOVE
HELP
QUIT
LAT 1.5° n
LON 145.0° w
HGT 35780 km
RNG 41234 km
ECHO 275 ms
ELEV 4.0°
AZIM 97.3°
ORBIT 260
ϕ 216

7

HAMS IN SPACE
THE RECENT PAST AND FUTURE PLANS

L. McFadden W5DID
R. Fenner W5AVI
W. Tynan W3XO

THE RECENT PAST

STS-9 Owen Garriott W5LFL

Almost everyone has heard of the first ham in space involving Owen Garriott aboard Columbia on Shuttle Mission STS-9. Objectives of the Amateur Radio participation in this mission were quite limited but included:

1. Demonstrate that Amateur Radio can operate on manned space missions without interference to primary mission tasks.

2. Directly involve the general public in the U.S. manned space program.

3. Demonstrate Amateur Radio's capability as a potential backup means of communication.

All of these objectives were met with W5LFL's historic amateur operation on this mission. The amateur installation was kept simple with as few interfaces to the Shuttle as possible.

Motorola MX 2 meter FM hand held transceiver.

Simple interface box that connected transceiver to astronaut headset and tape recorder.

Window mounted antenna.

Self contained batteries (No spacecraft power used).

Results:

Many contacts made with hams in U.S. and countries around the world.

Good PR for Amateur Radio and the U.S. space program.

No physical, electrical or functional interference with other spacecraft activities.

Potential for back)up communication shown.

It was a start!

STS)51F Tony England W5ORE) SAREX

This mission flown on Challenger in July 1985 represented an extension to the initial effort and success of STS-9. It was significantly more ambitious than was the Amateur Radio participation on the earlier mission in several ways:

Addition of slow scan TV uplink and downlink capability.

Use of spacecraft power.

Once again, 2 meter FM was employed with the same type of Motorola hand held transceiver as was used on STS-9. Because of the difficulty of obtaining an antenna connection to the payload bay, the same window mounted antenna as use on STS-9 was pressed into service.

The impact of Amateur Radio participation on STS)51F was enhanced by the inclusion of slow scan TV. Demonstrations for schools and other public groups were able to include the visual dimension as well as hear a voice. Also, for the first time ever, pictures were transmitted from the ground to the spacecraft. The first picture sent up was that of Tony's wife! Once again, Amateur Radio showed that it could be included on manned space missions without impacting other experiments and activities and that it could enhance public awareness of the U.S. space program.

THE FUTURE

SAREX A

In connection with a future Shuttle mission (It was to have been on STS)61E scheduled for March 1986.), a very ambitious array of equipment is being assembled. Included are:

Packet capability
- Beacon Mode.
- Keyboard to keyboard communication.
- Store and forward message delivery.
- Real time relay (digipeater).

Fast scan TV uplink.

Slow scan TV up and down.

Two)way 2 meter FM voice.

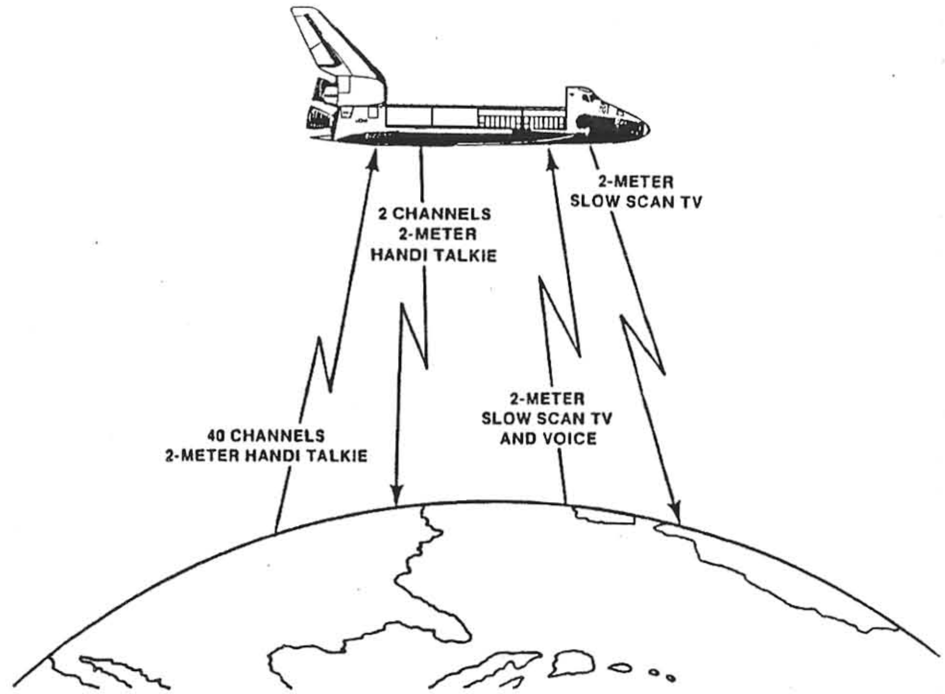
Two)way 10 meter FM voice.

SPACE STATION

AMSAT and ARRL are embarking on the most ambitious program attempted to date in Amateur Radio's Hams in Space Program. It intent is to make Amateur Radio a part of the Space Station Experiment suite, rather than a "if space is available" addition. This includes an agreement before hand as to space weight, Space Station power, antenna mounting points and electrical connections. To accomplish this we must come up with a very strong and convincing proposal, setting forth what Amateur Radio can do to enhance the Space Station mission and the U.S. manned space program in general. Emphasis will be placed on the facility that Amateur Radio can provide to enable direct access between the Station crew and civic groups, classrooms, youth camps etc. In order to have the desired impact with young audiences, will require fast scan TV, at least for the downlink. Since the Space Station is to be in a low altitude 28.5 degree inclination orbit, relay through a high altitude satellite will be necessary. With Space Station due to go up in about 1994, this requirement matches well with AMSAT's Phase 4 plans. According the Phase 4 proposal generated by Jan King W3GEY, the geostationary amateur satellite is likely to include a wide band digital transponder which will be able to accommodate fast scan TV with quality approaching that broadcast by the networks. Thus, it is planned to include on Space Station equipment capable of communicating through the Phase 4 satellite in this wide band digital mode. Of course, other modes will be supported as well including direct voice and digital communication between the Space Station amateur equipment and amateurs on the ground.

SAREX
SHUTTLE AMATEUR RADIO EXPERIMENT

A-S-86-00885



NASA-S-86-00888

SAREX

SPONSORS

ARRL (AMATEUR RADIO RELAY LEAGUE)

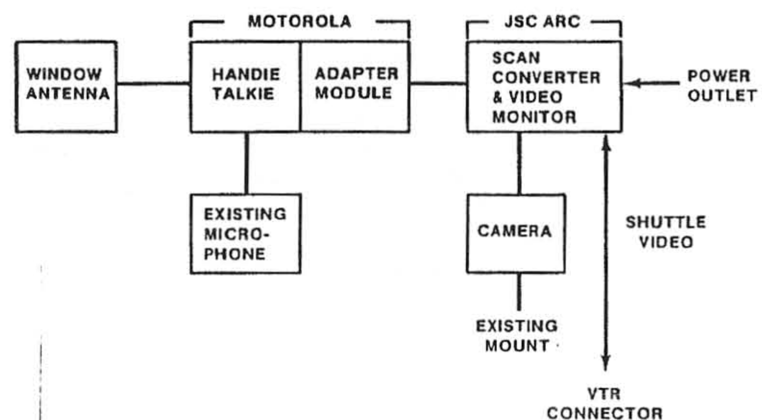
AMSAT (RADIO AMATEUR SATELLITE CORPORATION)

JSC AMATEUR RADIO CLUB

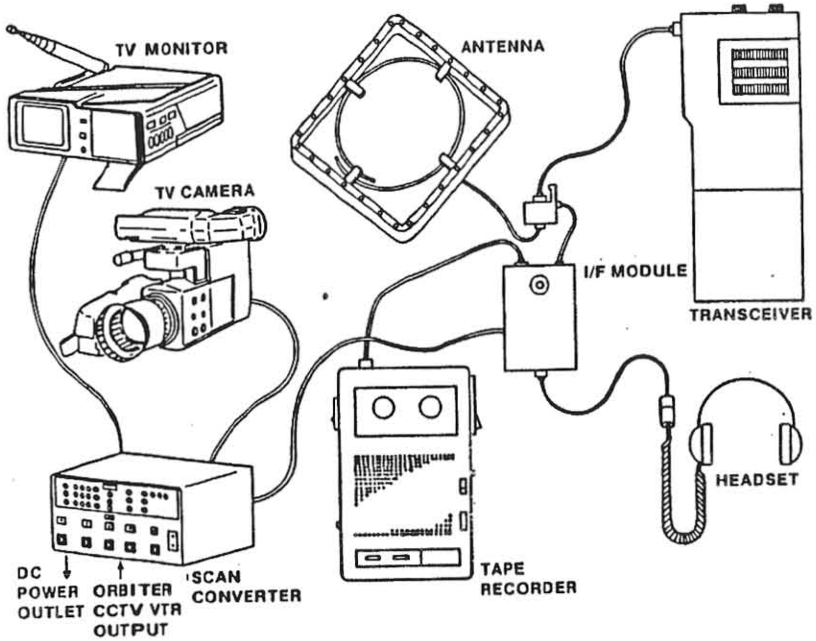
NASA

OTHERS

SAREX
BLOCK DIAGRAM



OPERATIONAL CONFIGURATION



SA-S-86-00890

SAREX
RESOURCES

HANDIE TALKIE	MOTOROLA ARC
SCAN CONVERTER	ROBOT RESEARCH
TV CAMERA AND MONITOR	PANASONIC
MICROPHONE HEADSET	NASA JSC
VIDEO BUFFER	NASA LEWIS ARC
POWER SUPPLIES	ABBOTT TRANSISTOR LABORATORIES
RIDE ON SHUTTLE	NASA
MISCELLANEOUS SUPPORT	NASA AMSAT ARRL

NASA-S-86-00892

SAREX
OPERATIONS

2 M HANDIE TALKIE
- SCHEDULED CONTACTS PRIMARILY WITH CLUBS AND SCHOOLS

SLOW SCAN TV
- PRIMARILY IN AUTOMATIC SEQUENCE MODE
- SOME SCHEDULED UPLINKS

SAREX
SLOW SCAN TV MODES

TRANSMIT

AUTOMATIC SEQUENCE

- 2 8 SECOND RED DATA FRAMES (LO RES)
- 1 8 SECOND GREEN DATA FRAME (LO RES)
- 1 8 SECOND BLUE DATA FRAME (LO RES)
- 1 12 SECOND ROBOT COMPATIBLE COLOR DATA FRAME (LO RES)
- 1 36 SECOND ROBOT COMPATIBLE COLOR DATA FRAME (HI RES)

SAREX
SLOW SCAN TV MODES CONT.

MANUAL
- 12 SECOND ROBOT COMPATIBLE COLOR (LO RES)
- 24 SECOND ROBOT COMPATIBLE COLOR (LO RES)
- 36 SECOND ROBOT COMPATIBLE COLOR (HI RES)
- 72 SECOND ROBOT COMPATIBLE COLOR (HI RES)

A-S-86-00894

SAREX
RESULTS

130 CONFIRMED VOICE CONTACTS

11 COUNTRIES WORKED

15 SSTV UPLINKS

HUNDREDS OF SSTV DOWNLINKS

NASA-S-86-00896

SAREX
SLOW SCAN TV MODES CONT.

RECEIVE

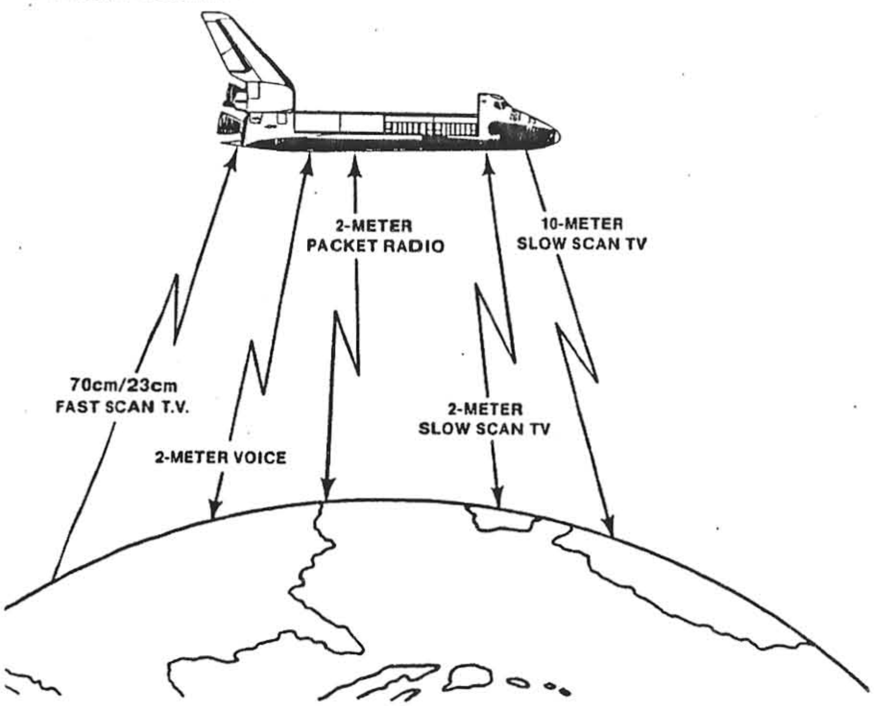
AUTOMATIC

THE SCAN CONVERTER WILL RECEIVE ANY OF THE MANUAL FORMATS AUTOMATICALLY

MANUAL

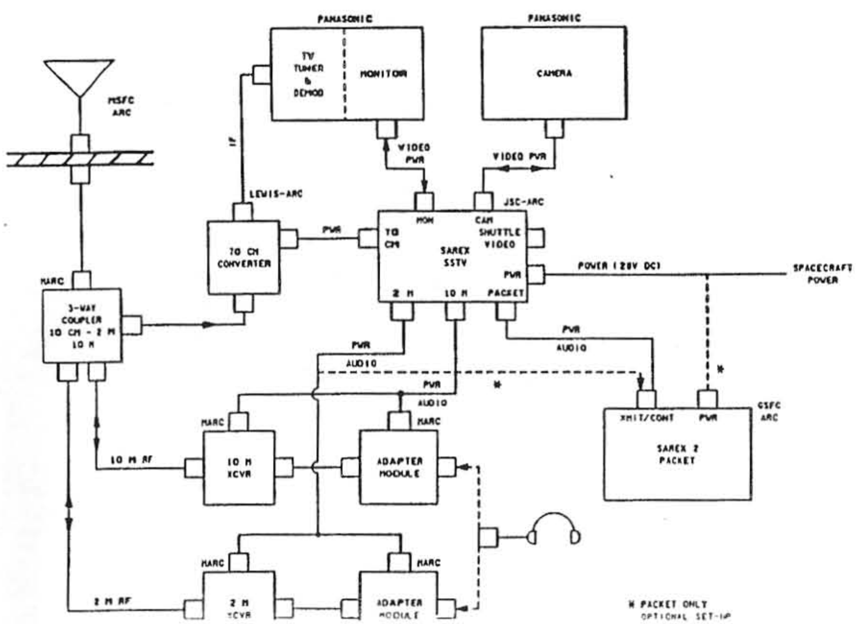
THE SCAN CONVERTER WILL RECEIVE ANY OF THE MANUAL FORMATS COMMANDED

SAREX A
AN AMATEUR RADIO EXPERIMENT FOR SHUTTLE



SA-S-86-00900

SAREX A



OPERATING MODES

1. FAST SCAN TV UPLINK WITH SSTV DOWNLINK ON 2m COORDINATED WITH VOICE ON 2m
2. 2 WAY VOICE ON 2m
3. SSTV AUTOMATIC DOWNLINK ON 10m AND 2m
4. PACKET 2 WAY ON 2m

NASA-S-86-00904

PROPOSED FAST-SCAN TV EXPERIMENT FOR SAREX A

ART ANZIC K8BVI
NASA-LeRC
MARCH 1986

CONSTRAINTS

- LOW GAIN, WIDE BANDWIDTH ANTENNA ON SHUTTLE (GAIN $\leq$ 3 dB)
- LOW TRANSMITTER POWER ON SHUTTLE (10 W MAXIMUM)
- MINIMUM ACCEPTABLE VIDEO SNR ON GROUND IS APPROXIMATELY 35 dB
- HIGH GAIN, NARROW BEAMWIDTH UPLINK ANTENNA REQUIRED (POSSIBLY STACKED ARRAY)
- GROUND TERMINAL ANTENNA TRACKING REQUIRED
- NO GROUND ANTENNA POINTING ERROR, RAIN LOSS OR OTHER DEGRADATIONS CONSIDERED
- AM-VSB MODULATION ONLY ON 70 CM BAND
- AM-VSB AND FM MODULATION CONSIDERED ON 23 CM BAND

SA-S-86-00906

LINK BUDGET CALCULATIONS

- THE FOLLOWING LINK CALCULATIONS WERE MADE

	70 CM BAND	23 CM BAND	
	AM-VSB	AM-VSB	FM
UPLINK	X	X	X
DOWNLINK	X	X	X

- GROUND TO SHUTTLE DISTANCES USED WERE 200 MI (OVERHEAD), 500 MI AND 1200 MILES (HORIZON)
- FM VIDEO TRANSMISSIONS ON 70 CM BAND ARE NOT POSSIBLE
- FM VIDEO TRANSMISSIONS ON 23 CM BAND MAY REQUIRE FCC WAIVER (BANDWIDTH OF FM SIGNAL IS APPROXIMATELY 14 MHz)

LINK PARAMETERS

	70 CM BAND	23 CM BAND	
	(AM-VSB)	(AM-VSB	(FM)
UPLINK (GROUND TERMINAL)			
RF POWER	100W	30W	30W
ANTENNA GAIN	17 dB	20 dB	20 dB
PROPAGATION LOSS	135-151 dB	145-160 dB	145-160 dB
RECEIVER NF	2 dB	3 dB	3 dB
SIGNAL BANDWIDTH	5 MHz	5 MHz	14 MHz
MODULATION INDEX	—	—	1
VIDEO SNR ON SHUTTLE	USABLE	NOT USABLE	USABLE
DOWNLINK (SHUTTLE)			
RF POWER	10W	30W	30W
ANTENNA GAIN	$<$3 dB	$<$3 dB	$<$3 dB
VIDEO SNR ON GROUND	NOT USABLE	NOT USABLE	NOT USABLE

NASA-S-86-00908

LINK BUDGET
UPLINK

MODULATION: AM-VSB
FREQUENCY: 70 CM BAND

		DISTANCE		
		200 MI	500 MI	1200 MI
TERMINAL OUTPUT POWER,	dBW	20	20	20
TERMINAL FEED LOSS,	dB	-1.0	-1.0	-1.0
TERMINAL ANTENNA GAIN,	dB	17	17	17
TERMINAL EIRP,	dBW	36	36	36
PROPAGATION LOSS,	dB	-135	-143	-151
SPACECRAFT ANTENNA GAIN,	dB	3.0	3.0	3.0
SPACECRAFT ANT. FEED LOSS,	dB	-0.5	-0.5	-0.5
SPCFT RCVD CARRIER PWR,	dBW	-96.5	-104.5	-112.2
K (BOLTZMAN'S CONSTANT),	dBW/deg.K/Hz	-228.6	-228.6	-228.6
T (160°K; NF = 2 dB)	dB/deg.K	22	22	22
BANDWIDTH (5 MHz)	dB/Hz	67.0	67.0	67.0
SPACECRAFT RCVR NOISE PWR,	dBW	-139.6	-139.6	-139.6
CARRIER TO NOISE POWER,	dB	43.1	35.1	27.4
FM IMPROVEMENT,	dB	—	—	—
NOISE WEIGHTING (CCIR)	dB	—	—	—
VIDEO SNR,	dB	43.1	35.1	27.4

CONCLUSION! GOOD QUALITY VIDEO APPROXIMATELY 500 MILES!

SA-S-86-00910

LINK BUDGET
UPLINK

MODULATION: AM-VSB
FREQUENCY: 23 CM BAND

		DISTANCE 200 MI	500 MI	1200 MI
TERMINAL OUTPUT POWER,	dBW	15	15	15
TERMINAL FEED LOSS,	dB	-1.5	-1.5	-1.5
TERMINAL ANTENNA GAIN,	dB	20	20	20
TERMINAL EIRP,	dBW	33.5	33.5	33.5
PROPAGATION LOSS,	dB	-145	-152	-160
SPACECRAFT ANTENNA GAIN,	dB	3.0	3.0	3.0
SPACECRAFT ANT. FEED LOSS,	dB	-1.0	-1.0	-1.0
SPCFT RCVD CARRIER PWR,	dBW	-109.5	-116.5	-124.5
K (BOLTZMAN'S CONSTANT),	dBW/deg.K/Hz	-228.6	-228.6	-228.6
T (300°K; NF = 3 dB)	dB/deg.K	24.8	24.8	24.8
BANDWIDTH (5 MHz)	dB/Hz	67	67	67
SPACECRAFT RCVR NOISE PWR,	dBW	-136.7	-136.7	-136.7
CARRIER TO NOISE POWER,	dB	27.2	20.2	12.2
FM IMPROVEMENT,	dB	—	—	—
NOISE WEIGHTING (CCIR)	dB	—	—	—
VIDEO SNR,	dB	27.2	20.2	12.2

CONCLUSION! **NOT USABLE!**

SA-S-86-00911

LINK BUDGET
UPLINK

MODULATION: FM (m = 1)
FREQUENCY: 23 CM BAND

		DISTANCE 200 MI	500 MI	1200 MI
TERMINAL OUTPUT POWER,	dBW	15	15	15
TERMINAL FEED LOSS,	dB	-1.5	-1.5	-1.5
TERMINAL ANTENNA GAIN,	dB	20	20	20
TERMINAL EIRP,	dBW	33.5	33.5	33.5
PROPAGATION LOSS,	dB	-145	-152	-160
SPACECRAFT ANTENNA GAIN,	dB	+3	+3	+3
SPACECRAFT ANT. FEED LOSS,	dB	-1	-1	-1
SPCFT RCVD CARRIER PWR,	dBW	-109.5	-116.5	-124.5
K (BOLTZMAN'S CONSTANT),	dBW/deg.K/Hz	-228.6	-228.6	-228.6
T (300°K; NF = 3 dB)	dB/deg.K	24.8	24.8	24.8
BANDWIDTH (14 MHz)	dB/Hz	71.5	71.5	71.5
SPACECRAFT RCVR NOISE PWR,	dBW	-132.3	-132.3	-132.3
CARRIER TO NOISE POWER,	dB	22.8	15.8	7.8
FM IMPROVEMENT,	dB	13.8	13.8	—
NOISE WEIGHTING (CCIR)	dB	10.2	10.2	—
VIDEO SNR,	dB	46.8	39.8	—
				BELOW THRESH-OLD

NOTE: fm = 3.6 MHz
NO AUDIO SUBCARRIER
FM THRESHOLD FOR VIDEO APPROX. 12 dB

LINK BUDGET RESULTS

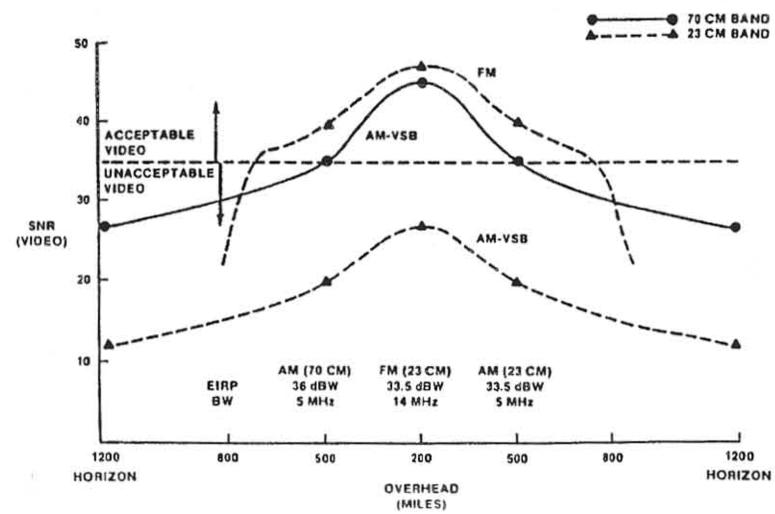
	200 MI 70 CM BAND	200 MI 23 CM BAND	500 MI 70 CM BAND	500 MI 23 CM BAND	1200 MI 70 CM BAND	1200 MI 23 CM BA
UPLINK						
SNR (AM)	43 dB	*	35 dB	*	*	*
SNR (FM)	—	47 dB	—	40 dB	—	*
DOWNLINK						
SNR (AM)	33 dB	*	*	*	*	*
SNR (FM)	—	*	—	*	—	*

*VIDEO SIGNAL QUALITY NOT USABLE

NOTE: MINIMUM SNR OF 35 dB REQUIRED FOR VIDEO;
RESULTS ARE FOR EIRP'S STATED IN LINK BUDGETS;
NO FM OPERATION ON 70 CM BAND POSSIBLE

NASA-S-86-00917

VIDEO SNR VS SHUTTLE DISTANCE
(OVERHEAD PASS)
UPLINK ONLY



CONCLUSIONS

- DOWNLINK VIDEO FROM SHUTTLE NOT PRACTICAL DUE TO RF POWER AND ANTENNA CONSTRAINTS ON SPACECRAFT
- VIDEO UPLINKS TO SHUTTLE ARE PRACTICAL IN BOTH 70 CM (AM-VSB) AND 23 CM (FM) BANDS
- NO AUDIO SUBCARRIER WAS USED WITH VIDEO SIGNALS; ALL AUDIO COMMUNICATIONS SHOULD BE ON 2M FM
- STRONG CONSIDERATION SHOULD BE GIVEN TO USE THE 23 CM BAND FM VIDEO UPLINK
- 23 CM BAND FM UPLINK VIDEO PROVIDES BETTER TV PICTURE QUALITIES FOR LONGER PORTIONS OF ORBIT WITH APPROXIMATELY 3 dB LESS (HALF POWER) OF UPLINK EIRP
- FINAL OPERATIONAL FREQUENCIES SHOULD BE COORDINATED WITH ARRL AND AMSAT

SATELLITE DIGITAL COMMUNICATIONS

Paul L. Rinaldo, W4RI
American Radio Relay League
225 Main Street
Newington, CT 06111

ABSTRACT

At launch time, the Phase 4 digital transponder will find itself in a world with many more packeteers and a greater appetite for transmission of anything that can be digitized. This paper provides some philosophical basis for sizing the Phase 4 packet resource. It also discusses the types of information that it may handle and the role that teleports could play.

INTRODUCTION

There has been a strong affinity between packet radio and the amateur satellites. In part, this is because the hi-tech experimenters are never satisfied to work on one thing at a time. Also, packeteers are eyeing satellites as pipelines for their long-haul traffic. Conversely, birdmen regard packet as users of transponders in their new satellites. Both groups are looking to public service, particularly disaster communications, as partial justification for their future projects. It is now clear that packet and satellite developers must work as a team if either is to reach their separate and joint goals. If there was any doubt of this in the past, there can't be now as we begin serious Phase 4 satellite system definition.

A Phase 4 geostationary satellite offers real-time relay of digital communications over one third of the earth's surface. The two satellites proposed would cover two thirds, with one third (much of Asia and the Indian Ocean area) unserved. Central Asia area has the smallest number of amateurs but has the largest general population and has had more than its share of disasters. The small number of amateurs makes it difficult to find the resources needed to build, launch and operate a third Phase 4 satellite over the Indian Ocean. Yet there are amateurs there who will need to take part in worldwide packet and satellite communications. We need to find an economical way.

Low-earth-orbit (LEO) satellites are needed to complement the coverage provided by geostationary satellites. LEOs have limited use for real-time relay because of their small footprints and short periods of mutual visibility. That fault becomes a virtue for digital store-and-forward (SAF) communications. At least LEO digital SAF satellites in the right orbit will provide service in fewer than 12 hours between nearly any two points on earth. So in our eagerness to launch Phase 4, let's not forget that we'll need to keep Phase 2 around for digital SAF communications.

Phase 4 and Phase 2 satellites won't satisfy all of our DX packet pipline needs by a long shot. The packeteers in Perth, Australia are to be in the area unserved by Phase 4, according to current planning. They could wait for the next LEO to pass, but likely will want to send packets sooner and use the worldwide packet network that will involve Phase 4 real-time relay. HF circuits within Australia could feed into the east coast which is to be within the Phase 4 service area. So, while planning Phase 4 satellites, we need to have HF feeders.

HF packet operation is well underway, thanks largely to Hank Oredson, WØRLI, who authored message-forwarding bulletin-board software. The ARRL Ad Hoc Committee on Amateur Radio Digital Communications is working with about 35 HF packet operators to improve the efficiency of the HF packet net. We are developing a network plan based on IONCAP propagation predictions. Also, we will shortly ask the FCC to grant a Special Temporary Authority (STA) for automatic operation of some key stations below 30 MHz. The STA is intended to demonstrate that HF packet stations can be operated under automatic control without transmitter malfunction and improper traffic being introduced. You can expect the HF packet network to be more effective in 1987 and for it to be fine-tuned well before Phase 4 satellites are launched.

Store-and-forward packet development is occuring mostly in the United States. There are some sticky third-party and other regulatory problems in many other countries, and they affect satellites as well as HF. The International Amateur Radio Union (IARU) is trying to clear the way. Papers on packet radio have been introduced at the IARU regional conferences.1/2/ A number of national societies have shown interest in packet radio because a growing number of their constituents have become active on the mode. Overseas counterparts of QST regularly carry packet articles. The Radio Society of Great Britain has recently introduced a monthly packet newsletter called Connect International.3/

PHASE 4 DIGITAL COMMUNICATIONS PLANNING

Dr Robert Kahn of ARPANET fame told us that we need to use top-down planning in a network. That would have been nice from the outset, but we didn't have his underwriter--the Federal Budget. Amateur packet radio has developed largely on a bottom-up basis out of the pockets of the participants. After all, wasn't that how 2-meter FM repeaters were funded? That developmental technique has worked pretty well to date. But we're in trouble if we plan a synchronous-satellite system that way.

One thing to consider is that the signal will have to travel 22,300 miles. That translates to a certain effective isotropic radiated power (EIRP) considerably above what the HT and rubber ducky can produce. Only better-equipped stations would be able to work the satellite directly. This strongly suggests having teleports to access the satellite and connect to the terrestrial packet network which can accommodate the most modest apartment-dweller packet station.

Channel access poses some problems. One consideration is that signals take over 10 ms to get from earth to the satellite, some delay processing within the satellite depending on its design, and another 10 ms or so back to earth for near-real-time relay. From this, it is easy to see that a listen-before-transmit channel-access scheme would be no better than a pure-ALOHA system which allows stations to transmit at any time. ALOHA lets a maximum of only 18% of the peak offered load get through without collisions. A satellite transmitter that can be used only 18% of the time would be a wasted resource. Precision time slotting could increase the throughput, but that might be difficult to coordinate and police. Another technique is to have 5 receivers, each capable of 18% throughput, feed into one transmitter. Such a scheme would permit 90% transmitter utilization during busiest periods. But that would involve the cost and complexity of 5 receivers and a multiplexer capable of reorganizing 5 digital streams into one.

Another problem is traffic volume. There is an adage in the telecommunications profession to the effect that it is impossible to manage a good network. If it's good, people will leave the bad ones, and the good one will become hopelessly congested, so the saying goes. Let's see, there were 7000 packeteers a year ago and 20,000 now. If the number continu]Os to treble each year, that would extrapolate to 300,000 by the time Phase 4's candle is lit. Maybe 300,000 is unrealistically high. But the worldwide Amateur Radio population is about 1,635,000. Just two countries, the United States (with 421,000) and Japan (with 653,000), amount to 66% of the world amateur population. Even if you scale down the 300,000 to something that engenders more confidence, it's still going to make 20,000 pale by comparison. The problem is that we'll have to make a five-year prognostication and either guess accurately or have some ways to control the floodgates. Teleports can serve a vital function as traffic-flow controllers to make sure that the load offered to the satellite does not exceed a critical point after which its throughput declines.

High traffic capacity translates to high signaling speeds. By 1990, a 9600-bit/s packet link will not handle the traffic between two neighboring cities, not to mention a satellite covering one-third of the globe. What speed is needed? As fast as possible, certainly 56 kbit/s or faster. Right now, we don't have a production-model 9600-bit/s modem, let alone 56 kbit/s or higher. We have 5 years to work on it, don't we? Yes for ground stations, no for the satellite. The satellite needs to have its parameters defined in the next year in order to have a launch in 5 years. Unless we want to go out on a limb and risk failure, we have to base the parameters on space and ground modems that can be prototyped in 1987. Flight hardware development must follow shortly. However, there will be time for several generations of fine-tuning of ground modems, but then they need to get produced in quantity and in the hands the ground stations by launch time.

Maybe you were not convinced by the sheer number of packeteers that might be around in 1990. What happens to the number of packeteers over the lifetime of the satellite if we have a "good" network? What happens when the amateur television guys learn about the image-transmission capability that a high-speed digital transponder would offer? Do they know that a 56-kbit/s channel would do a fair job of (almost-full-but-jerky-motion) television? "Hey, packeteers, would it be okay for us ATVers to use the digital transponder for television during quiet hours?" We can't just wait for the camel to slip its nose into the tent because, metaphorically speaking of course, the rest of the beast will inch itself inside.

Packet data and image communications are not naturally compatible but can be made so by proper planning. One dissimilarity is in their duty-cycle profiles. Packet keyboard traffic means a line of text sent every few seconds at high speed with lots of room in between for other people to get a packet in edgewise. Keyboarded and buffered messages take only a few seconds or minutes to transmit. Single-frame television or facsimile would be about the same. But motion ATV could mean many minutes of transmission at 56 kbit/s. There are problems to be solved in multiplexing data and image communications, but they are not so formidable as to justify separate transponders.

At speeds of 9.6 kbit/s and above, packetized voice becomes quite practical. However, a higher transmission rate will be needed for other users. As with ATV, we can find ways to accommodate voice in a high-speed digital transponder.

Add all this up, and what do you have? An Integrated Services Digital Network (ISDN) in the sky! A high-speed packet transponder can handle anything that can be digitized. This basic resource can be used in different ways, dependent only on ground-station equipment. An early and firm definition of the Phase 4 digital transponder will serve as a call for experimenters to forge their ideas in silicon well before the time Phase 4 becomes a reality.

It would be a shame if we repeated history and developed the ground-station equipment <u>after</u> Phase 4 is launched. If we want Phase 4 to be used, we will need commercially made Amateur Radio equipment in sufficient quantity. Manufacturers' lead times must be taken into consideration. First, however, we need to convince them that (a) Phase 4 is a certainty, (b) parameters are firm, and (c) there will be a market large enough to justify their investment of resources.

CONCLUSION

If Phase 4 is to be launched in 5 years, we need to define the digital-transponder subsystem in the near future. It must accommodate voice and image communications as well as data communications. Accordingly, we should shoot for the highest practical throughput. Prototype development must proceed rapidly, and we need to work with manufacturers to ensure that ground-station equipment is available in quantity at launch time.

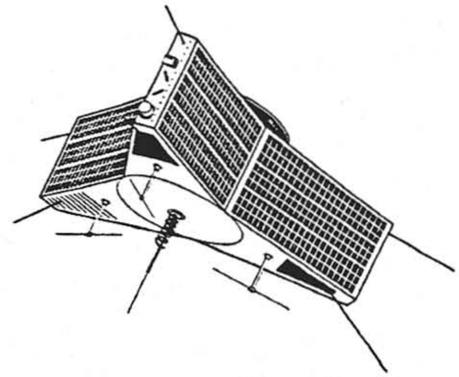
REFERENCES

1 Rinaldo, P, "Amateur Packet Radio in Region 3," presented at the IARU Region 3 Conference in Aukland, New Zealand, November, 1985.

2 Rinaldo, P, "Packet Radio in IARU Region 2," presented at the IARU Region 2 Conference in Buenos Aires, Argentina, October, 1986.

3 Wade, I., editor, Connect International, RSGB, monthly, North America annual subscriptions £6.93 for issues through June 1987, £9.24 thereafter. (All subscriptions are renewed on July 1 annually.)

ACSB and CASROS



by
James Eagleson WB6JNN
President, Project OSCAR
15 Valdez Lane
Watsonville, CA 95076

Since UHF / L-band satellites are firmly part of the Amateur Satellite program's future, some would rightly ask "Why bother with ACSB or SSB on these 1 MHz or wider satellites when FM can provide better quality and has been proven by its extensive use on commercial satellite links?"

It is certainly true that FM is the mode of choice for many services on current commercial satellites, but this is not universal. California Microwave, and others, have converted much of their operations to ACSB-like modes to provide up to 6000 links where only 2000 or less were previously available.

Actually these systems use a mix of ACSB, FM, and various data transmission techniques, depending on customer requirements.

Amateur requirements are much less critical in terms of numbers of users.

My observations of western and midwestern passes of OSCAR 10 over the past two years show typical useage to be about 10-12 SSB QSO's in the upper half of the passband at any given moment. Thus we have slightly over one QSO per 5 KHz, typical. It was also noted that the density was slightly higher in the 145.900-930 region than in the 930-950 region so that 3-4 KHz spacing was common in the more crowded parts of the passband.

I have been able to observe only a few European-US passes since these have not usually been at a convenient time or elevation angle at my location. Useage on these passes has been much higher... perhaps approaching 2.5 KHz per QSO over about 60 KHz of the passband. Thus we sometimes see 20-25 QSO's at any given moment during peak useage times for a total of 40-60 users.

The CW portion of the satellite is not used nearly as extensively as the Voice portion on most Western passes (only 4-5 QSO's) and most Mid-USA passes show only slightly more activity. Admitedly, I have not spent a great deal of time looking for CW stations in my studies, however.

There are typically one or two SSTV QSO's evident on null-free passes and some RTTY and Packet activity when signal levels are high enough. However, it is probable that more than two users are represented by each QSO since RTTY and Packet users tend to flock to one or two frequencies.

Even with 1 MHz or even 10 MHz wide satellites on the horizon we can expect that the usage level of such satellites for DX activity will not increase significantly. Most such activity will probably center around a small portion of the total passband and take up less than 100-200 KHz. Let`s face it, DX tends to be a herd activity where 20 or 30 bulls all fight over the same poor cow!

Ragchewing and Technical Discussions have been much more evident on OSCAR 10 than on earlier satellites because of the much longer access time available. Technical discussions and liaison activities seem to occur higher in the passband around 145.840-145.850 MHz where the concentration of other users tends to thin out.

These activities will probably take up only 200-400 KHz of the passband on a 1 MHz wide satellite and the same spectrum will also support the more casual DX contacts.

Specialized modes such as SSTV and RTTY/Packet will most likely require only 100 KHz or so with most CW activity able to operate in a similar but seperate 100 KHz segment.

Thus we have 700-800 KHz committed for activities already existing on OSCAR 10 with the remaining 200-300 KHz available for other possible activities. Please keep in mind that these figures are estimations of requirements on my part based on current activities. I **project** that these will be the likely spectrum requirements. The actual AMSAT recommended band plan could be some other mixture, however.

FUTURE ADDITIONAL USES

If my projections hold true, we should have about 300-400 KHz left to be used in some other fashion not currently being exploited on our satellites.

Some of these uses could be interlinking activities, teleconferencing networks, traffic handling networks, bulletin services, emergency communications, and a variety of other things left to the imagination of the Amateur Radio Community.

How can best implement these new services with minimum impact to current services? With the wider available pass band should we look at alternative modes other than SSB?

POWER REQUIREMENTS

A second consideration, and by no means insignificant, is the average power consumed by stations using the satellite.

FM has a peak-to-average power ratio of 0 dB. That is, the average and peak power of FM is the same.

Standard speech and SSB (since they are nearly identical in nature) have a typical peak-to-average ratio of about 12-18 dB... depending on whose data one chooses.

ACSB of the STI/SEA variety has a peak-to-average ratio of 6 dB.. largely due to the use of a Pilot Carrier.

Level One ACSB without pilot tone and using 2:1 compandoring has a peak to average ratio about 1.8-2.0 dB higher than speech.. about 10-16 dB during speech but better when pauses are averaged into the formula.

The proposed Project OSCAR Level Two ACSB technique which was outlined at the ARRL PACCOMM Convention in San Jose places the normal zero-beat carrier about 7-10 dB below peak speech yielding 6-9 dB peak to average power.

Outlined briefly, Level Two uses the normal SSB carrier by "leaking" it around the crystal filter so that an SSB Reduced Carrier (SSBRC) signal is transmitted. This seems to be the best system to exploit existing circuitry for ACSB transmission.

The only additions to transmit circuitry will then be the pre-emphasis, 2:1 compressor circuits, and whatever circuit is required to "leak" and control the level of the partially re-inserted carrier.

Reception is a bit more complicated but uses Phase Lock Loop circuitry which is totally independant of the transmission path variations and interferences and can use readily available PLL-synthesizer chips.

Either a seperate IF and Crystal Filter is used for AGC and carrier reception or a 2nd IF in the Audio spectrum so that Op Amp filters can be used. I will be publishing further details within the normal magazine lead times, probably in QEX.

Those truly interested in pursuing experimentation along these lines further can write to me through Project OSCAR, 15 Valdez Lane, Watsonville, CA 95076.

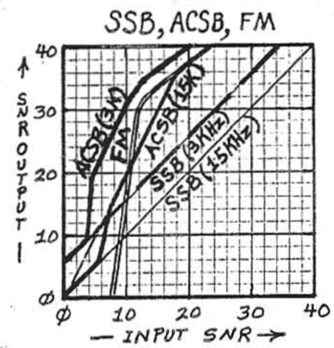
Any way we look at it, FM has a significantly higher power penalty when used on solar powered satellites than any form of SSB would have.

BUT FM SOUNDS BETTER!

It is hard to argue against anyone who suggests that FM provides better fidelity and less noise than standard SSB given a signal level at least 12 dB above the noise level.

Having granted that, it is also hard to argue against anyone who points out that SSB sounds better and is much clearer than FM when the signal level falls below about 8 dB above the noise.

In fact, FM typically becomes unusable at 6-8 dB input SNR!



Consider also that when an FM arrives at 8 dB above the noise in a receiver having the minimum useable bandwidth of 15 KHz, an SSB signal will be arriving at 7.8 dB **better** SNR (10 Log 15/2.5) in its 2.5KHz wide receiver. In other words SSB would produce 15.8 dB SNR at the same power level FM would achieve only 8 dB SNR because of the difference in IF bandwidth required to receive each mode.

FM, on the other hand, would rapidly exceed SSB SNR once either exceeded about 10-12 dB incoming SNR. At 6dB above our 8dB SNR example, or at 14 dB above the receiver noise, the FM signal would be close to "full quieting".

SSB, on the other hand, would have only gone from the 15.8 dB SNR level to 21.8 dB SNR in a linear fashion.

Pre-emphasis and de-emphasis of the SSB signal would improve its recovered SNR by 2-3 dB by reducing post detection noise. Thus we would have 23.8-24.8 dB SNR.

By using ACSB there would be an apparent 20-25 dB SNR improvement due to 1:2 audio expansion. Thus our Level One ACSB or Level Two signal would provide a recovered SNR of 40-50 dB at the same signal level at which FM is also just achieving "full quieting"

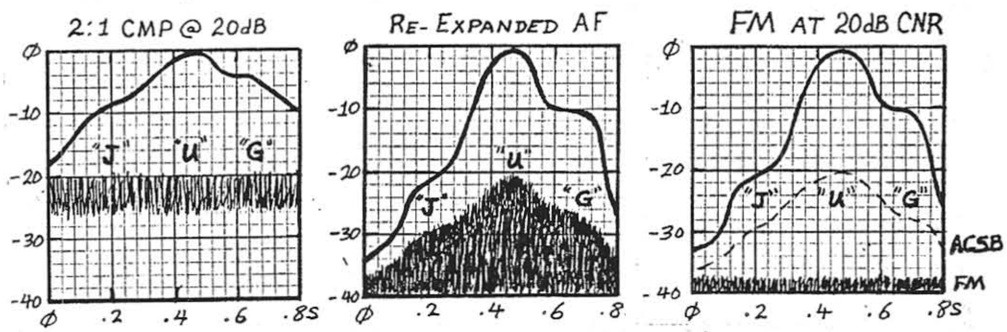
SOUNDS TOO GOOD TO BE TRUE

It is!

In reality, 2:1 ACSB has no better SNR than standard SSB.

Well, it is about 2-3 dB better due to the de-emphasis noise bandwidth reduction, perhaps.

However, since the 1:2 expandor follows the dynamics of the audio, an "apparent" improvement (subjective) will be heard since noise is reduced during non-speech periods and during weaker syllables. During strong syllables the speech itself covers the noise adequately.



To the average ear, the "apparent" SNR will seem to be between 30-50 dB somewhere depending on the type of background noise, the listeners sensitivity to noise, and the nature of the voice and speech being received.

Apparent distortion, on the other hand, will be higher than FM would be at the same SNR. The typical FM transmitter has distortion products falling at or below -30 dB.. roughly 2-3% THD. At an SNR of 30 dB, therefore, we would have possible addition of noise and these distortion products yielding a slight (3 dB) increase in the apparent distortion but still falling below 3-4% THD. Thus would would not hear any distortion on a weaker FM signal since it would be masked by the background noise.

ACSB, however, really has only about 18 dB SNR when its apparent SNR is 30-36 dB. Thus the "distortion" levels, in reality noise, would be at 18 dB.. approximately equivalent to 10% THD.

This is most apparent on the sillibant "s", "ch", and similar sounds and is not unlike the distortion heard on weak FM signals when multipath is present. It is often described as "puffiness", "roughness" or "muddiness".

Put into HI FI terms, at low SNR conditions ACSB doesn't have the "transparency" that FM does. It "colors" the sound more and sounds less like the speaker is in the same room as the listener.

Then again, ACSB is generally considered to have more "punch" under weak signal conditions. This is particularly true under mobile conditions.

While FM signals often "picket fence", "kerchunk", or have large noise bursts when signals are weak, ACSB under the same conditions will have little "picket fencing" and will have a better SNR than the FM signal. Having said that, the ACSB signal will have some distortion and "quaver" or "uneasiness" caused by slight level variations and selective fading of the signal. There will be no noise bursts such as FM would have.

THE BOTTOM LINE

Given FM or SSB and all the required bandwidth for either mode, 100 FM stations require more peak transponder power than 100 ACSB stations for a given downlink quality.

SSB or 2:1 ACSB have lower average power drain but about the same peak power requirements. FM has better quality at a given SNR, but ACSB yields this SNR at a lower power level.

FM sounds somewhat better at expected downlink SNR levels but ACSB would provide better clarity and more fade margin (FM SNR fades much faster than ACSB).

If care was taken to balance the tonal response of an ACSB and an FM signal arriving at a level which would give 25 dB SNR at the input to the ACSB radio (17 dB CNR in the FM radio), most of us would have a hard time judging which sounded "better". They would sound "different".

ACSB requires newer, different technology and is therefore somewhat more complex for the average station to implement. This is only a short term objection, however.

It is likely that both FM and ACSB will find utilization on Phase IV Satellites, but ACSB should be the primary mode for most utility users.

CAS SYSTEMS

What kind of utility use is likely on a Phase IV satellite?

The Geosynchronous satellite proposed for Phase IV makes an excellent relay system for users located between zero and many thousands of miles from the sub-satellite point of the transponder.

It is, in fact, much better than HF in this regard in that all points visible to the satellite can communicate with each other. There is no "skip zone". Stations inches apart to thousands of miles apart can communicate with each other with the same ease.

A synchronous satellite has no serious variations in signal path conditions so that any time of the day or night, any weather conditions, and any blockages will remain the same at all times.

Once adequate access to the transponder has been established, little variation should be experienced except that due to deterioration of the Ground Station's equipment or satellite transponder loading.

Thus a geosynchronous satellite is excellent for uses requiring long communications periods with no interruptions, coverage of large regions while maintaining local coverage, or "broadcast" activities where information must be deciminated over a large region.

Examples of such uses include emergency communications, public service communications, traffic handling, networks, teleconferences, liaison activities, bulletins, and informational networks such as Westlink.

Other possible uses include remote sensing of widely scattered scientific experiments via communication links through the satellite, expedition communications and telemetry, and teleconferencing for educational or scientific programs. While FCC approval and guidelines must be obtained for these latter activities, there are many potential non-commercial users whose needs cannot be met through commercial satellites both due to the expense of uplink/downlink equipment and/or cost to operate through such transponders.

And, of course, interlinking of repeaters or translators in the Amateur Service could be a major use of a Phase IV transponder.

GETTING THERE

Unlike the movie "Being There" where a complete idiot turned the world of business upside down by just being "in the right place at the right time", Public Service through Amateur Satellites is going to take some dedicated effort.

It won't just "happen"!

First, most public service people I know are more acquainted with the hand-held than with an AZ-EL rotor. Their emphasis is **communications**, not hardware.

Second, the number of us who are technically inclined in the hobby has been, and still is, a minority. In natural disasters one must be able to draw from the **majority** in order for there to be much likelihood that someone is going to be "in the right place at the right time".

Third, it takes more than a hand-held to access a satellite! You can't totally ignore hardware if you wish to communicate most effectively.

My observation with OSCAR 10 is that the minimum requirements for even receiving adequate downlink signals is beyond the capability of the hardware available to the typical VHF user. There is NO way that they can receive Phase III or Phase IV satellites from their cars using the typical 5/8-wave mag-mount whip!

Let's face it, ours is a mobile society where our spare time is largely spent on the road... whether commuting or vacationing.

Thus any Phase IV or advanced Phase III program must recognize this factor.

Furthermore the single family dwelling is rapidly becoming an extinct entity. Perhaps some of us who are senior engineers or who live in the country can afford a house, but the average person in the USA today is living in shared housing of one kind or another. This is especially true in urban centers like the Santa Clara Valley, New York, L.A., or Chicago.

I know of very few Bay Area DX'ers who have not had some kind of run around with neighbors, city, or both about antennas... even OSCAR antennas!

In a word, we will not attract the numbers of Radio Amateurs required to fund a major Phase III or Phase IV project unless we provide some means of satellite access for those whose operations are either predominately mobile or are limited by their housing situation.

COMMUNITY ACCESS STATIONS

I have proposed Community Access Stations as one way of providing better satellite utility for those not able to directly access geosynchronous systems. While some of my QEX article this subject was changed in emphasis by their editing process, it represents a set of possible methods of accessing OSCAR satellites by indirect means.

What was not clearly presented due to the editing is that I feel that certain safeguards should be built in to such systems so that there is no negative impact on current amateur satellite supporter/users.

This is one reason why I am firmly promoting use of ACSB techniques for linking rather than FM. FM links can provide better quality with less complexity but only with unacceptable power and bandwidth penalties.

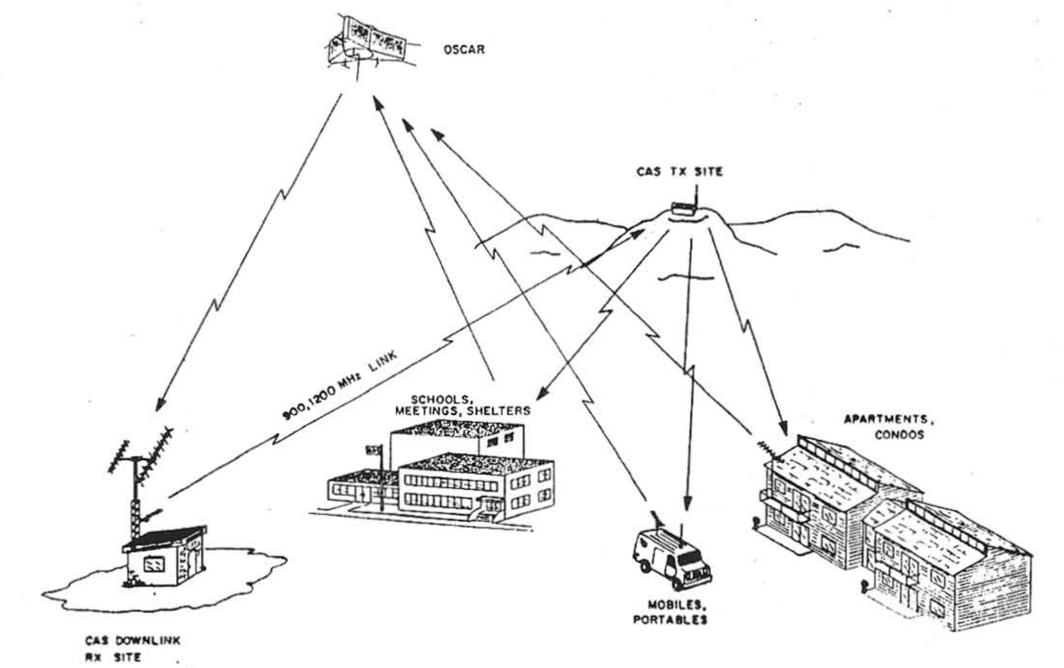
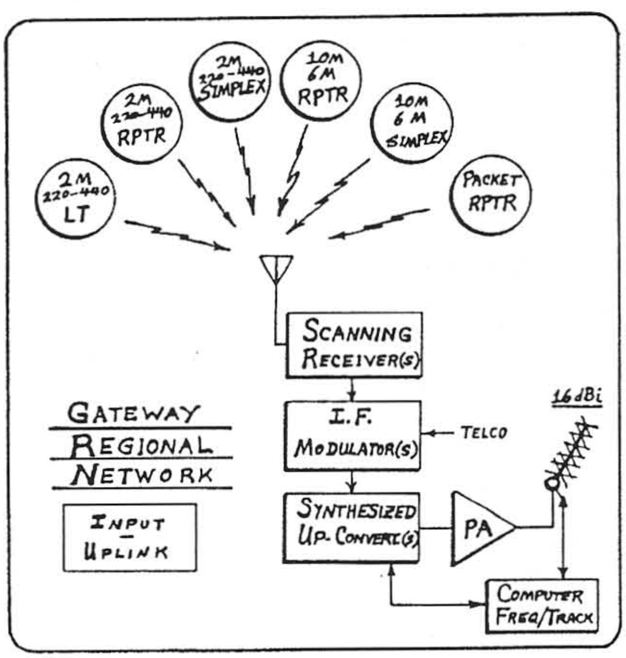


Fig 1—A pictorial of a community access system receive only system.



Summed up, there are three kinds of CAS possible... CASROS, or Community Access Receive Only System; CAS-LT, or CAS Linear Translators; and CAS-MST, CAS Multiple Source Translators.

The CASROS provides a good downlink to stations in a given area so that demonstrations can be given without the hassle dragging around a large Two Meter antenna and so that apartment dwellers, for example, can concentrate on providing a good 435 Uplink signal using the relatively small antenna required rather than putting up the more complex and obvious AZ-EL Two Meter Circular as well.

For the more creative mobile operator, the CASROS provides a usable downlink so that with a 100 W amp and a small antenna he could actually operate mobile through a Phase III or Phase IV bird.

The CAS LT has proven to work well enough through OSCAR 10 so that indirect operation can be obtained either mobile or from a base station. It's limitations, of course, center around control of uplink power and noise, disparity between close in, strong stations and outlying, weaker stations, and the need for a set aside continuous spectrum of whatever bandwidth one wants to cover out of the satellites passband.

None of these are insurmountable problems but there is a better way.

CAS-MST combines the best features of Remote Base, Repeater, and Linear Translator techniques. In essence, a given source station can tune in and work a given destination station through the CAS-MST system.

The source station could be AM, FM, SSB, ACSB or a Repeater, Remote Base, Simplex Access channel (from any mode), a portion of a Linear Translator or even a phone patch set up for this purpose.

The essential element is that the source must be controllable either by Touch-Tone (TM) or some other means of controlling the tuning and functions of the CAS-MST.

If I wanted to use a CAS-MST I would first access either a repeater with CAS capability, a Simplex Remote Base, or a defined portion of a Linear Translator.

I would then use Touch Tones (TM) or some other control means to access the CAS system.

At this point I would begin to hear a portion of the satellite downlink signal. Probably the default condition would be that the system would come up tuned to the beacon. That way the I can go through a brief process of "zero

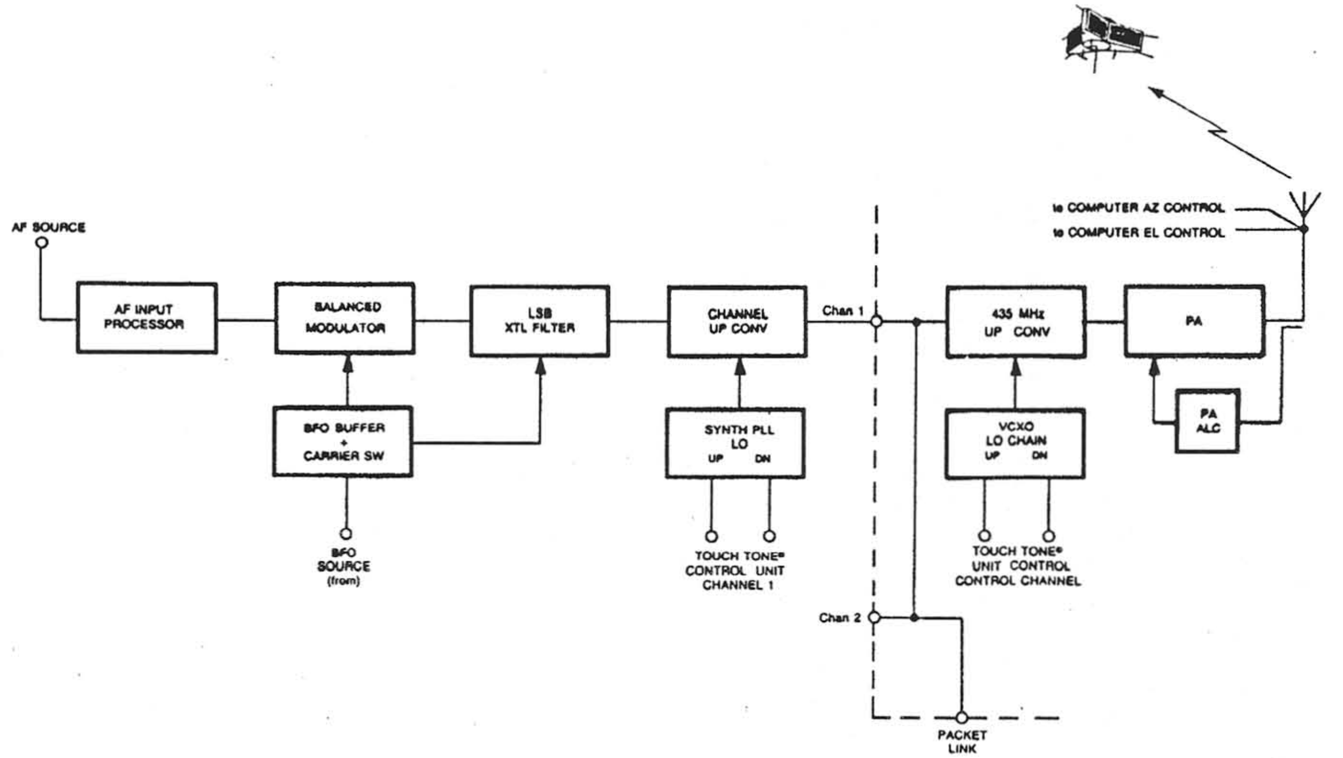


Fig 3—A block diagram of the CAS uplink transmitting station.

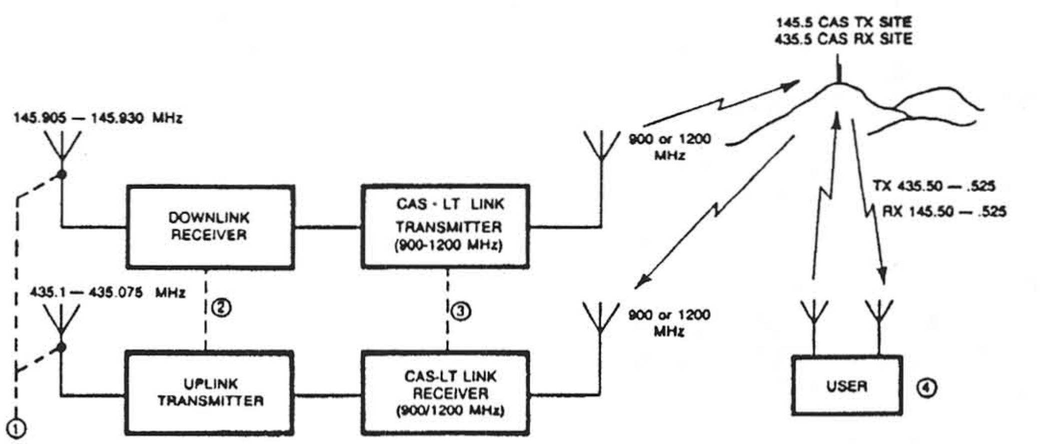


Fig 4—The CAS-LT block diagram. At location 1, the required hardware for az-el tracking includes a 2-m and/or 70-cm beams, az-el rotators, and a computer or remote controller. Location 2 features frequency tracking. The system should be remotely or automatically adjusted to perform its responsibilities. A link system is shown at location 3. It consists of two channels, a separate transmitter and receiver and separate antennas or diplexed.

beating" the beacon by hitting "#" for "up" and "*" for down, for example, then I would key in a sequence, say "5-5Ø" or "5-7Ø" to tune the CAS-MST IF Subsystem 5Ø or 7Ø KHz up from the beacon to the area of activity I am interested in tuning.

Now all I need to do is to use the "up"/"down" "#" or "*" keys to tune in a station I wish to talk to then key in the appropriate access code to initiate transceive operation. That code could be, say, 7-1-1.

The CAS-MST is designed to automatically track any Doppler Shift (for Phase II or III satellites) and adjust for uplink and downlink system drifts.

This is not as difficult to achieve as one might think. If everything is synthesized and/or digitally adjustable and all operations are referenced to the beacon frequency, the ACTUAL uplink and downlink frequencies will not matter. Even though they will be different for stations located in New York City and San Francisco, their relationship to the beacon will always be the same.

The technique DOES require that a beacon carrier be present at all times, however, slightly impacting the satellite design. This is not that difficult to provide, however.

Using beacon reference provides one other kind of operation that is challenging. If a set of "channels" are set aside at beacon + 75ØKHz, 752.5KHz...76ØKHz (5 channels), participating repeaters, remote bases, or linear translators could access each other by dialing up an interconnect and destination code (say, 825 #25) to bring up any desired machine on the system. The CAS-MST would then check the other four "working channels" to see which one was available then both machines would switch to that "channel" to complete the QSO and leave the calling channel free.

Obviously some means of access control between machines would need to be established and the CAS-MST in each instance would need to be able to ensure proper operation of its linked system.

Project OSCAR has set aside significant funding to develop the various modules required to accomplish this kind of system. We will use whatever commercial equipment that can easily be applied to the problem and develop the specialized hardware.

Obviously in the absence of OSCAR 1Ø we will use terrestrial linking and, possibly, FO-12 for our evaluations. We will publish results as time goes on.

If you have experience in synthesizer design in the 5Ø

MHz region, in Touch Tone (TM) control circuitry, or other areas you think might be of use to us, please feel free to contact me at the address given earlier.

MONOLITHIC MICROWAVE INTEGRATED CIRCUITS

BY

AL WARD

WB5LUA

NOVEMBER 9, 1986

AVANTEK
MONOLITHIC MICROWAVE INTEGRATED CIRCUITS
(MMIC)

* 50 OHM GAIN BLOCK

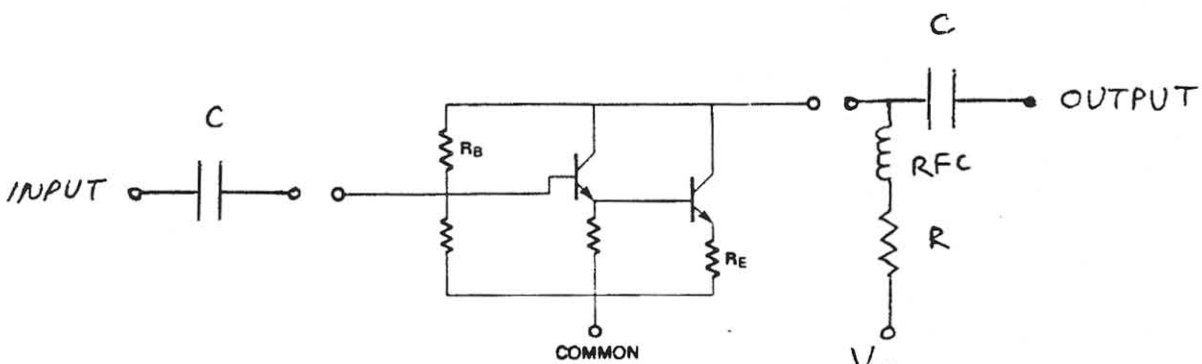
* BROADBAND DC TO 4GHZ.

* DARLINGTON CONNECTED TRANSISTOR PAIR

* INTERNAL BIASING

* INTERNAL FEEDBACK ENSURES STABILITY

* EASY TO CASCADE



RB - Shunt Feedback Resistor
RE - Series Feedback Resistor

OTHER ADVANTAGES

* LOW COST

* SMALL SIZE

* REPRODUCIBLE PERFORMANCE

* HIGH RELIABILITY

* EASY TO USE

MMIC
APPLICATIONS

* RECEIVERS   RF/IF
  TV
  TVRO
  DBS
  COMMUNICATIONS

* RF POWER AMPLIFIERS

* TEST EQUIPMENT

* ELECTRONIC DEFENSE SYSTEMS

* COMMERCIAL MARKET

MANUFACTURERS

* AVANTEK

* ALPHA

* TEXAS INSTRUMENTS

* SIEMANS

* CALIFORNIA EASTERN LABORATORIES

* PLESSEY

* PLUS OTHERS

MMIC
MANUFACTURING PROCESSES

* MMIC CHIP MANUFACTURING SIMILAR TO TRANSISTORS
* NITRIDE SELF-ALIGNMENT ION IMPLANTATION TECHNIQUES ARE USED FOR PRECISE CONTROL OF DOPING AND NITRIDE PASSIVATION
* RESISTORS ARE FABRICATED DIRECTLY ON SUBSTRATE
* DESIGNING MASKS IS EXPENSIVE
* DESIGN ITERATIONS REQUIRED BUT COSTLY
* DEVELOPING A FACILITY IS EXPENSIVE
* NEED A HIGH VOLUME MARKET TO MAKE PRODUCTION COST EFFECTIVE

MMIC
PACKAGING

* 100 MIL METAL/CERAMIC "MICRO-X" PACKAGE
* 70 MIL CERAMIC PACKAGE
* 200 MIL CERAMIC PACKAGE
* TO-8 AND TO-12 PACKAGE
* PLASTIC PACKAGE

AVANTEK MONOLITHIC AMPLIFIER PERFORMANCE SUMMARY

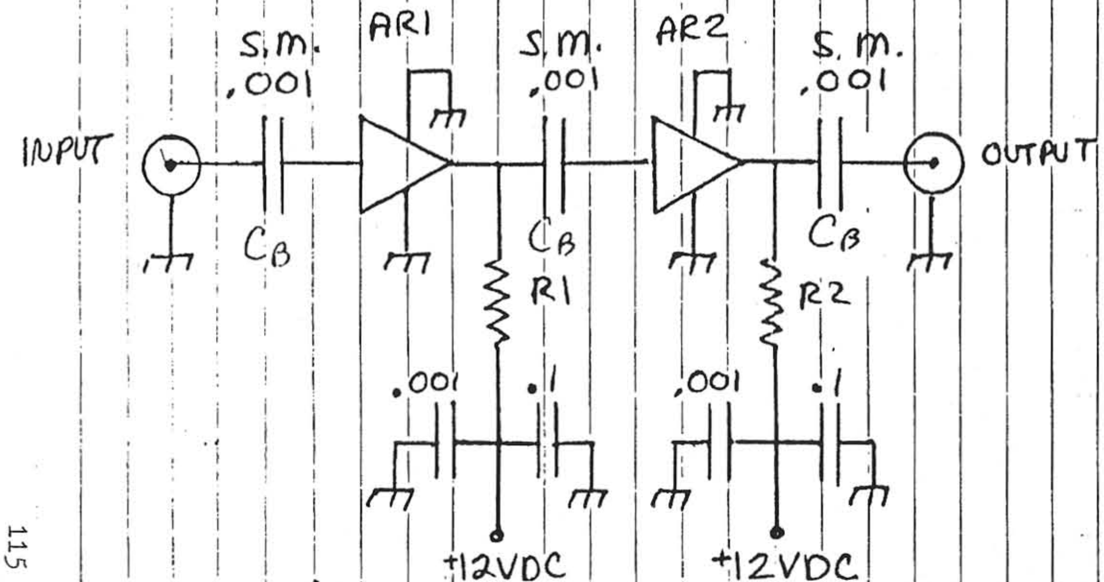
TYPICAL GAIN/COMPRESSION VERSUS FREQUENCY

MSA-	30	50	144	220	432	902	1296	2304	3300	MHz.
0104	19	19	19	18	17	14	12	9	6	dB
	+8	+8	+7	+6	+4	**	**	**	**	dBm
0204	13	13	13	13	12	11	10	8	6	dB
	>+7	>+7	>+7	>+7	+7	+5	+4	+2	**	dBm
0304	13	13	13	13	12	11	10	8	6	dB
	>+13	>+13	>+13	>+13	+13	+11	+10	+5	**	dBm
0404	8	8	8	8	8	8	7	6	5	dB
	>+13	>+13	>+13	>+13	>+13	+13	+13	+13	**	dBm
4-0404	>+19	>+19	>+19	>+19	>+19	+19	+19	+19	**	dBm
02/03 *	26	26	26	26	24	22	20	16	12	dB
	>+13	>+13	>+13	>+13	+13	+11	+10	+5	**	dBm
02/03/04 *	34	34	34	34	32	30	28	x	17	dB
	>+13	>+13	>+13	>+13	+13	+13	+13	x	**	dBm
03/04/04 *	-	-	-	-	-	-	-	22	16	dB
	-	-	-	-	-	-	-	+13	**	dBm

* Devices are from the __04 family
** Not specified
x Combination not desired for 2304 MHz. due to compression of 03 stage
\- Not analyzed

Data obtained from Avantek data sheets

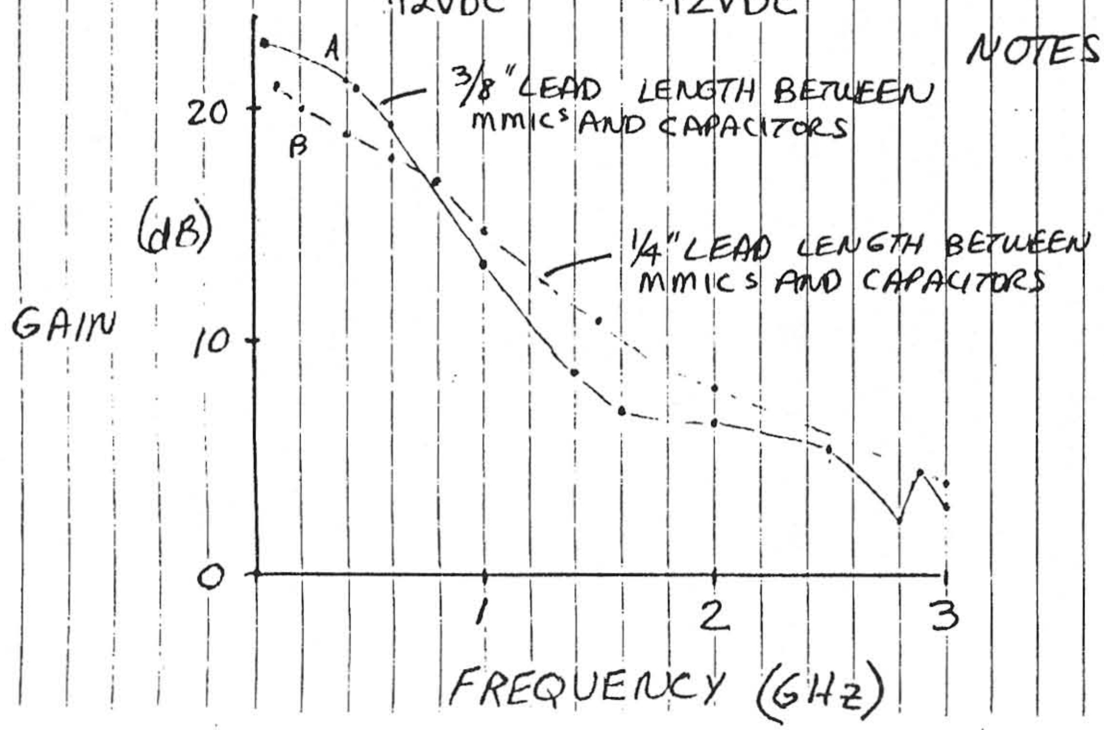
A.J. WARD
WB5LUA
JULY 18, 1985
REV.B, 9-9-85



AR1	AVANTEK MSA-0204 MMIC	
AR2	AVANTEK MSA-0304 MMIC	
R1	270 OHM .5 W RESISTOR	
R2	220 OHM .5 W RESISTOR	

CAPACITORS IN UF.

CONNECTORS BNC



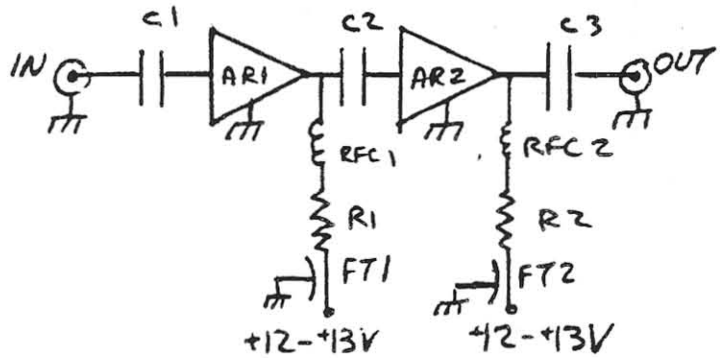
NOTES

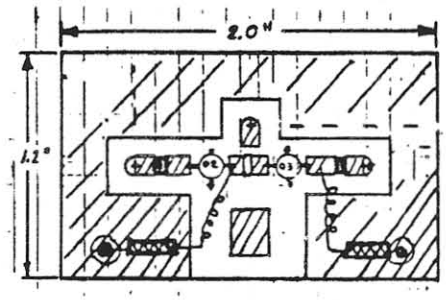
1. "DEAD BUG" CONSTRUCTION TECHNIQUES UTILIZED - SEE NOTE
2. .1 uFd Bypass CAPACITORS ELIMINATE LOW FREQUENCY OSCILLATIONS IN BIAS NETWORK
3. USE OF .1 uFd BLOCKING CAPACITORS ALLOW HF OPERATION DOWN TO 1.2 MHz.

VHF MMIC AMPLIFIER

WB5LUA
7-13-86

MMIC AMPLIFIER LAYOUT





COMPONENT LAYOUT

C1-C3 5C-100pf CHIP CAP.
RFC1,2 4 TURNS #28GA. ENAMEL WIRE 1/8" I.D. S.W.D.
R1,R2 BIAS RESISTORS-SEE TABLE
FT1,FT2 470-1000pf FEEDTHROUGH
AR1,AR2 AVANTEK MMIC

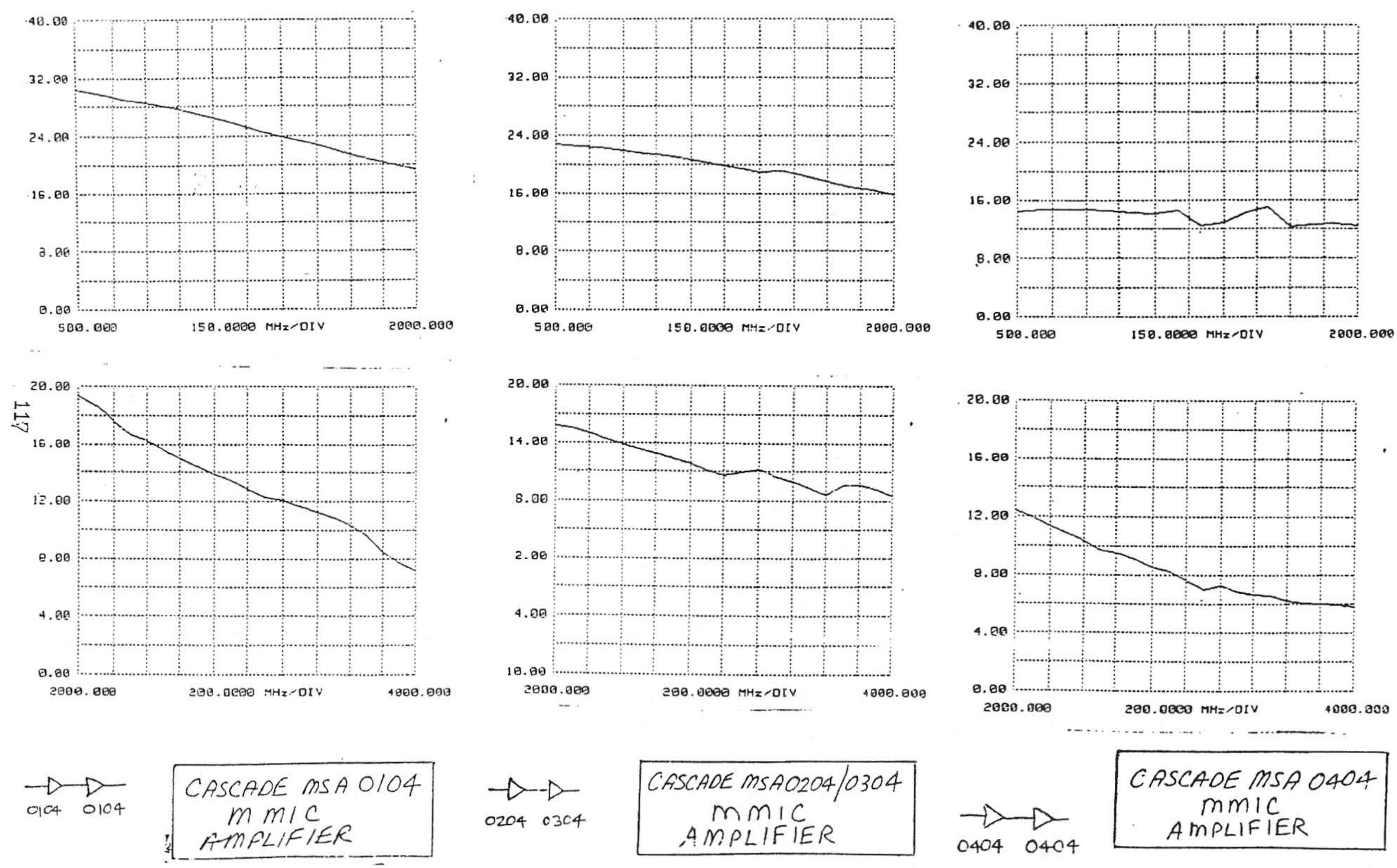
- SLASHED AREA IS COPPER
- 50Ω LINEWIDTHS ARE .100"
- DIELECTRIC IS .062" G-10

DEVICE	I_C * (mA)	BIAS RESISTOR OHMS FOR V_{CC}=13V	WATTS (DISS.)	COST (SINGLE QTY'S)
MSA 0104	30	267	.24	$ 2.75
MSA 0204	30	267	.24	$ 2.90
MSA 0304	40	200	.32	$ 3.00
MSA 0404	50	150	.38	$ 3.25

* RECOMMENDED I_C FOR CONTINUOUS OPERATION

MICRO-X (35 STYLE PACKAGE) VERSIONS AVAILABLE AT COST ≈ $9.00 EACH. OFFER SLIGHTLY GREATER GAIN (≈2dB) AT 1-2GHz. SHOULD BE EVEN BETTER AT 3-4GHz.

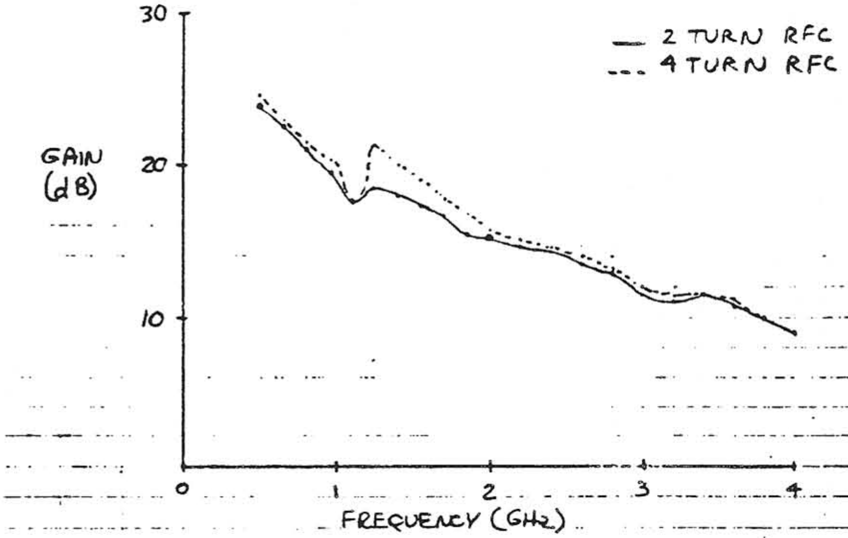
A.J. WARD
WB5LUA
9-8-85

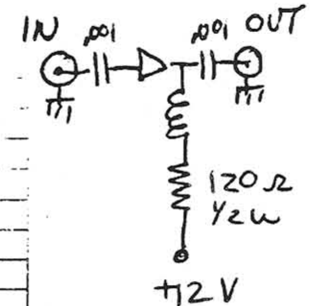


MMIC AMPLIFIER GAIN PERFORMANCE
(MICROSTRIP VERSION)

WBSL-UA
7-14-86

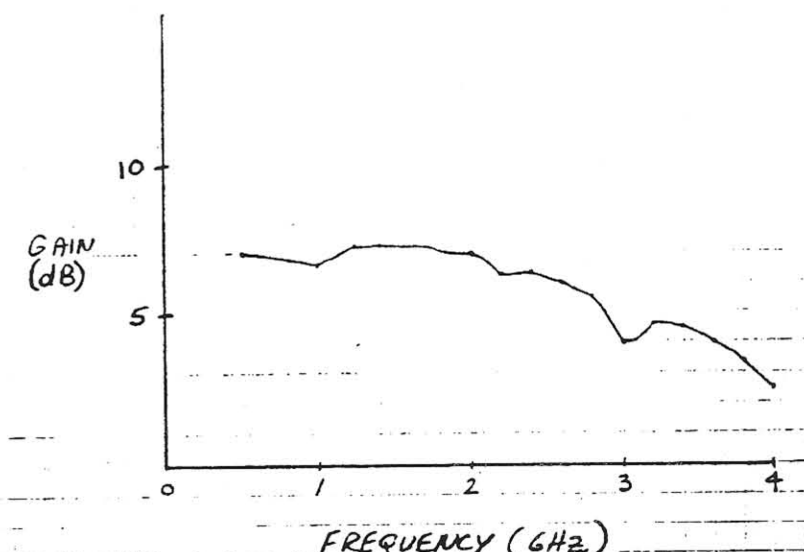
MSA 0835 MMIC AMPLIFIER

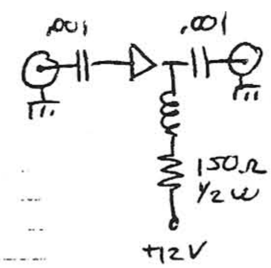




MEASURED PERFORMANCE FOR 2 AND 4 TURN RF CHOKES

MSA 0485 MMIC AMPLIFIER

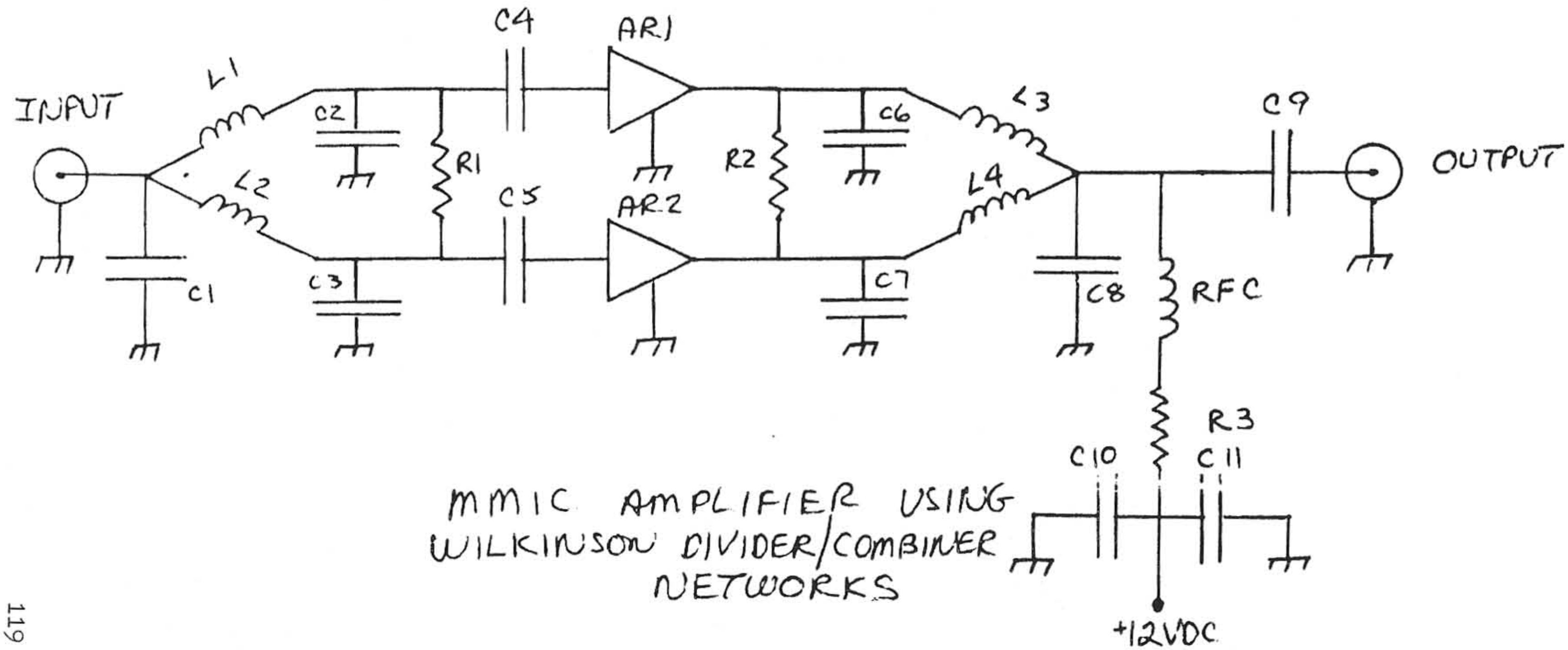




MEASURED PERFORMANCE FOR MSA0485 MMIC AMPLIFIER

(MICROSTRIP VERSION)

WB5LUA
7-14-86

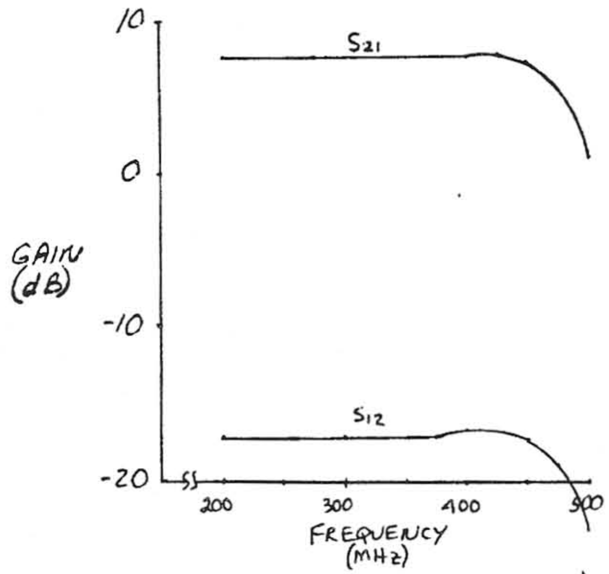


MMIC AMPLIFIER USING WILKINSON DIVIDER/COMBINER NETWORKS

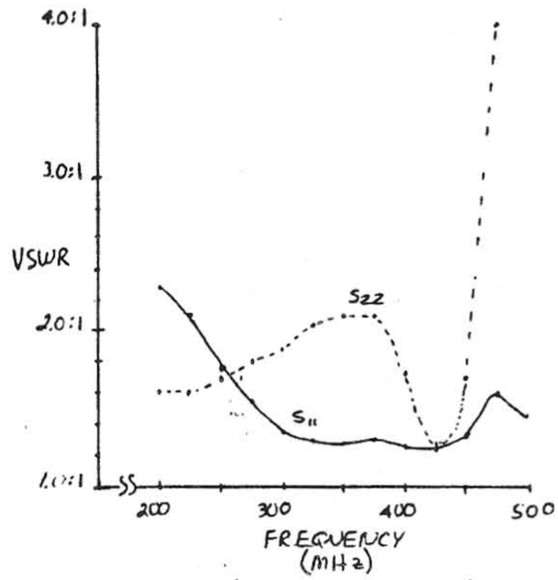
Freq.	220 MHz	432 MHz
C1, C8	20pf S.M.	1-10pf VARIABLE CAPACITOR
C2, C3, C6, C7	10pf S.M.	5pf S.M.
C4, C5, C9, C10	470pf S.M.	100pf S.M.
C11	.1 ufd DISC	.1 ufd DISC
L1, L2, L3, L4	50nH (see text)	26nH (see text)
R1, R2	100Ω	100Ω
R3	62Ω 1W	62Ω 1W
RFC	.47uH	.47uH
AR1, AR2	MSA0404	MSA0404

COMPONENT VALUES FOR CIRCUIT DESCRIBED IN FIGURE 10

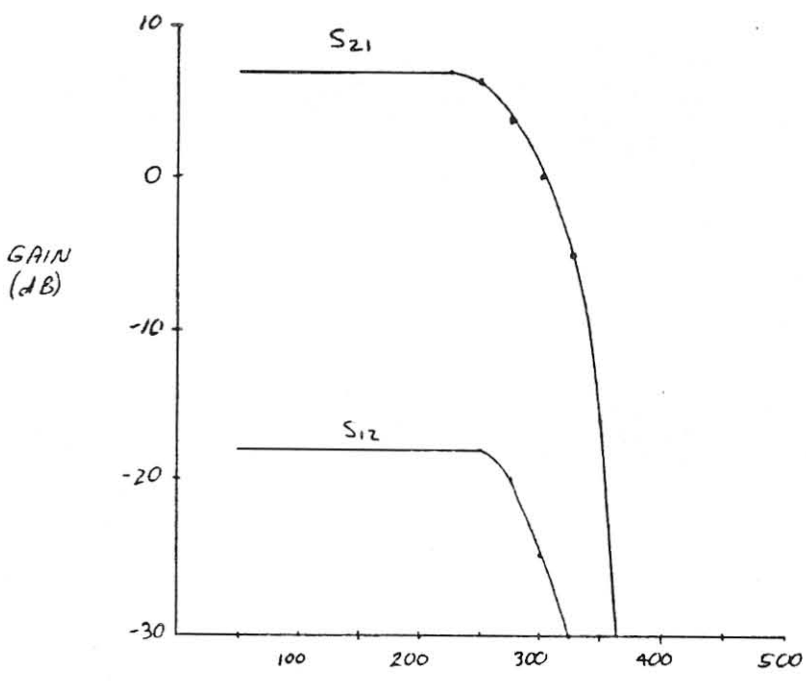
WB5LUA



FORWARD (S21) AND REVERSE (S12) GAIN OF 432 MHz PARALLEL MMIC. MSA-0404 AMPLIFIER.

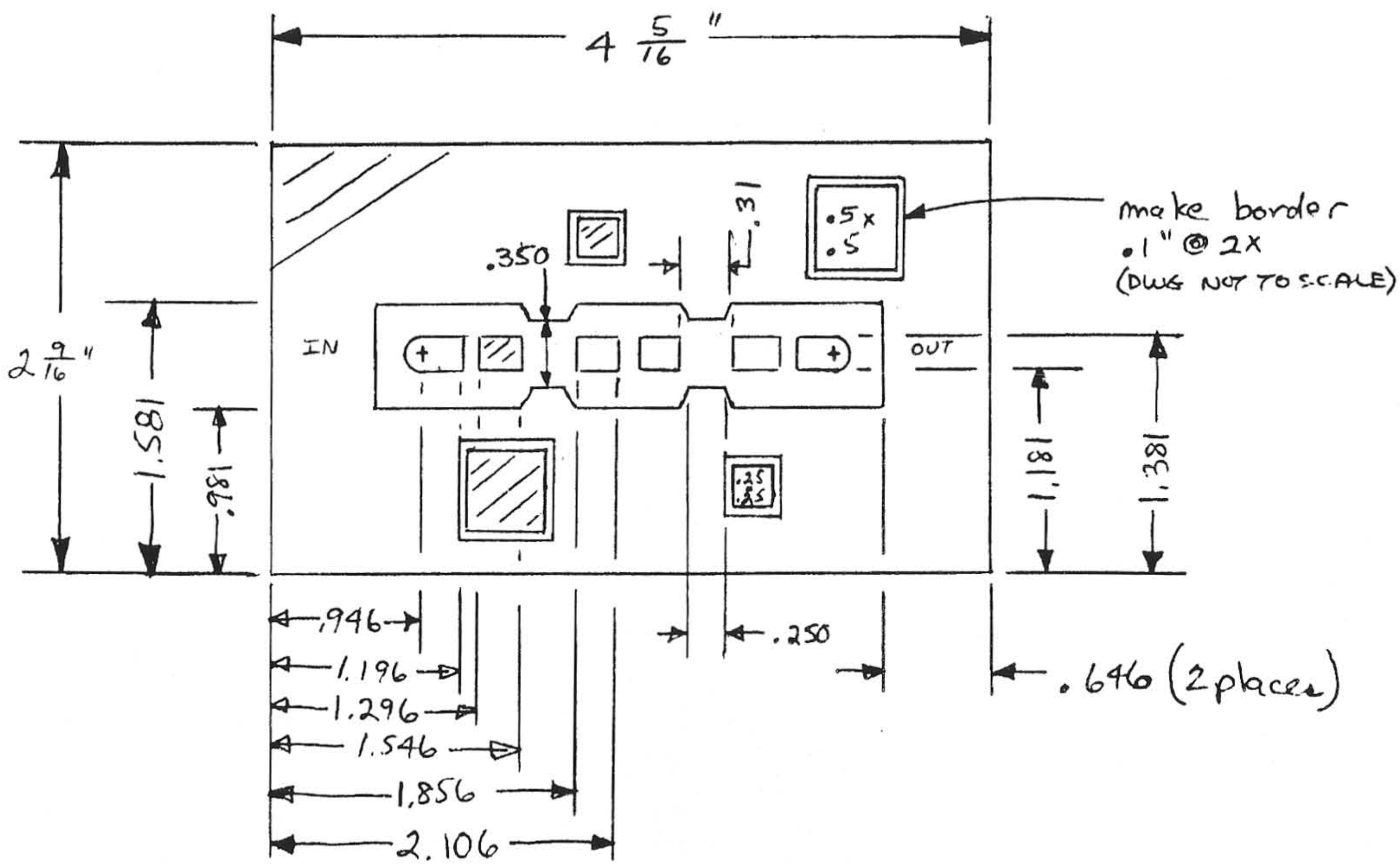


INPUT (S11) AND OUTPUT (S22) VSWR OF 432 MHz PARALLEL MMIC. MSA-0404 AMPLIFIER.



FORWARD (S21) AND REVERSE (S12) GAIN OF 220 MHz PARALLEL MMIC AMPLIFIER

WB5LUA
7-14-86



NOTES: 1. DIMENSIONS IN INCHES
2. DIMENSIONS ARE 2X
3. SLASHED AREA IS COPPER
4. ε_r = 5.0, THICKNESS IS .062"

CASCADE MMIC AMPLIFIER
CIRCUIT LAYOUT
A. J. WARD
JAN 6, 1985

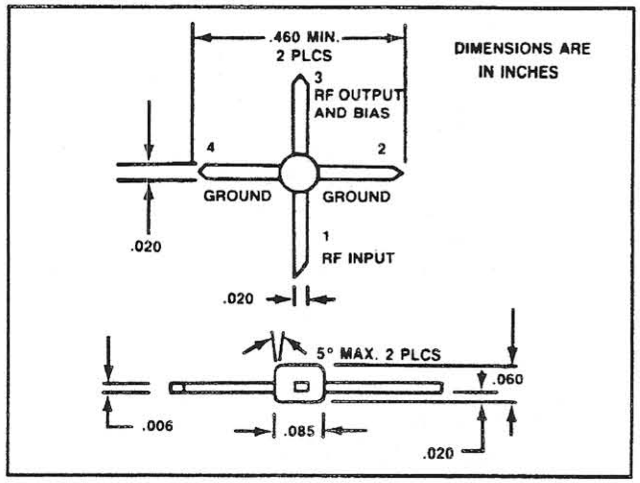
preliminary data sheet

AVANTEK

MODAMP™
MSA-0185, MSA-0285, MSA-0385, MSA-0485
Cascadable Monolithic Silicon
Integrated Circuit Amplifiers
Advanced Product Information
January, 1986

FEATURES

- **Low Cost Plastic Packaging**
- **Cascadable (VSWR<2:1)**
- **Smooth Single-Pole Gain Rolloff**
- **Unconditionally Stable**



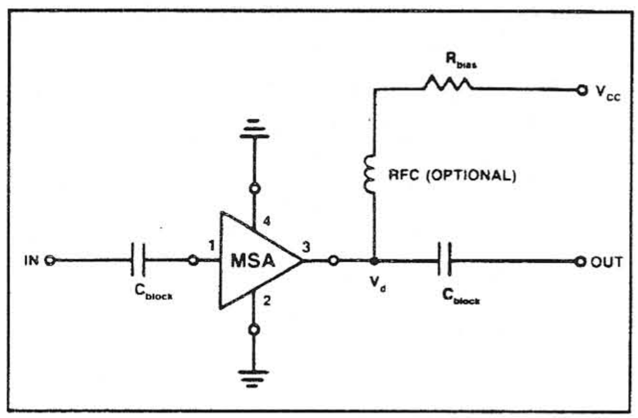
Avantek 85 Plastic Package

DESCRIPTION

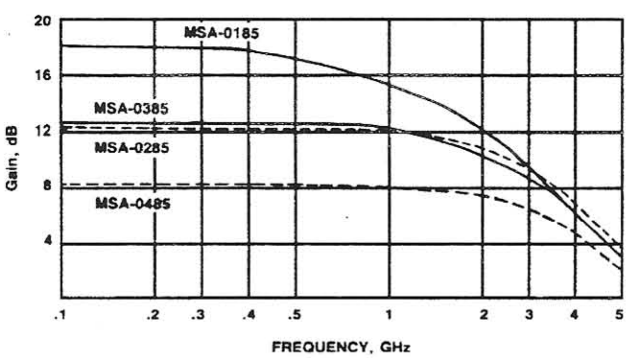
Avantek's MSA-0185, MSA-0285, MSA-0385 and MSA-0485 are a new series of silicon bipolar Monolithic Microwave Integrated Circuits, MODAMPs™, manufactured in a low cost, high performance plastic package. These MODAMPs™ are designed for use as general pupose 50 ohm gain blocks. Typical applications include narrow and broad band IF and RF amplifiers in commercial and industrial applications.

All Avantek MODAMPs™ use nitride self-alignment, ion implantation for precise doping control, and both gold metalization and nitride passivation for high reliability.

Typical Biasing Configuration



Typical S_{21} Gain vs. Frequency



TYPICAL ELECTRICAL SPECIFICATIONS; $T_A = 25°C$

DEVICE	V_{CC} (V)	R_{bias} (Ω)	Typical I_d (mA)	Typical V_d (V)	Typical @ 500 MHz $\|S_{21}\|^2$ (dB)	Typical @ 500 MHz $P_{1\ dB}$	Typical @ 500 MHz $NF_{50Ω}$	Typical $f_{1\ dB}$[1] (MHz)
MSA-0185	12	410	17	5	17.4	1.0	5.0	550
MSA-0285	12	280	25	5	12.8	4.0	6.0	1150
MSA-0385	12	200	35	5	12.8	10.0	5.5	1150
MSA-0485	12	140	50	5	8.2	13.0	6.3	2100

NOTE 1: Frequency at which gain is 1 dB less than at 100 MHz.

TYPICAL SCATTERING PARAMETERS, MSA-0185

$V_{CC} = 12V,\ I_d = 17\ mA$

Freq.	S_{11}		S_{21}		S_{12}		S_{22}	
MHz	Mag	Ang	dB	Ang	Mag	Ang	Mag	Ang
100	.068	163.8	18.46	170.7	.077	4.1	.068	−13.8
500	.062	105.8	17.40	140.6	.084	15.2	.072	−67.7
1000	.065	71.5	15.61	110.7	.102	24.3	.087	−123.8
1500	.036	59.0	13.70	86.6	.127	26.3	.104	−161.2
2000	.059	148.9	12.30	67.1	.157	20.5	.157	−177.2
2500	.096	142.0	10.62	48.8	.180	17.7	.156	154.9
3000	.136	139.3	9.30	33.6	.202	12.0	.145	143.9
3500	.205	129.0	7.89	18.6	.218	5.3	.157	135.3
4000	.279	120.0	6.62	3.1	.246	−4.2	.165	127.3
4500	.335	110.3	5.41	−9.1	.250	−9.9	.159	122.5
5000	.390	99.4	4.26	−20.7	.251	−17.4	.149	124.2
5500	.433	91.1	3.24	−31.0	.256	−22.3	.155	131.0
6000	.479	83.1	2.25	−41.4	.259	−29.6	.174	136.1

TYPICAL SCATTERING PARAMETERS, MSA-0285

$V_{CC} = 12V,\ I_d = 25\ mA$

Freq.	S_{11}		S_{21}		S_{12}		S_{22}	
MHz	Mag	Ang	dB	Ang	Mag	Ang	Mag	Ang
100	.121	173.5	12.88	174.2	.116	1.4	.126	−7.9
500	.113	154.1	12.75	156.0	.120	4.7	.123	−37.5
1000	.100	130.1	12.47	130.5	.127	6.7	.123	−75.4
1500	.077	120.2	11.75	109.1	.141	9.9	.123	−112.2
2000	.062	126.2	10.99	90.0	.155	8.8	.127	−121.0
2500	.085	147.5	10.35	67.1	.174	5.7	.129	−165.5
3000	.140	146.6	9.35	45.7	.188	−.9	.129	171.2
3500	.207	136.4	8.23	29.6	.199	−5.5	.127	154.8
4000	.273	123.5	7.26	13.6	.207	−10.4	.125	141.7
4500	.344	111.8	6.17	−2.3	.214	−16.9	.123	135.1
5000	.410	101.9	4.90	−16.5	.210	−22.4	.122	135.9
5500	470	92.4	3.91	−28.9	.222	−27.1	.132	139.7
6000	.516	85.2	2.77	−40.4	.216	−32.5	.165	144.1

TYPICAL SCATTERING PARAMETERS, MSA-0385

$V_{CC} = 12V,\ I_d = 35\ mA$

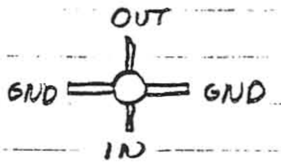
Freq.	S_{11}		S_{21}		S_{12}		S_{22}	
MHz	Mag	Ang	dB	Ang	Mag	Ang	Mag	Ang
100	.068	172.1	12.97	174.3	.118	1.2	.154	−10.6
500	.059	156.0	12.78	152.5	.121	5.3	.164	−45.5
1000	.047	145.8	12.40	128.0	.131	9.8	.185	−87.9
1500	.045	172.2	11.75	103.3	.145	11.7	.214	−120.4
2000	.058	173.0	10.80	83.0	.176	10.7	.253	−142.3
2500	.170	174.6	10.25	59.5	.187	5.5	.256	−172.6
3000	.243	157.3	9.10	38.2	.204	−.3	.251	168.0
3500	.319	140.2	7.77	21.4	.214	−6.1	.252	152.4
4000	.386	124.3	6.47	2.9	.219	−13.7	.254	138.4
4500	.456	110.7	5.04	−9.4	.222	−18.4	.237	130.3
5000	.508	99.6	3.90	−23.5	.219	−23.7	.235	125.6
5500	.557	88.7	2.72	−34.0	.225	−26.0	.245	123.7
6000	.596	80.9	1.70	−45.1	.227	−31.2	.265	122.9

TYPICAL SCATTERING PARAMETERS, MSA-0485

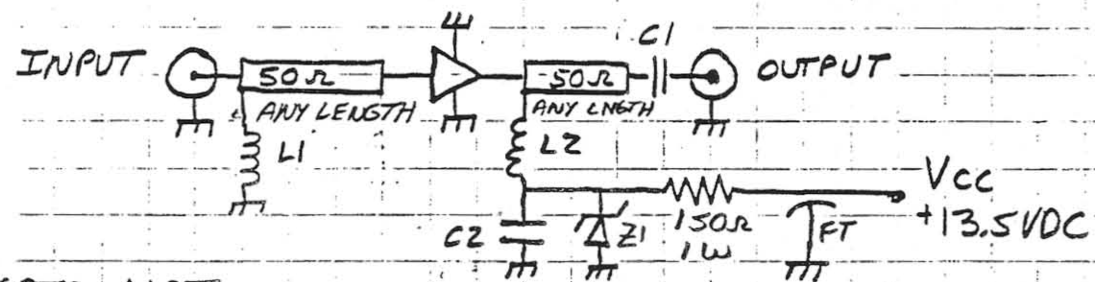
$V_{CC} = 12V,\ I_d = 50\ mA$

Freq.	S_{11}		S_{21}		S_{12}		S_{22}	
MHz	Mag	Ang	dB	Ang	Mag	Ang	Mag	Ang
100	.185	176.9	8.23	175.3	.155	.1	.103	−13.6
500	.180	168.6	8.22	156.5	.156	1.1	.127	−54.4
1000	.173	159.1	8.16	135.1	.161	3.2	.178	−93.9
1500	.174	156.8	8.08	111.7	.170	3.6	.239	−121.4
2000	.190	151.1	7.73	89.6	.186	2.9	.285	−144.8
2500	.240	159.5	7.61	68.7	.204	−.5	.338	−165.2
3000	.313	150.6	6.93	45.9	.221	−5.6	.355	176.2
3500	.391	139.0	5.97	27.3	.226	−10.9	.370	160.5
4000	.465	126.4	4.93	7.8	.250	−22.9	.383	146.9
4500	.524	114.6	3.57	−6.4	.246	−26.1	.385	137.4
5000	.579	105.5	2.39	−21.5	.243	−30.6	.373	129.8
5500	.617	96.6	1.30	−32.3	.242	−32.6	.391	125.1
6000	.643	89.2	.20	−43.7	.242	−38.0	.415	120.8

CGY-40 GaAs MMIC AMPLIFIER



FEATURES
- COST $16.30 ea.
- Pout +17 - +18 dBm 1dB C.P. @ 2304/3456 MHz
  +19.5 dBm SATURATED @ 2304/3456 MHz
- MODERATE GAIN - see table below
- NO TUNING
- G-10 DIELECTRIC MATERIAL
- UNCONDITIONALLY STABLE FROM VHF UP
- NOISE FIGURE UNDER 4dB



PARTS LIST

L1, L2	5 TURNS .075" ID S.W.D. #26 GA.
C1	100 pf CHIP CAP
C2	1000pf CHIP CAP
FT	1000pf FEEDTHRU
Z1	1N752 5.6V ZENER - FOR TRANSIENT PROTECTION

OPERATING PARAMETERS

V mmic = 4.5 V
I mmic = 60 mA

NEG. BIAS CAN BE APPLIED TO INPUT OF MMIC VIA L1 FOR AGC.

GAIN VS. FREQUENCY

FREQ.	GAIN
902 MHz	9.4 dB
1296 MHz	9.3 dB
2304 MHz	7.5 dB
3456 MHz	5.1 dB
4000 MHz	3.7 dB

DEVICE AVAILABLE THROUGH:
MICROWAVE SEMICONDUCTOR CORPORATION
201-469-3311

A. J. WARD
8-17-86

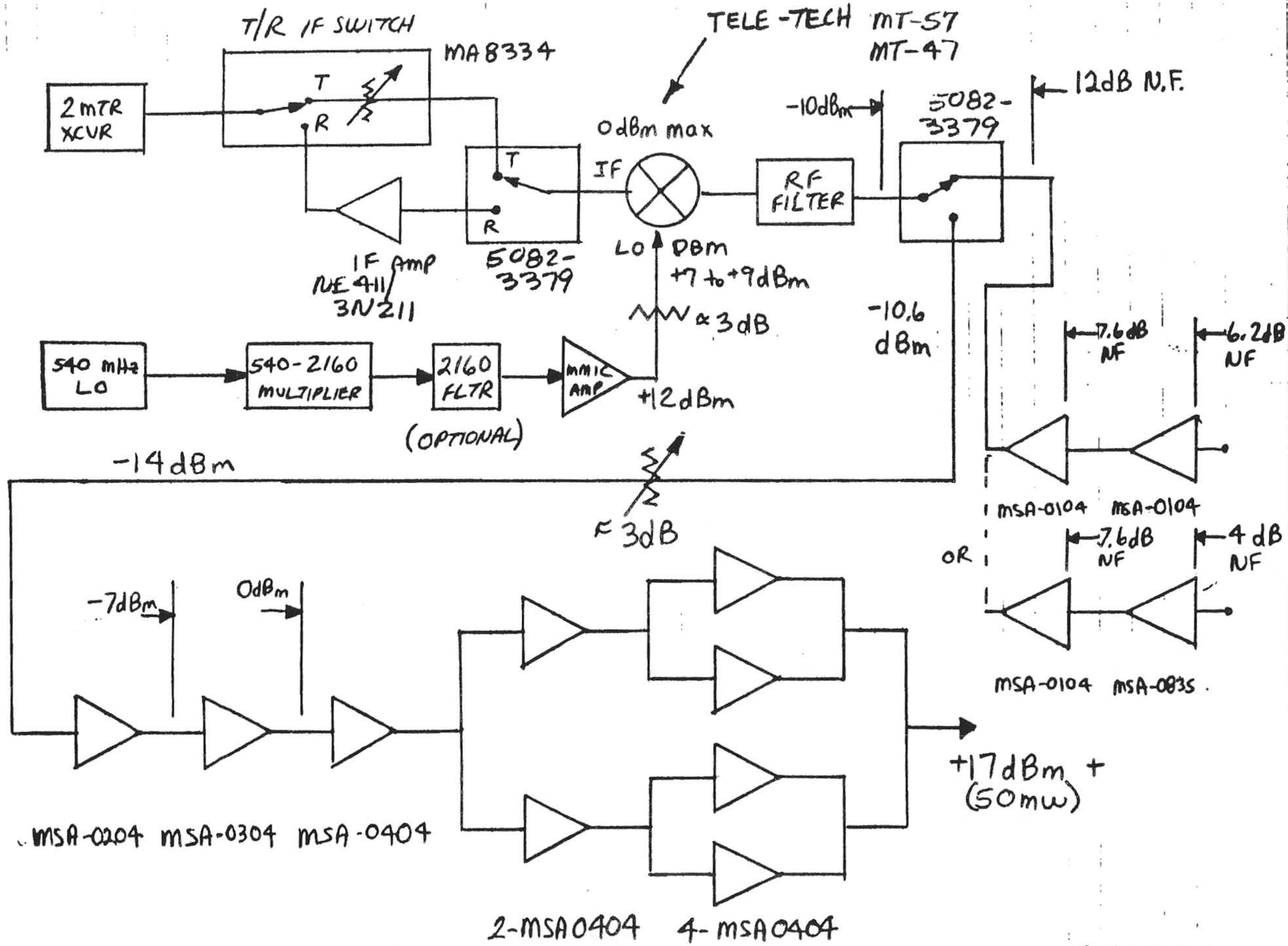
2300 MHz TRANSVERTER DESIGN

BY

AL WARD

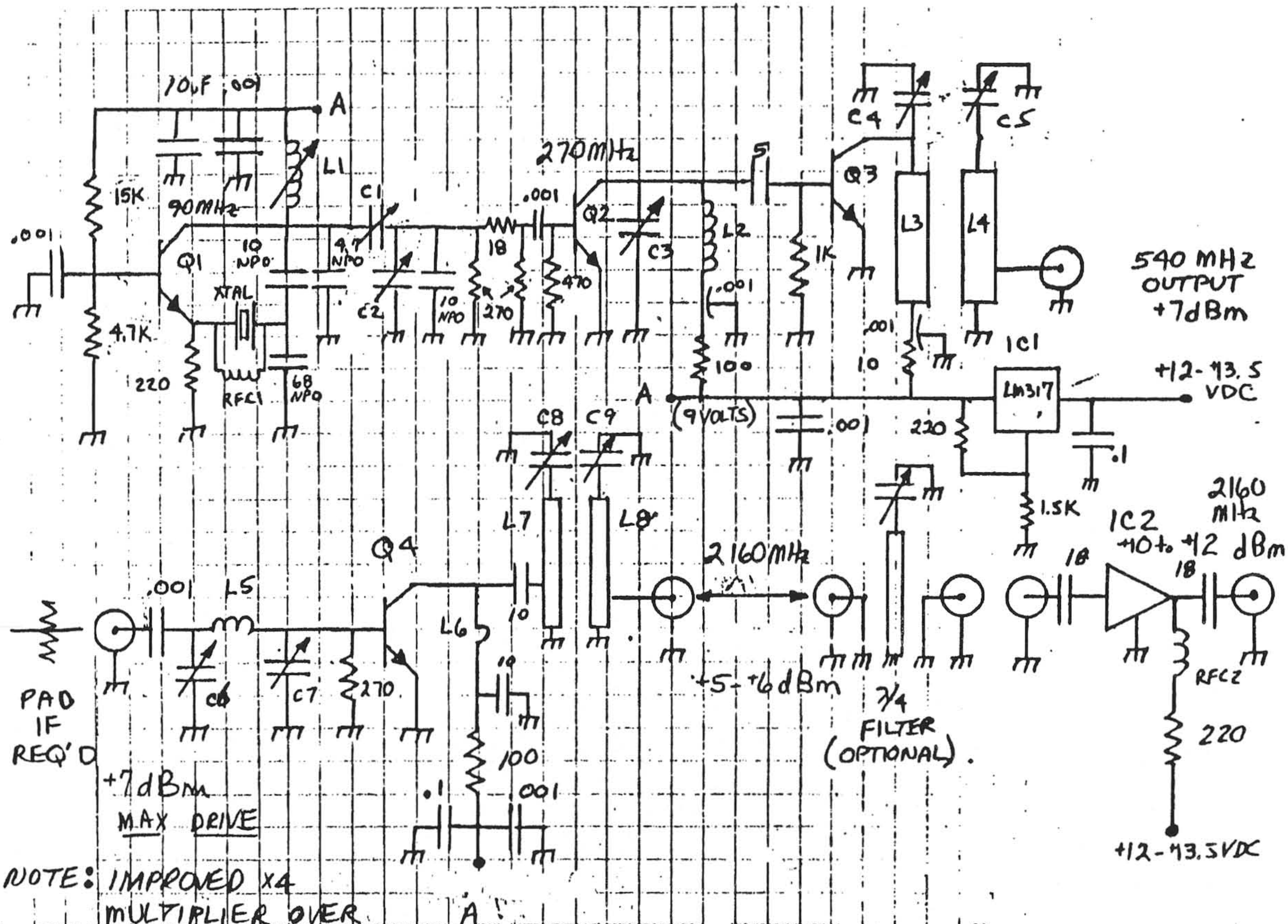
WB5LUA

NOVEMBER 9, 1986



2304 MHz TRANSVERTER

FIGURE 1
WB5LUA

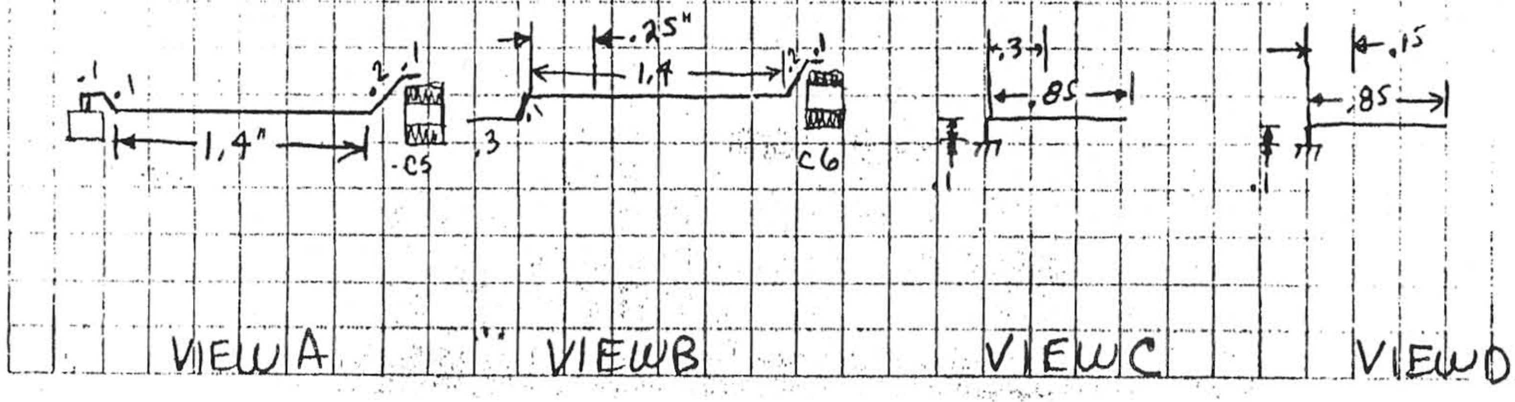


NOTE: IMPROVED X4 MULTIPLIER OVER SEPT 85 VERSION

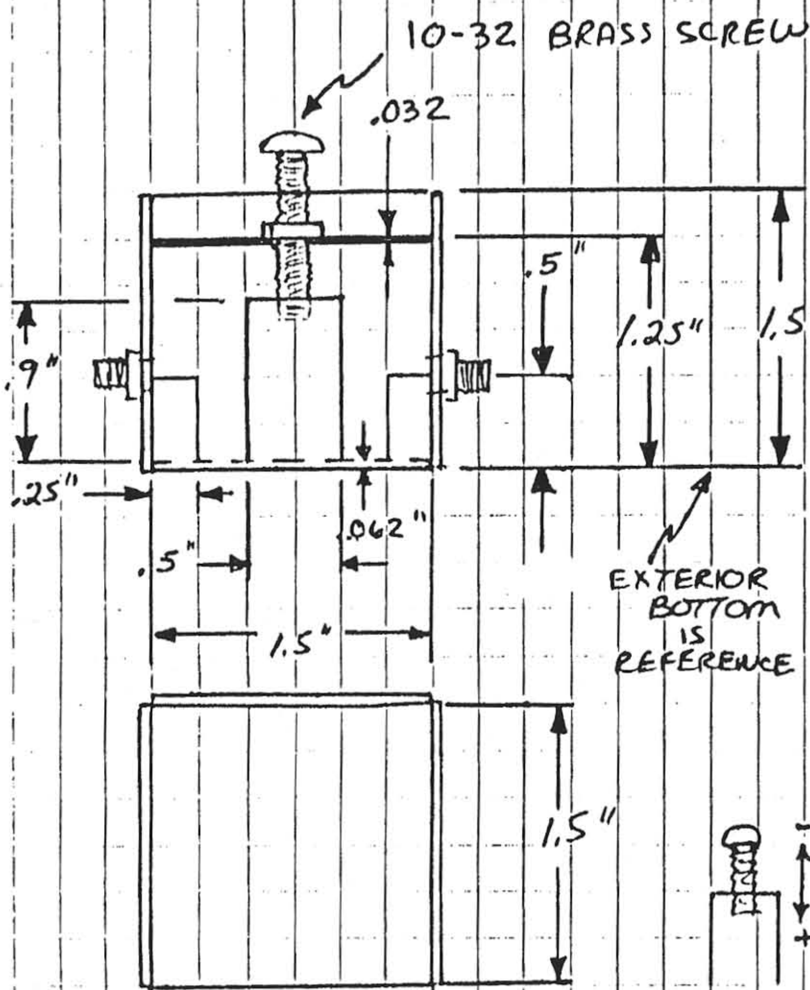
2160 MHz LOCAL OSCILLATOR
FIGURE 2

REVISION B
WB5LUA
7-30-86

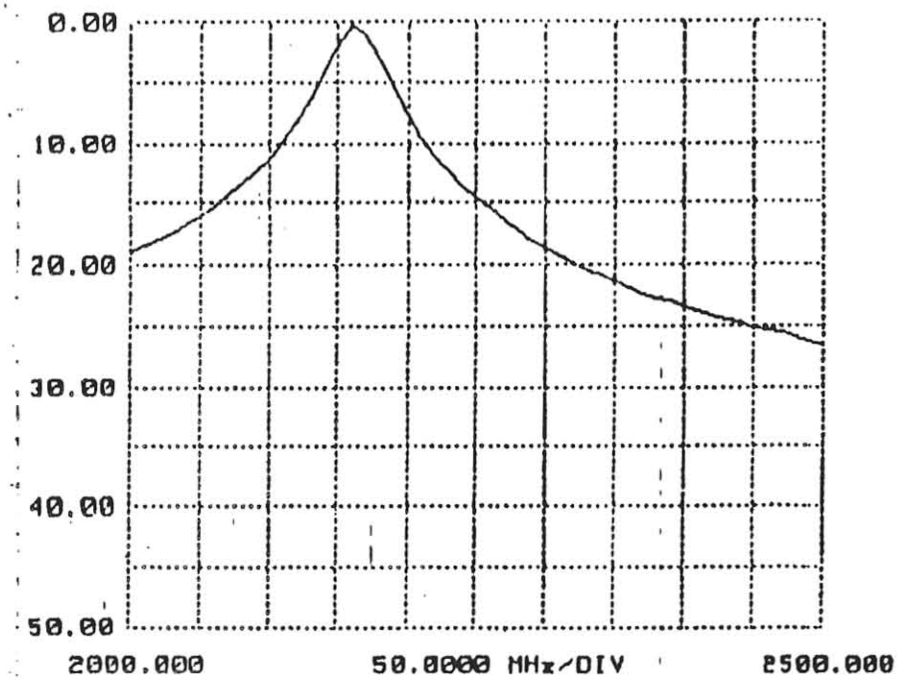
L1	4T #24GA .25" ID COILFORM (W/ SLUG)
L2	3T #24GA .125" I.D. S.W.D.
L3	.5 INCH WIDE MICROSTRIPLINE .125 INCH ABOVE GROUNDPLANE - SEE VIEW A (SPA .1" edge)
L4	.5 INCH WIDE MICROSTRIPLINE .125 INCH ABOVE GROUND PLANE - SEE VIEW B (Tap .25" From Ground edge)
L5	2 TURNS #24GA .125" I.D. SWD
L6	1 TURN .125" I.D. MADE FROM LEAD OF 1/4 WATT 100 OHM RESISTOR
L7	.25 INCH WIDE MICROSTRIPLINE .85 INCH LONG AND .1 INCH ABOVE GROUNDPLANE. TAP CAPACITOR .3 INCH UP FROM GROUND - SEE VIEW C
L8	SAME AS L7, TAP OUTPUT .15 INCH UP FROM GROUND - SEE VIEW D. SPACE L7 AND L8 .1 INCH APART EDGE TO EDGE
IC1	LM317 VOLTAGE REGULATOR
IC2	MSA 0404 AVANTEK MMIC
C1-C5	.8-16pf PISTON TRIMMER
XTAL	90 MHz OVERTONE CRYSTAL
RFC1	.38 uH MINIATURE RF CHOKE
Q1, Q2	2N3563, 2N918
Q3	2N3866
Q4	HXTR 3101 (Hewlett Packard)
C6, C7	1.8-6.0 pf MINIATURE CERAMIC VARIABLE CAPACITOR (MOUSER ELECT. P/N 24AA070
C8, C9	.3-3.0 pf MINIATURE PISTON TRIMMER
RFC2	6 TURNS #28GA .125 INCH ID SWD

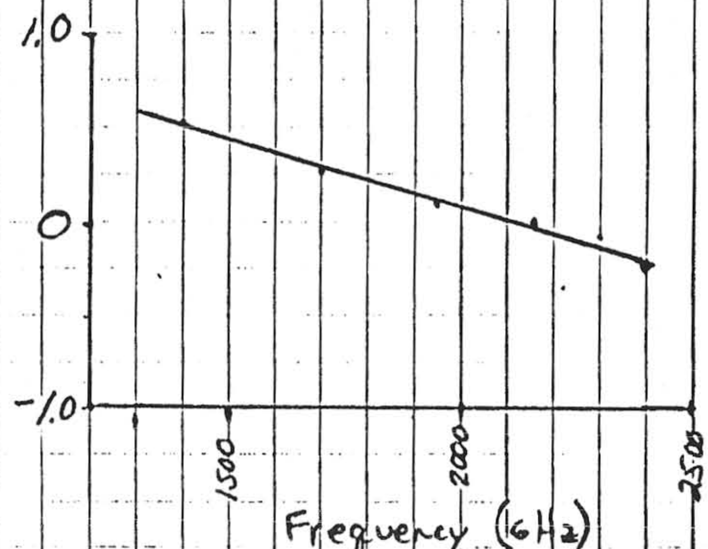


2160 LO
PARTS LIST
REVISION B



2160 MHz CAVITY FILTER
FIGURE 3



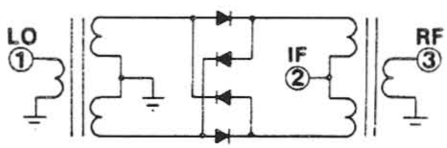


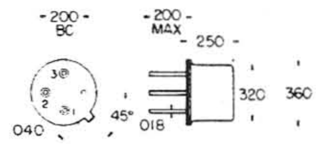
PENETRATION VS. FREQ.

2304 MHz. DOUBLE BALANCE MIXER

- TELETECH MT-57 $26.00 SINGLE QTY'S (HP QUAD DIODE)

  MT-47 $8.00 SINGLE QTYS (NEC QUAD DIODE)
- SPECIFIED AS A BLOCK DOWNCONVERTER DBM
  - RF 900-1400 MHz
  - LO HIGH SIDE INJECTION (UP TO 2GHz.) +7 dBm
- TO-5 PACKAGE





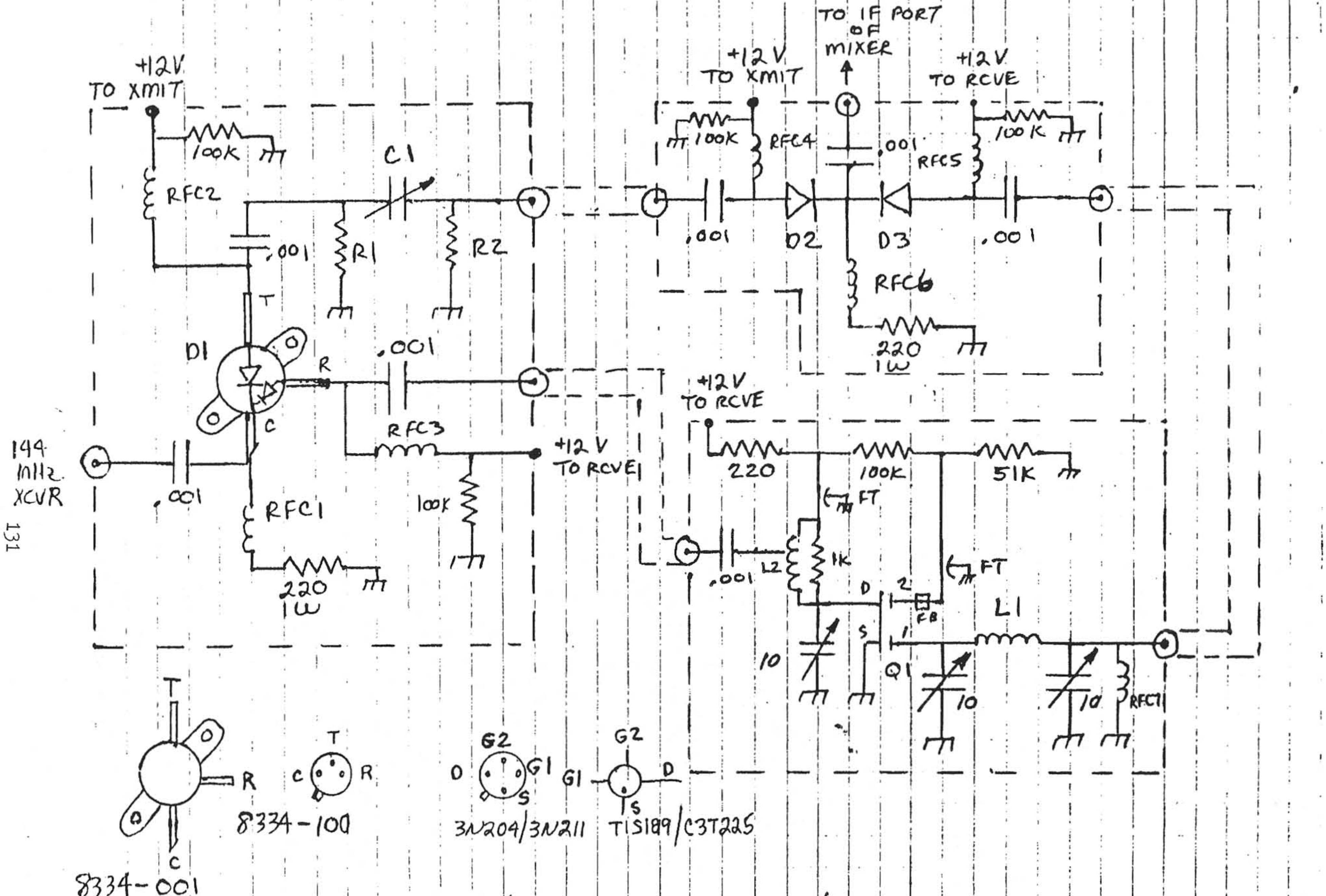
- MEASURED PERFORMANCE
  - RF 2304 MHz
  - LO 2160 MHz @ +6 dBm
  - IF 144 MHz

  CONVERSION LOSS (SSB) ⇒ 9.5 dB
  LO-IF ISOLATION ⇒ 25 dB
  LO-RF ISOLATION ⇒ 22 dB

- MANUFACTURE

  TELETECH
  2050 FAIRWAY DRIVE
  BOX 1827
  BOZEMAN, MT 59715
  (406) 586-0291

AJ WARD
WB5LUA
9-14-85



TRANSMIT /RECEIVE IF SWITCH / IF AMPLIFIER
FIGURE 4

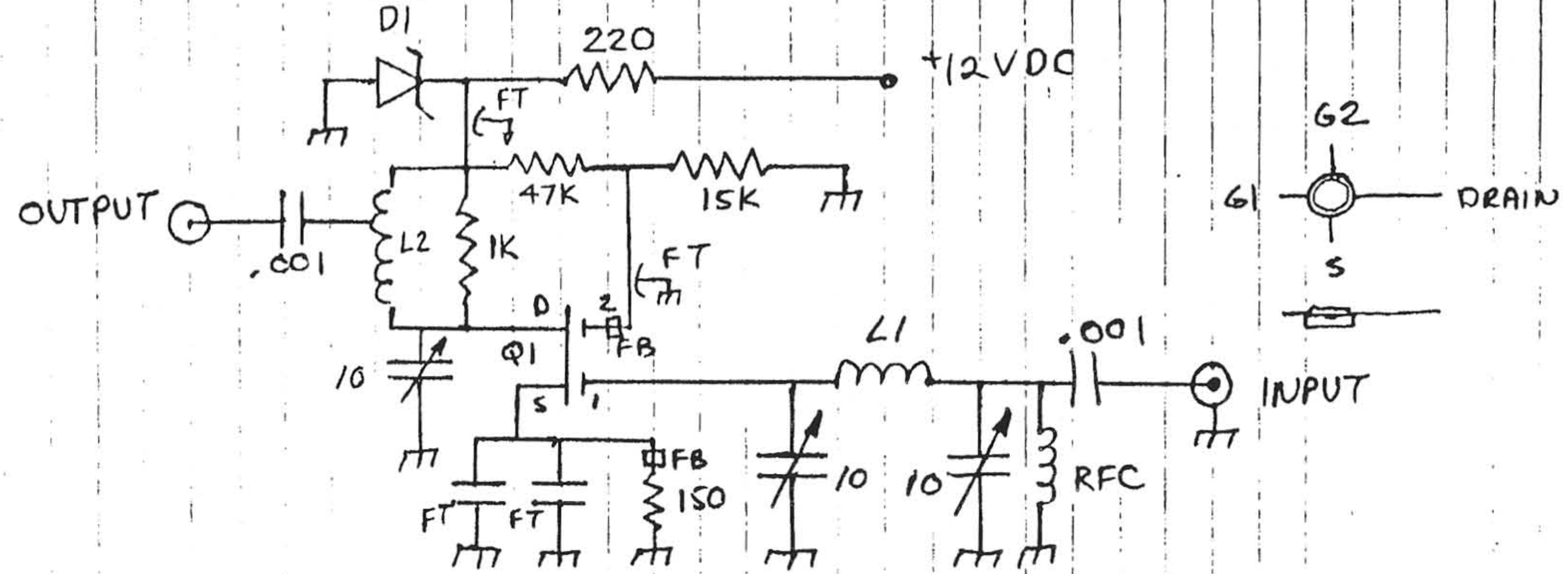
AJWARD
WB5LUA
5-28-85

Q1	TIS189, 3N204, 3N211 DUAL GATE FET	
D1	MA8334 T/R SWITCH SERIES (-100 is 10W version and -001 is 100W)	
D2, D3	MA 47047, 47110, 47123 PIN SWITCHING DIODE or HP 5082-3379	
RFC1-RFC7	1 uH MINIATURE RF CHOKE	
R1	50Ω 10W NONINDUCTIVE RESISTOR	
R2	51Ω 1/2W CARBON RESISTOR	
C1	1-2 pf ADJUST FOR DESIRED DRIVE LEVEL AT DBM	
FB	FERRITE BEAD	
L1	6 TURNS #18 GUAGE .25" I.D. SPACED WIRE DIAMETER	
L2	5 TURNS #18 GUAGE .25" I.D. S.W.D., TAP 1 TURN FROM COLD END	
FT	470-1000 pf FEED THROUGH CAPACITOR	

- UNLESS OTHERWISE SPECIFIED ALL RESISTORS ARE 1/4 WATT CARBON
- UNLESS OTHERWISE SPECIFIED ALL CAPACITORS ARE DIPPED SILVER MICA

T/R IF SWITCH/IF AMPLIFIER

AJWARD
WB5LUA
5-28-85



Q1 NE41137 GaAs DUAL GATE MESFET (CALIFORNIA EASTERN LABORATORIES)
L1 6 TURNS #24 GUAGE WIRE .25" I.D. S.W.D.
L2 5 TURNS #24 GUAGE WIRE .25" I.D. SWD TAPPED 1 TURN FROM COLD END.
D1 IN752 ZENER DIODE (5.6 VOLT)
FT 470-1000 pf FEED THROUGH / BYPASS CAPACITOR
FB FERRITE BEAD
RFC 1uH MINIATURE RF CHOKE

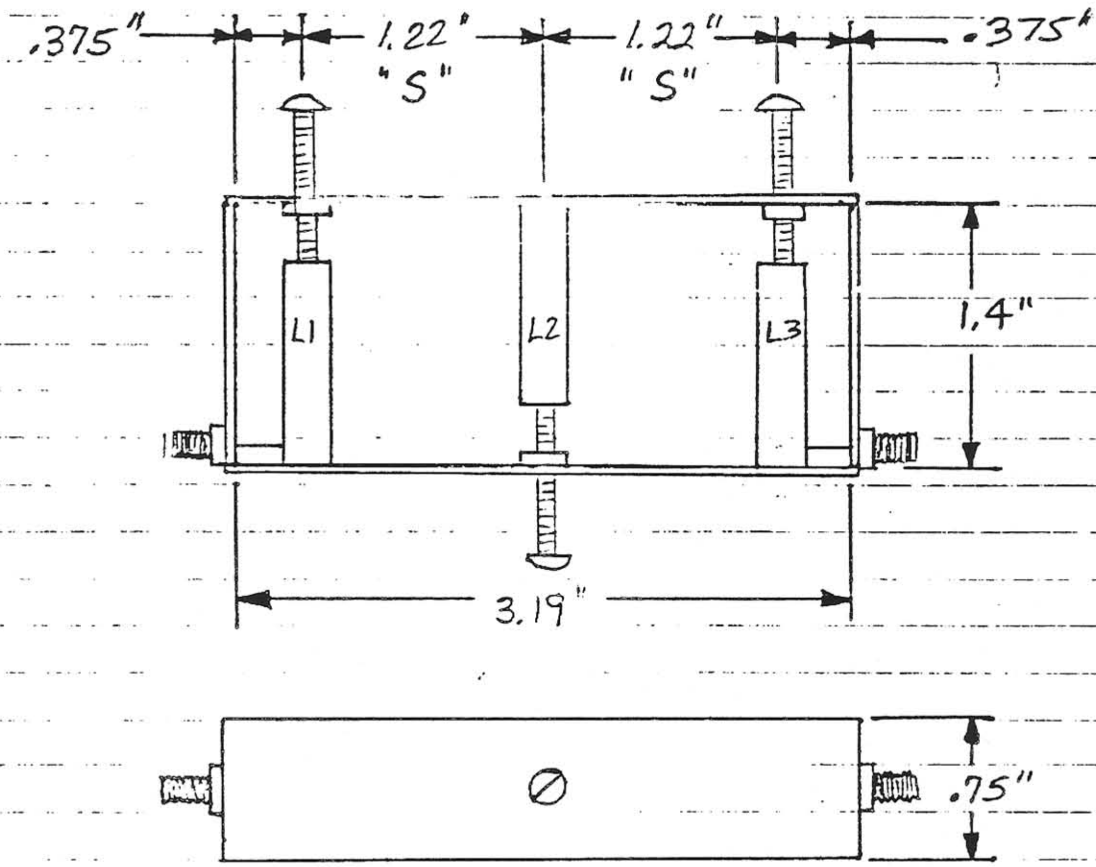
ALL RESISTORS ARE 1/4 WATT CARBON
ALL CAPACITORS ARE DISC OR S.M UNLESS OTHER WISE SPECIFIED

NF = .5 - 1.0 dB $V_{DS} \approx 4V$ $V_{G2S} \approx .5V$
G = 24 dB TYP $I_D \approx 6\text{-}10mA$

NE411 I.F. AMPLIFIER
FIGURE 5

WB5LUA
A J WARD
5-28-85 6

2304 MHz. INTERDIGITAL FILTER

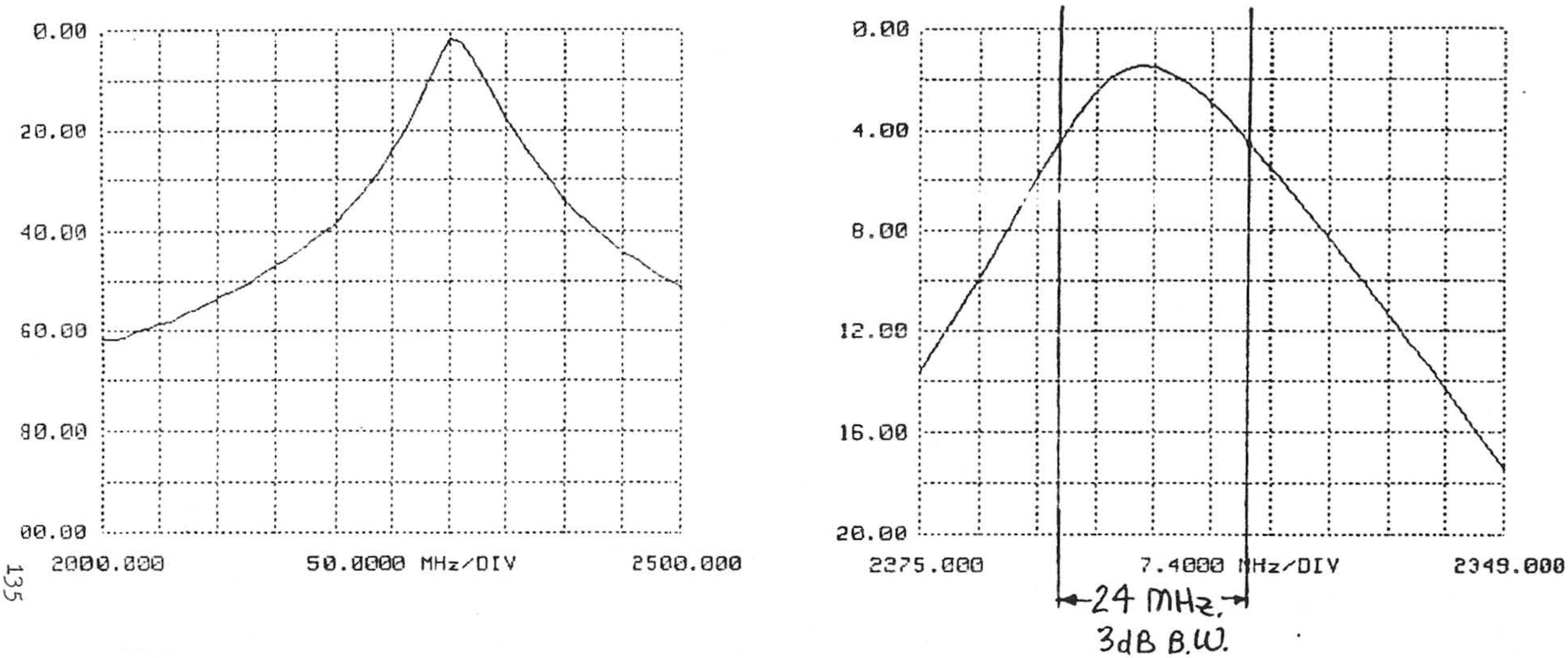


L1, L3 .25" DIA BY 1.1" LONG, TAPPED AT .070" FROM SHORTED END.

L2 .25" DIA BY 1.08" LONG.

- TUNING SCREWS ARE 4-40 BRASS WITH NUTS SOLDERED TO INSIDE WALL.
- BOX MADE FROM .062" G-10 - ALL DIMENSIONS ARE INSIDE BOX MEASUREMENTS.
- DESIGN PARAMETERS OBTAINED FROM COMPUTER PROGRAM WRITTEN BY JERRY HINSHAW, N6JH AND FEATURED IN "HAM RADIO MAGAZINE" JANUARY 1985

A.J. WARD
WB5LUA
9-15-85

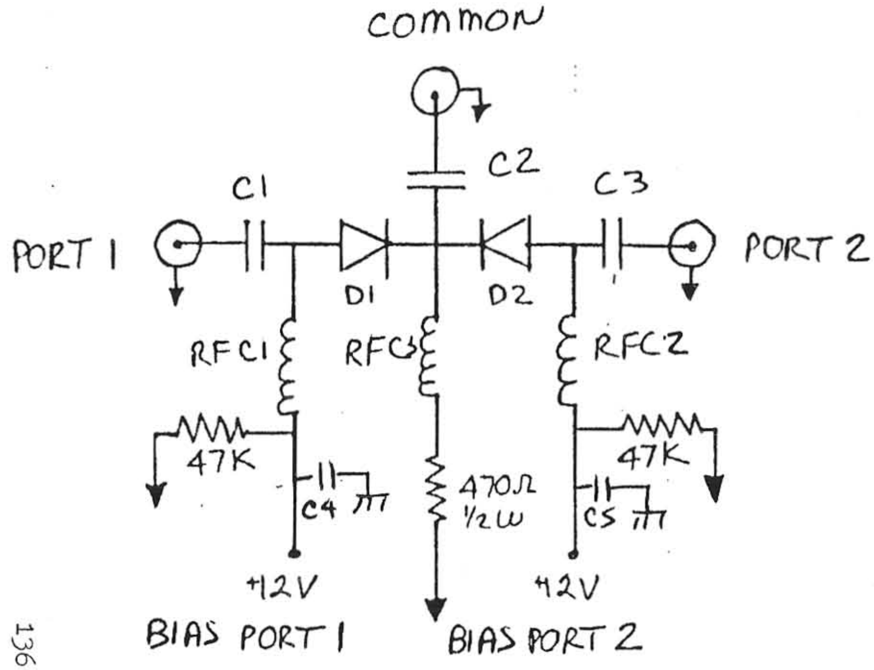


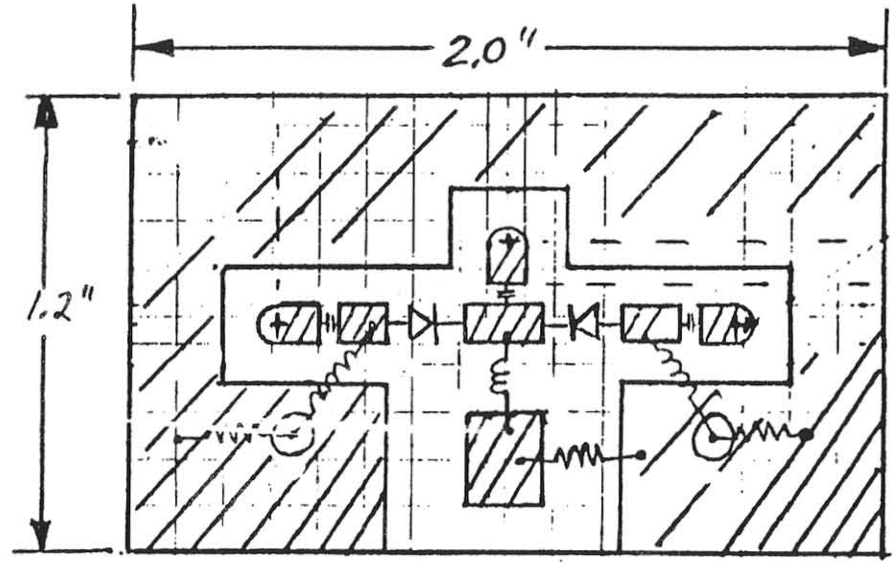
SWEPT RESPONSE OF 2304 MHz BAND PASS FILTER

LOSS 1.5dB @ F_o for 3dB BW of 24MHz
61.0dB @ 2016 MHz (IMAGE WHEN USING 144MHz IF)
45.0dB @ 2160 MHz (LO)
.5dB @ F_o when adjusted for MIN. LOSS.

FIGURE 7

WE UA





COMPONENT LAYOUT

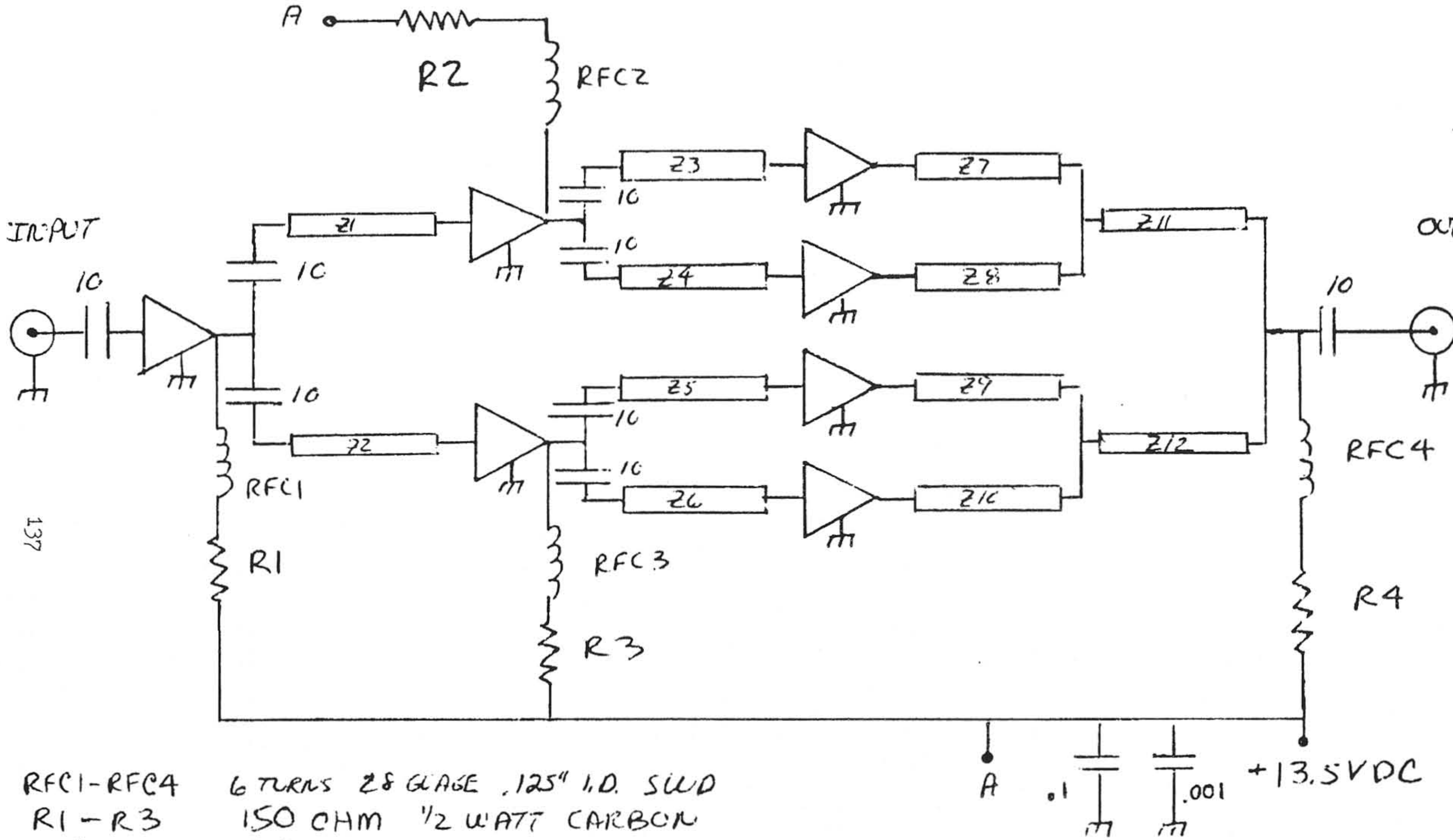
C1, C2, C3	22 pf CHIP CAP
C4, C5	22-100 pf CHIP CAP. OR F.T.
RFC1, RFC2, RFC3	4 TURNS #28 GA. 1/8" I.D. S.W.D
D1, D2	HP 5082-3379

50 OHM LINEWIDTHS ARE .1 IN. WIDE. DRAWING IS 2X. DIMENSIONS ARE 1X. SLASHED AREA IS COPPER.

2304 MHz RF SWITCH

WB5LUA

FIGURE 8

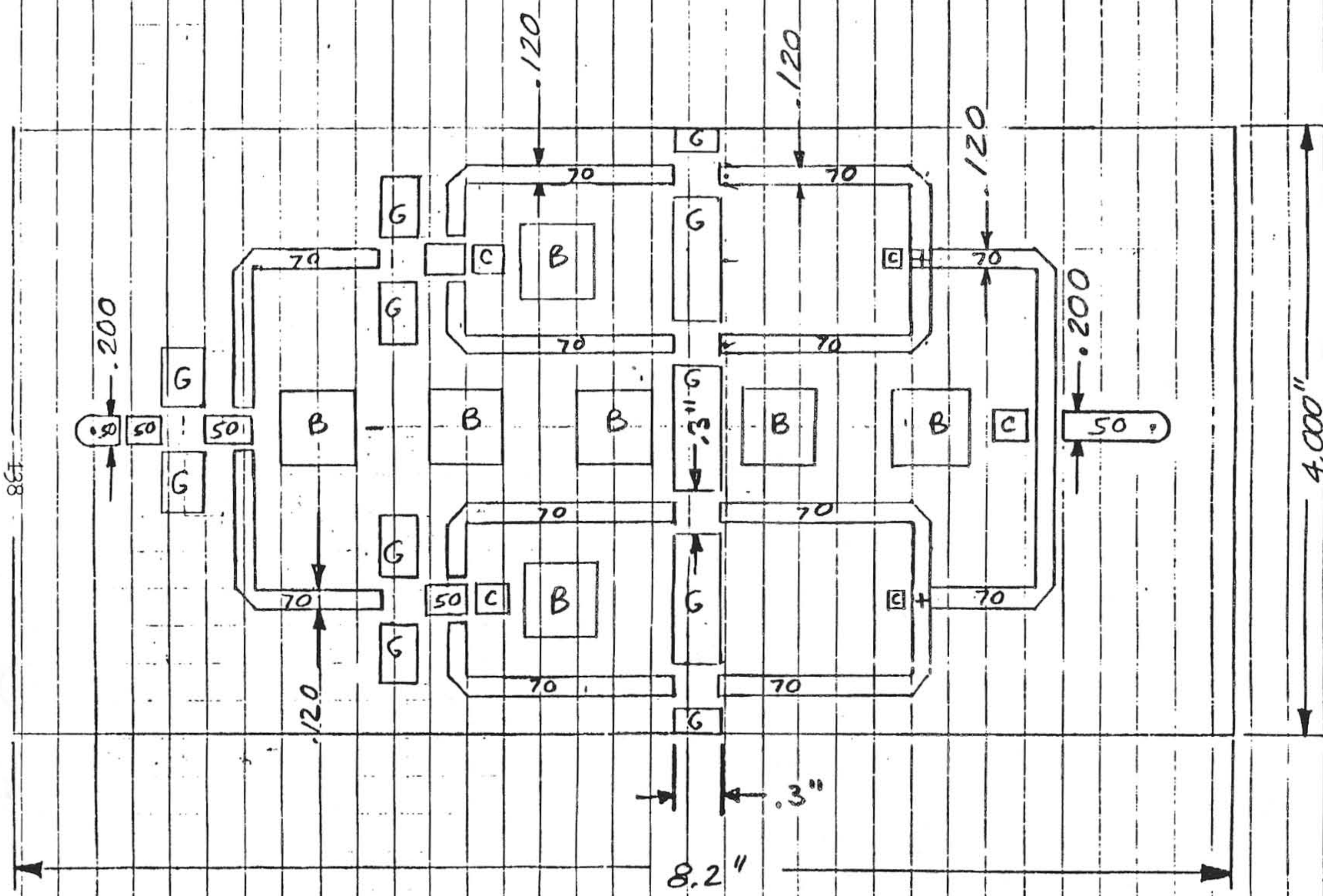


RFC1-RFC4	6 TURNS 28 GUAGE .125" I.D. SWD
R1-R3	150 OHM 1/2 WATT CARBON
R4	30 OHM 2 WATT MIN. CARBON
	CONSISTS OF 5-150 OHM 1/2 WATT CARBON RES. IN PARALLEL

SCHEMATIC
2.3 GHz MSA-0404 MMIC AMPLIFIER

FIGURE9

WB5LUA



PRINTED CIRCUIT BOARD LAYOUT
FIGURE 10

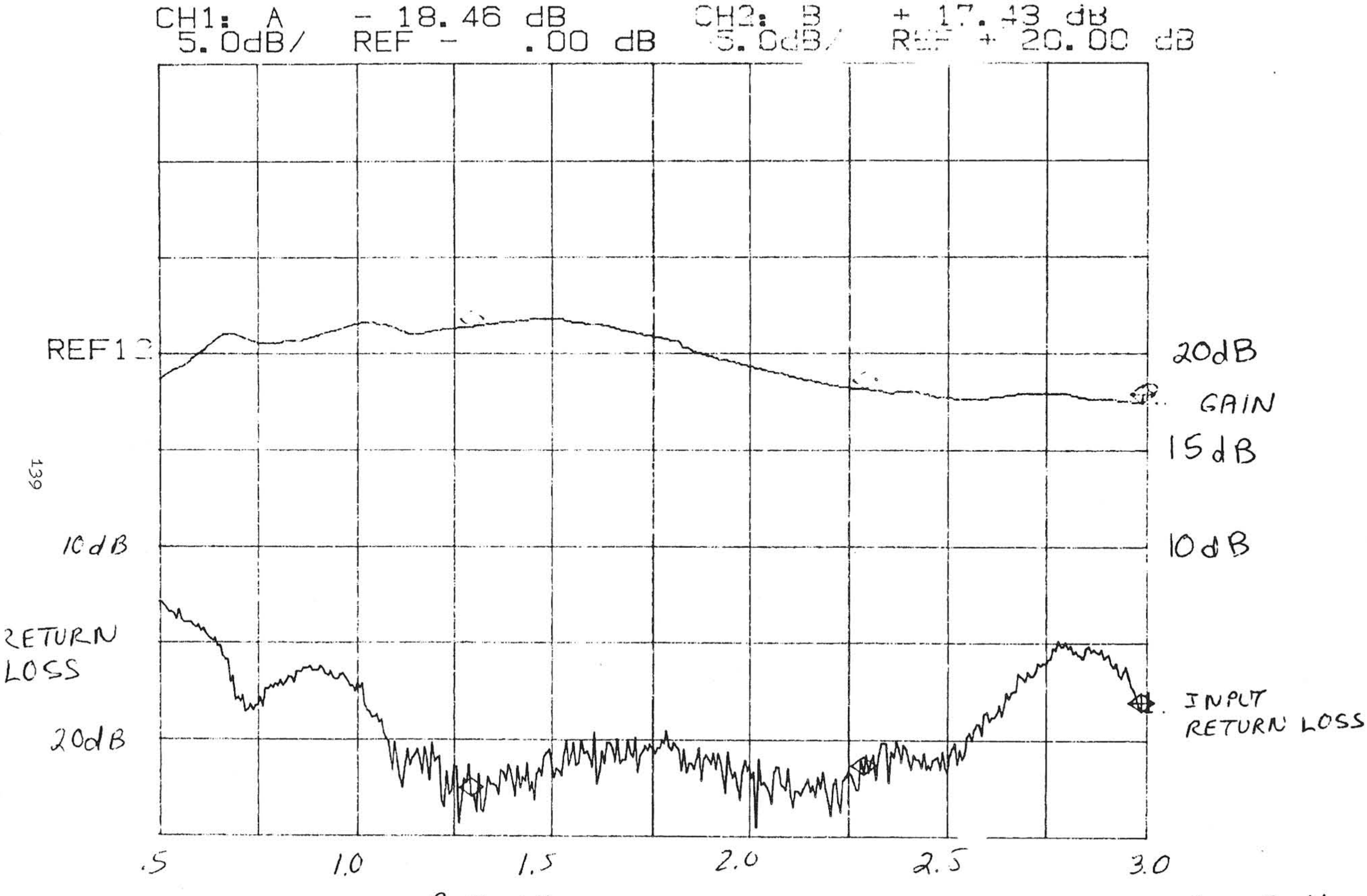


FIGURE 11
WB5LUA

W3IWI
JAS-1 PSK MODEM
OCT. 86

The following is a collection of notes to / from W3IWI concerning PSK modem developments. These have been circulated on AMSAT TeleMail, DRNET, and on many packet radio bulletin boards.

W3IWI FILE PSK.ANN

PSK MODEMS FOR FO-12

This is a brief report on FO-12 PSK modem progress. The TAPRites (NØADI, WA7GXD, & W3IWI) have been working on an adaptation of the JARL / JAMSAT PSK demodulator described in August 1986 QEX. (The QEX article only covers the 'dem' part of the required modem).

Our plan is for TAPR to make this design available as a reproducible package -- it has not yet been decided whether this will be a full kit or a semi-kit; if it is the latter, then all parts not supplied will be available from Radio Shack, JAMECO, or similar suppliers.

>>> Details will be announced just as soon as they are decided.<<<
>>> Please don't bug us about availability yet! <<<

There are several differences (all additions) from the QEX design. The modem is designed to work with a TNC1 (including Heath HD4040 and AEA PK-1) or TNC2 (including MFJ, Paccomm, AEA PK-80 & GLB TNC2 clones) and connects thru the 20-pin 'modem disconnect' header plus the normal radio I/O jack. The modem has an IN/OUT switch so that you can change between FO-12 and normal terrestrial operation without swapping any cables. If you try to use this design with another type of TNC, you will have to insure that you have access to the RX data input to the TNC at TTL level bypassing the normal FSK demod. You will also have to provide the 'raw' TTL level TX data and TX clock (either 16x or 32x baud rate) and you should also provide a 'carrier detect' input to the TNC (active low) so that the TNC will know when the modem is locked up.

The modem has been designed with digital AFC to interface to any of the more modern all-mode radios. This involves having the radio make 10 Hz (e.g. with TS811) or 20 Hz (e.g. with FT726) steps using the inputs that allow to to step up/down from buttons on the microphone.

Our design includes two modulators: Manchester FSK as required for the FO-12 FM uplink and 1200 baud PSK. The PSK modulator has been included for two reasons -- it lets you run loop-back tests with the PSK demod, and more importantly it allows amateur experimentation with PSK packets. PSK should be 10-20 dB superior to the 'Bell 202' AFSK-FM in common use on VHF. The composite PSK signal generated by the modulator is your normal digital data exclusive-or'd with an audio carrier in the 1400 to 1800 Hz range (exact frequency chosen to match your SSB radio's filters).

The design also includes LED 'bar graph' indicators for both received signal level and tuning. The interface to the uplink radio are the normal TX audio and PTT lines. Your transmitter must operate in FM for the Manchester FSK FO-12 uplink or SSB for PSK use. On the receive side, your SSB receiver supplies RX audio to the demodulator, and preferably should support digital frequency stepping for the AFC circuit described earlier.

Here at W3IWI, I now have a full functional prototype running. I want to thank Tak Okamoto (JA2PKI) for providing me with a JA-land circuit board which made my life a lot easier! I have been running local loopback tests and am convinced that the basic design is sound. 'Eye-patterns' on the PSK demod show that data filters are nearly optimal, and lock-up time is quite acceptable.

The next step in my testing will involve cramming 1200 baud PSK thru ordinary commercial radios to characterize their performance. I have some concern about the filters in commonly used radios since I found a couple of years ago that a stock FT726 was unsuitable for 1200 baud FSK work. Initial testing will be done on the Kenwood TS711 / 811 pair and an FT726. If someone want to loan an IC-271 / IC471 pair we will gladly test them too. I am very anxious to find some other packeteer within 150 miles who has an FO-12 modem running so that I can make real 'on-the-air' tests.

The other 'next step' is to finalize the circuit board layout and test that implementation. We will keep you posted as this work proceeds.

73 de Tom, W3IWI
10 October 1986

W3IWI FILE PSK.001

Just a brief update on the FO-12 PSK modem activity here at W3IWI. As I reported earlier I have been working on the prototype TAPR unit, and the demod portion is virtually identical to that published in the August issue of QEX.

(1) An annoying problem of RFI susceptability that caused the TNC2 to 'croak' spontaneously has been fixed by better shielding. The problem was pickup on the ribbon cable connecting the TNC2 'modem disconnect' header to the PSK modem.

(2) We have been running local loop-back tests involving FT726 (on 2M or 70cm) and TS711 / 811 radios. A few pieces of good news (in the following remember that it makes no difference if you use USB or LSB on either end of the link. The NRZI encoding in packet data involves only data transitions and does not depend on the absolute polarity of the data):

a). The digital AFC works fine on the 711 / 811 radios. There is no tendency to drop lock or data when stepping. This is very good news since I was concerned about phase discontinuities when stepping. It is a real ball to crank the xmtr to simulate doppler and watch the receiver follow it. The 811, with its 10 Hz steps seems very well suited to use on PSK.

b). The bandpass filters in the TS811 seem quite good for 1200 baud PSK. No assymetry can be found and eye patterns look equally good running the radio on USB or LSB.

c). My FT726 was modified a couple of years ago when we found that a stock 726 had bad group delay distortion on 1200 baud FSK packets. The mod involved putting in a different ceramic filter, but even with that filter the delay distortion was pretty bad if the radio was on USB, but acceptable on LSB. The old finding on FSK seem to be borne out on PSK -- performance on LSB is superior to USB on my unit.

d). Haven't tried other common radios yet. If anyone would like to offer a truly 'stock' FT726 or an IC271 / 471 for the 'Consumers Report' activities, please let me know. Either 2M or 70 cm is OK.

(3) It isn't easy to calibrate weak signal performance of these modems. The scheme which I have been using for evaluation is to compare the Noise voltage (sans data) with the signal+noise voltage at the output of the coherent detector when the signal is very weak. With a (S+N)/N voltage ratio just over 3 (i.e. S+N/N = 9-10 dB) I see a Bit Error Rate (BER) of better than 1:10e-3.

The eye patterns indicate that the data filter we are using is close to optimum for the 1200 baud rate (filters throughout demod are 2nd order with cutoff at 900 Hz). The inference is that we are within a couple of dB of the theoretical optimum performance for coherent PSK with the QEX design. A more detailed assessment of these parameters will require considerably more accurate testing procedures.

(4) Demod lockup performance seems quite good. I am able to send normal on / off packets thru the unit with a TXD parameter on a TNC2 of 50 (i.e. 1/2 second) even when signals are weak after the signal has been been tuned to the center of the demod passband by the digital AFC. However this did require two minor modifications to the QEX circuit to prevent the PLL error integrator (U3a) from running away. First, I replaced U3 with a low offset quad op amp chip (I used a TLC274 Quad CMOS part, Radio Shack #276-1750). Then I found it desirable to add DC stability by shunting the integrator (use the W1 jumper) with a 30-50 Meg resistor.

(5) The QEX article did not describe the Manchester modulator needed. To see what is required, you might read the article by Lyle Johnson (WA7GXD) on page 10 of the September issue of Packet Radio Magazine. The design we are working on allows both PSK and Manchester FSK. If you refer to the schematic on page 11 of Lyle's article, To generate PSK you disconnect the upper input to the XOR gate (labelled '2') and feed in a 1600 Hz square-wave signal (we use a NE555 at 3200 Hz and a divider to insure a 50% duty cycle).

(6) Here in the Balto / Wash area I have a FO-12 simulator beacon on the air, just waiting for somebody else to get a demod working. This weekend it has been on 145.800 sending a PSK 'BRAAAAAP' every minute. A couple of the locals have been putting together PSK modulators so that they can send me signals from outside the shack, but we have no success to report yet. For this testing W3IWI is QRV on either 2M or 70cm.

(7) For those of you who will be in Dallas for the AMSAT Annual Meeting on Nov.8th, you can see this hardware working. I plan to set up a full working one-way demo, complete with a show 'n tell on the digital AFC, eye-pattern measurements, etc. Thanks to the program chairman, N5BRG for adding this presentation at the last minute and helping to scrounge some of the items we will need for the demo.

If anybody else has a PSK modem working by then, bring it along and we can give a full demo. I have been offered the loan of a set of the G3RUH modem boards, and with some luck we might have them there too. I am most anxious to compare the two designs.

More on the project as it proceeds -- 73 de Tom, W3IWI
14 October 1986

W3IWI FILE PSK.002

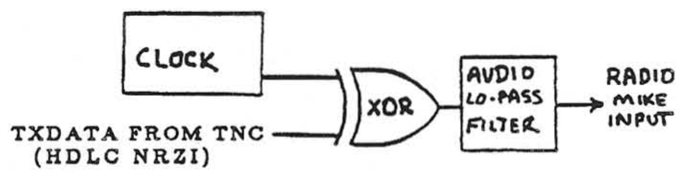
Here are some more comments about the PSK modem activity. James Miller, G3RUH posted a note that seemed to indicate that he was a bit miffed that I was describing 'blow by blow' the activity here. If I offended James, then I offer my most sincere apologies. Let me stress again -- James' modem is available NOW and represents the only set of boards that you can purchase today. The other two options that are available to you today are to build the JARL / JAMSAT modem described in the August QEX, or to make the modifications to the G3RUH Phase-3 modem [available from Radiokit in the US] as described by the VK folks. There have also been a limited number of boards of the JARL / JAMSAT / QEX design that were made in Japan and offered by JA2NYK [all of my testing to date has been on a JA2NYK board hand delivered to me by JA2PKI in August].

TAPR is working on an adaptation / enhancement of the JARL / JAMSAT / QEX design (for which I currently have the only working prototype) but there will be snow on the ground before it is available. If the collective wisdom of satellite users is that the designs now available meet all your requirements, then tell me quickly so that we can abort the TAPR effort. If you want something NOW then exercise one of the options in the previous paragraph.

If you don't want to see the 'blow by blow' account of what is being done, then let me know ASAP --- preparing these reports takes a fair amount of time for me. The reasons for putting out these reports is that TAPR and AMSAT have both been accused of working in a vaccuum, so that other interested parties were excluded from participating. I had hoped that these reports would help get some adrenalin flowing.

So far I have not done any side-by-side tests of the G3RUH vs. JARL / JAMSAT / QEX design. I was offered the loan of a G3RUH board, but so far it has not arrived. I have reviewed the schematic of the 'RUH design as published in OSCAR NEWS. James' design is much simpler and involves less as many ICs as the design we are working on. The design published in QEX uses a Costas loop which involves a lot of analog signal processing. The G3RUH design immediately converts the signal from analog to digital before entering the PLL (which runs at 2x the audio 'IF' frequency). Around 1944, Van Vleck showed that the S/N loss for using an infinitely clipped representation of a stationary, zero-mean noisy signal in a correlation process is (pi/2) or approximately 2dB. Since the BER vs. S/N measurements are tough to make, it would be very illuminating to compare actual performance of the two designs with identical input signals.

James also took me to task for a certain imprecisness in my discussion of the modulator side. He pointed out quite correctly that PSK and Manchester were the same thing. I had reasons for making the distinction which may also serve to educate you on the modulation processes. First let us look at a generic block diagram of the modulators in use:



Your uplink to the FO-12 spacecraft requires three things from you:
(1) Your xmtr must operate on FM, and
(2) the clock in the above block diagram must be 1200 Hz, and
(3) the 1200 Hz clock must be synchronized with the TXDATA bits.

The G3RUH modem and the mode I had been calling 'Manchester' are designed to meet all three criteria.

On the other hand, if you want to generate signals like the spacecraft downlink, then the requirement is that you need to generate a carrier whose phase can be inverted depending on the polarity of the TXDATA. Since a tone passing thru an SSB radio generates a carrier, then it is only necessary to apply a phase shift to the tone which can again be accomplished by the circuit above. However in this case, the composite data you generate must be well matched to the bandpass filters in the SSB radio.

Experience with both AO-10 PSK uplinks and on the bench with the modem I have been evaluating shows that a typical SSB radio wants the pilot tone to be around 1600 Hz. Further, it makes absolutely no difference if it is synchronous with the data; it only needs to exhibit good phase stability. Thus in our design we offer the user the choice of either the locked 1200 Hz clock derived from the TNC's TXCLOCK signal (the mode we call 'Manchester' since that is what the builders of FO-12 called it), or a second stable, free-running VFO at about 1600 Hz (the mode we call PSK since that is how it is to be used) for simulating the downlink or for terrestrial weak-signal packet experimentation. The latter is implemented using an NE555 running at 3200 +/- 400 Hz and a divide-by-2 flip-flop to insure a 50% duty cycle clock.

James reported that his on-the-air PSK tests thru the FO-12 used his 1200 Hz 'Manchester' modulator thru his SSB radio. When I have tested that scheme here I have found that performance is severely degraded since stock radios simply do not properly pass the PSK data thru their stock SSB filters. Perhaps James has been lucky in that his FT-726 may have different filters than mine. I would suggest that he would achieve better performance in the 'PSK' mode if he were to raise the tone frequency.

Whilst commenting on this need for centering the PSK data in the passband, let me make a couple of additional comments. I see from James' OSCAR NEWS article that he centers the receive data at 1500 Hz in the passband. Part of the optimization necessary to match your modem to your radio is to fine-tune this center frequency -- I have tended to come out closer to 1600 Hz every time I have tried this with the TS811 whether I receive on USB or LSB. With PSK data (plus NRZI encoding) it makes no difference if you use USB or LSB providing the receiver's filters are symmetric.

On the FT-726 I have here, I find the results more spotty. I note differences on USB vs. LSB which indicate that the receiver's filter is assymetric. When transmitting thru a 726, you use the receiver's filter when you are in the 'normal' (single-band) mode, but the transmitter uses a separate set of filters in the SAT (split-band) mode. Of the 4 possibilities (USB vs. LSB, normal vs. SAT) on xmit, no two are similar in the required equalization on my radio.

Now let me discuss the FM 'Manchester' uplink mode. In my local tests, I have seen that it is rather critical to set the xmit audio level correctly. 2-3 kHz deviation is all you need.

>> It is very easy to over-deviate! Don't do it. <<

If you listen on a separate FM radio while you transmit and bring the audio gain up from zero, the recovered audio will get louder for a while, and then decrease as you pass thru the first null of the Bessel function, and then increase again. Under no circumstances should you set the audio level past the first maximum! If you go too high, the signal becomes so distorted that it cannot be correctly demodulated (also shown by the eye-patterns). In planning for the SAREX2 mission, I made a number of similar tests on the AFSK-FM signals which indicated that a typical FM receiver was much more tolerant of frequency errors if the deviation was kept below about 3 kHz and recommended that people crank their TX audio gain down to have less problem with uplink doppler shift. I would suggest that the same advice applies on the FO-12 FM uplink.

Finally - congratulations to James for sending PSK signals thru FO-12. So far I have not had the time to try such tests here and have been content to do bench testing. I know that our colleagues in JA-land have been exercising their PSK hardware during the limited FO-12 digital tests while the satellite is in view of the JARL telecommand station. I wonder if anybody else is actually on the air yet?

73 de Tom, W3IWI
26 October 1986

W3IWI FILE PSK.003

Posted: Mon Oct 27, 1986 10:53 AM GMT
From: MSWEETING
To: TCLARK/AMSAT1
Subj: ON PSK and FO-12 Modem

Dumped on 27 Oct 86 02:44:28 Monday by ELE093

From: JAMES MILLER G3RUH via MSWEETING
Date: 1986 Oct 26 @ 22:00
Subj: PSK and FO-12 etc

Tom Clark says that "preparing these reports takes a fair amount of time", which must rate as one of the understatements of the year. I also spend more than a fair amount of time scribbling for what sometimes seems like little reward, and appreciate his feelings! [This memo has taken 3.5 hours]

Through his recent notes he is (among other things) providing a valuable "education service" in matters PSK, a subject which is not yet as common knowledge as FSK or SSB.

Below are some notes to augment the debate. First a couple of comments on Tom's comments. After that a bit called "The Theory" about PSK demodulation, and requirements in respect of JAS-1/FO-12 as brief as I could make it. Finally "The Practice" lets it all hang out.

TRANSMITTING PSK
I agree with everything Tom has written about transmitting PSK through typical transceivers. The only justification I make for using a "carrier" of 1200 Hz at the Mic input is that it works - just. It works a LOT better if you experiment to find the best for your particular equipment, and 1500-1700 Hz is likely to be optimum. You MUST use a stable oscillator, i.e. particularly one that doesn't wobble when there is lots of RF about. One day perhaps YAESU/ICOM/KENWOOD etc will provide another bell and whistle on their boxes, labelled PSK!

RECEIVE AUDIO CARRIER FREQUENCY
On the receive side, I expect users to experiment and find out the optimum audio frequency for their set-up. There is nothing sacrosanct about the 1500 Hz on my modem drawing. In fact with the FT726, on OSCAR-10 telemetry I often use(d) RX bandwidth and Shift controls fully anticlockwise, for which 2200 Hz is best!

PSK - THE THEORY

PSK DEMODULATION. Demodulating a Phase modulated signal calls (in principle) for two things; a phase reference signal, and a phase detector where the input signal is compared with that reference.

Sometimes the implementation of these requirements lead to a circuit in which its hard to spot that they are separate requirements - but they are.

PHASE REFERENCE. This has to be extracted from the input signal, and is usually called "carrier recovery". There are two common circuits which do this, the "Costas Loop" and the "Squaring Loop"; there are also hybrids. For practical purposes their performance is the same.

PHASE DETECTOR. Its function is to compare the local recovered carrier phase with the incoming signal's phase, and output some measure of their difference. There are quite a number of ways of implementing this function, and the choice has to be based on diverse criteria such as outright performance on the one hand, and say economy on the other.

Three typical kinds can be instanced, in descending order of circuit complexity; the analogue multiplier, the modulus or commutator, and the digital EXOR gate. The spread in signal processing performance of these is about 2 db; in complexity as much as 10:1

FO-12 MODE JD DOWNLINK LIKELY SNR. Assume the following. Satellite TX power 1 watt eirp, range 4600 km, f = 435 MHz, RX antenna gain 18 db, RX noise temperature 1000K, RX bandwidth 2400 Hz.

These figures give a probable received SNR of 24.3 db. For the satellite overhead (R=1500 km), the SNR rises to 34 db. there will be fluctuations due to tumbling.

REQUIRED SNR based on BIT ERROR RATE. Assume packets of 1000 bits, and repeats of 1 in 10 packets. Then the Bit Error Rate needs to be no worse than 1 in 10000. This requires a theoretical E/No (energy/bit to Noise power/Hz) of 9 db.

Allow 3 db decoding loss (no receiver/decoder is ever perfect), this E/No need rises to 12 db, or 16:1. Given the bit rate of 1200 bits/sec, and a RX bandwidth of 2400 Hz (say), the channel SNR needs to be better than 16*1200/2400 = 8:1 in power (3:1 in voltage), i.e a minimum of 9 db.

THE PRACTICE

For my JAS-1/FO-12 modem design I had to choose 1. a carrier recovery circuit, and 2. a phase detector.

The Carrier Recovery circuit had to be simple, robust and repeatable. I saw no need for analogue processing here - a digital squaring loop is simple and adequate, and caters automatically for a wide range of input signal levels.

I tried out several circuits for the squarer; the simplest consisting of an RC network and an EXOR gate. It worked beautifully - but was just not repeatable. In the end I returned to my AO-10 design based a 1/4 cycle delay line - tried, trusty, robust.

In choosing the Phase Detector, I looked at the signal-to-noise expectations for this application. A minimum received SNR of 9 db is needed (see above). yet the likely received SNR was going to be + 15 db up on this, rising +10 db more as the satellite approached, less any tumbling effects.

Weighing this up I came to the conclusion that for practical purposes the satellite's signal would appear to be pretty well noiseless most of the time for a modestly equipped station.

Was there any point therefore, in trying to drag the last couple of db out of the aether. I felt not - hence the choice of a simple EXOR gate phase detector.

(Perhaps I should add that anyone sending me an SAE or 4 IRC can have the circuit diagram of a cheap, aperiodic, analogue multiplier phase detector; it uses 4 CMOS chips and two dozen discretes, and can be wired up to my FO-12 modem design - 6 signals, 2 power.)

FINAL FINAL

To promote the flow of adrenalin - has anyone any thoughts on the post-detector low pass filter?

Best wishes

James Miller

W3IWI FILE PSK.004

I appreciate G3RUH's reply on the PSK modem. At least we aren't in major disagreement about any points. I would like to comment about on the S/N and BER items. James indicated that the effective bandwidth (which determines the 'N' in the S/N ratio) for his design is determined by the SSB receiver filters and hence is 2-2.5 kHz. He then showed that he should achieve S/N of 24-34 dB on FO-12, even with a rather 'punk' 1000K noise temperature.

However, the effective noise bandwidth for the JARL / JAMSAT / QEX Costas loop demod is not determined by the receiver bandwidth. The Costas loop heterodynes the incoming audio signal (which really should be thought of as a being a very low IF) one more time to an final IF centered on zero frequency using the phase coherent carrier derived from the phase lock loop. This baseband signal then passes thru a 2nd order Bessel low-pass filter with a 900 Hz cutoff yielding an effective noise bandwidth close to the 900 Hz value (vs. the 2400 Hz in James' example), thus yielding an S/N (or E/No) difference of a factor of about 2.5 = 4dB (all other conditions being equal).

This difference is over and above the pi/2 = 2dB 'van Vleck' S/N difference (due to pre-detection vs. post-detection clipping) I reported on earlier. James is quite right that the typical downlink signal from FO-12 should be so good that these differences are probably insignificant (except under very marginal circumstances). I also want to stress that my analysis is based only on a theoretical comparison of the two implementations; a true comparison requires a test with both modems operating side-by-side.

In addition to the S/N requirements on the data channel, a second S/N consideration needs to be reckoned with -- the PLL used to extract the phase coherent carrier. In DJ4ZC's Phase-3 'AFDEM', Karl used a very narrow bandwidth (a few Hz) loop to extract the carrier. It was demonstrated time after time that the AFDEM would grovel into the noise and get locked well before data could be copied. However this was at the expense of very long lockup times and sophisticated automatic tuning logic. I notice that James' design has a switch that allows two different carrier extraction loop bandwidths -- loop time constants appear to be about 2 and 50 msec.

The JARL / JAMSAT / QEX design as currently implemented here has only a single user selectable time constant in the PLL -- about 5 msec. This leads to a lockup time that is fast enough to use a TNC2 TXD of 40 (400 msec, including radio keyup plus demod lockup, not much slower than required by the same radios running conventional 'Bell202' AFSK-FM). I have seen no problem staying in lock at an S/N (measured in the 900 Hz baseband passband) in the in the 4-8 dB range. I would be most interested in hearing a report from James on the PLL capture S/N requirements for his design. I plan to do some experimenting to try to see if the PLL time constant can be optimized further.

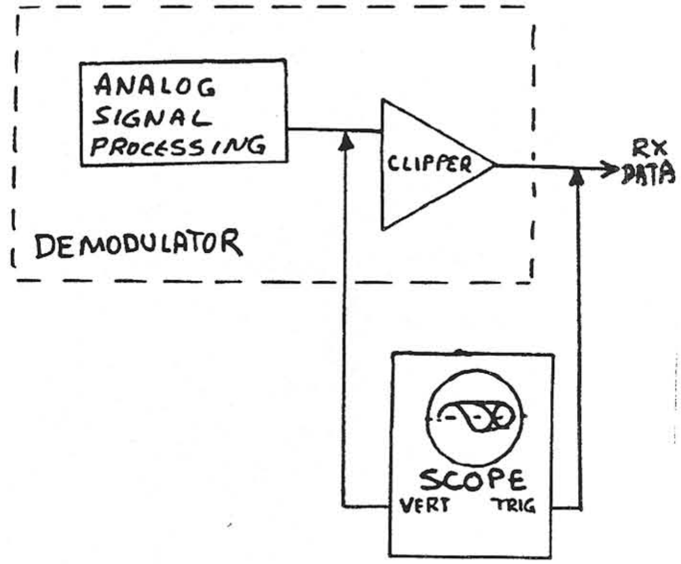
James also asked about post-detection low-pass filters. The design we are using here has the baseband 'IF' pretty well optimized for 1200 baud data with the 900 Hz 2nd order low-pass filter described above. There is no need for post-detection filtering since the matched filter is integral to the detection process. I have convinced myself that the Japanese designers came close to optimizing these filters for use in combination with radios like the TS811. The eye patterns look quite clean.

For those of you who aren't familiar with eye patterns, I will demonstrate them at Dallas. Basically you synchronize a scope's horizontal sweep with the digital data and set the sweep rate so you can see a few recovered data bits. Then use the scope's vertical input to examine the low-pass filtered baseband signal just before it is clipped (at TP1 in the QEX schematic). If the data is alternating 1/0, then the scope would display a 600 Hz (nearly sinusoidal) signature. Since the data has 'runs' of 0s and 1s, then the scope trace may go several bit samples before it changes polarity (i.e. there are frequency components in the data at sub-multiples of 600 Hz). The visual appearance is not unlike a set of 600 Hz 'beads' on a string encased within a 'sausage skin' envelope. Each of the 'beads' has the appearance of an eyeball with an open iris -- thus the name eye pattern. The best performance occurs when the transitions thru the middle are repeatable, with no transitions half-way thru a bit -- i.e. the eyeball being wide open. A bleary eyeball is either a sign that demod performance has degraded or that too much liquid refreshment has been consumed!

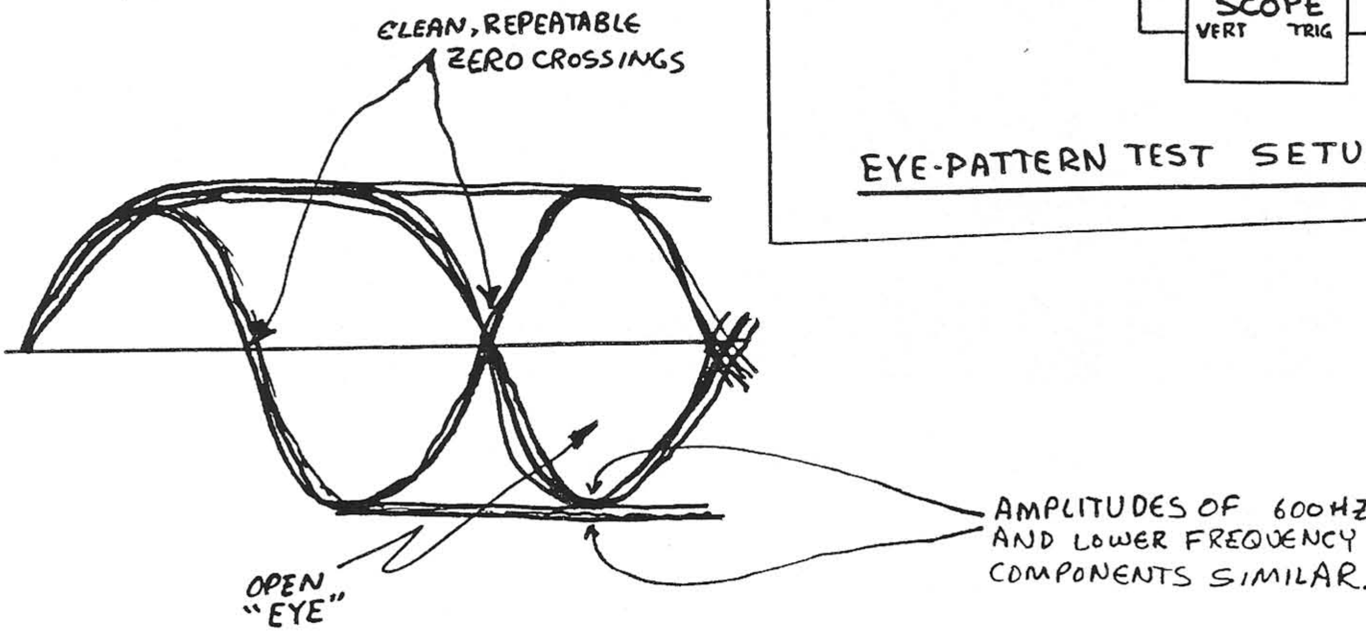
Since James' implementation converts from analog to digital before the coherent detection processing, it is not clear how eye pattern measurements would be made on his demod.

One more point James and I agree on -- writing up reports like this is a lot of work! I was pleasantly surprised at how many of you responded to my earlier note by saying that you were actually reading this diatribe. A few folks indicated that they had learned something too. Therefore if James is willing (and if Martin and the UoS crew continue to relay the commentary back and forth across the pond), I would suggest that we use this forum to continue this discussion in 'publick'. Or, to quote G3IOR, "I used to be a masochist until I found out I enjoyed it so much that I had to give it up!"

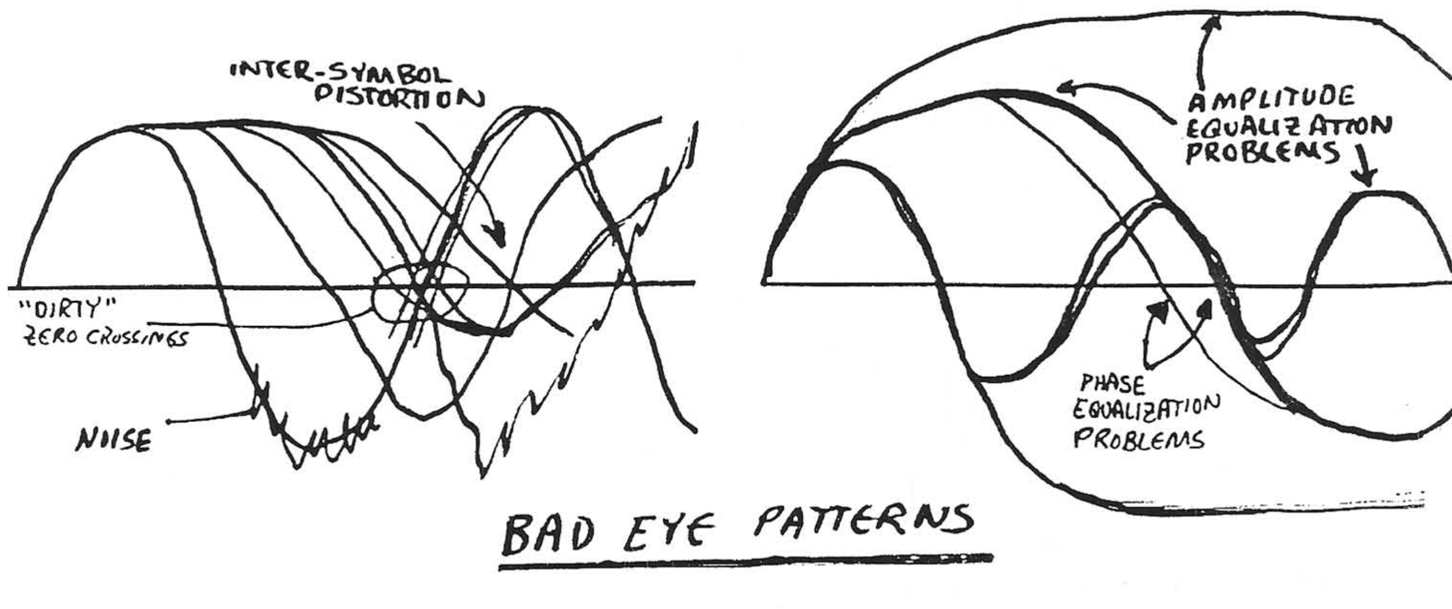
73 de Tom, W3IWI
29 October 1986



EYE-PATTERN TEST SETUP



GOOD EYE PATTERN



BAD EYE PATTERNS

A PSK Demodulator for the JAS-1 Satellite

By Fujio Yamashita, JS1UKR, JARL, Sugamo 1-14-2
Toshima-Ku, Tokyo, 170 JAPAN

WITH ADDED COMMENTS BY W3IWI

Introduction

The digital transponder on the JAS-1 satellite is designed to transmit its downlink signal by PSK modulation. Therefore, reception of the downlink signal requires a PSK demodulator. Several circuits are available, but this article introduces another recently developed.

A PSK signal can be thought of as carrier-suppressed double sideband (DSB). To demodulate the signal, a carrier signal identical in frequency and phase as the received PSK signal is required. The key to demodulation is knowing how to regenerate a carrier coherent to the received PSK signal. An SSB receiver is only used as the linear frequency converter and does not work for PSK demodulation.

The carrier frequency of a down-converted PSK signal is chosen to be around 1600 Hz so the spectrum of the signal falls within ±600 Hz. There are several reasons why a frequency of 1600 Hz is chosen. Here, the signal can pass through the flat part of the passband of a conventional amateur SSB receiver, capable of receiving voice communications up to 3 kHz. Because the rate of information is 1200 bits/s, it is better for the carrier frequency to differ by 1200 Hz, considering carrier suppression.

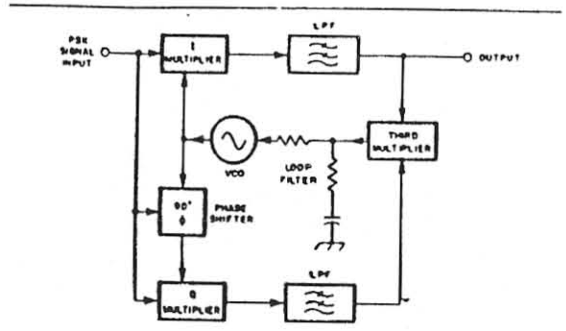


Fig 1—Basic diagram of a Costas loop.

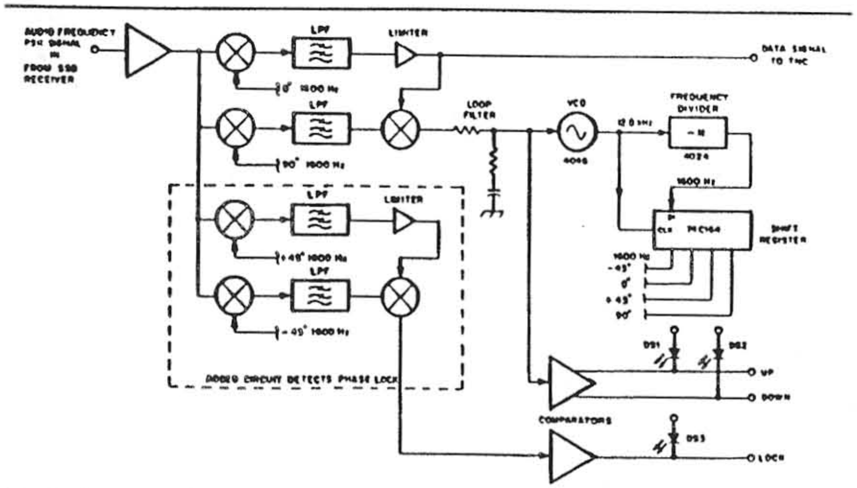


Fig 2—Block diagram of the demodulator circuit.

145

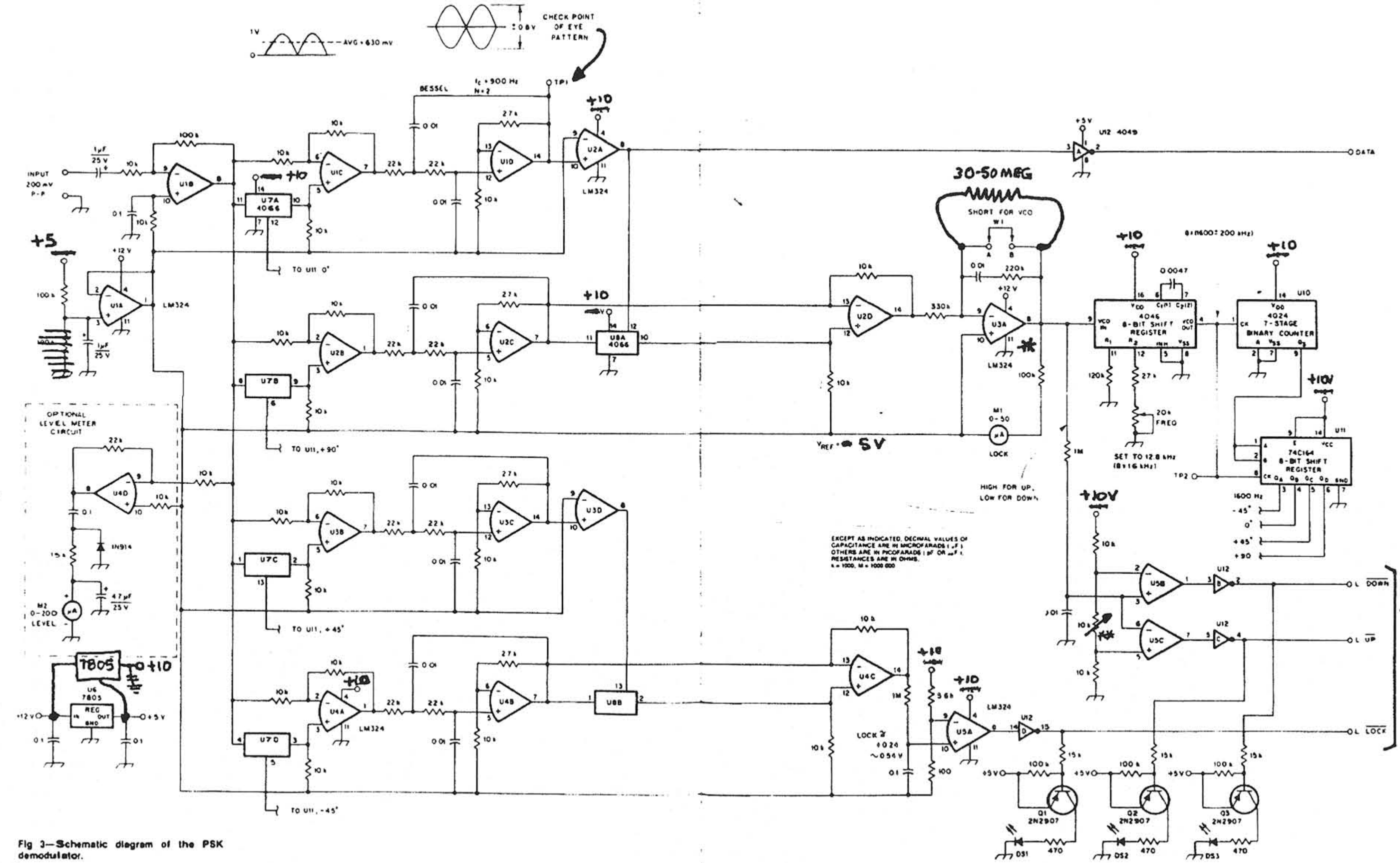


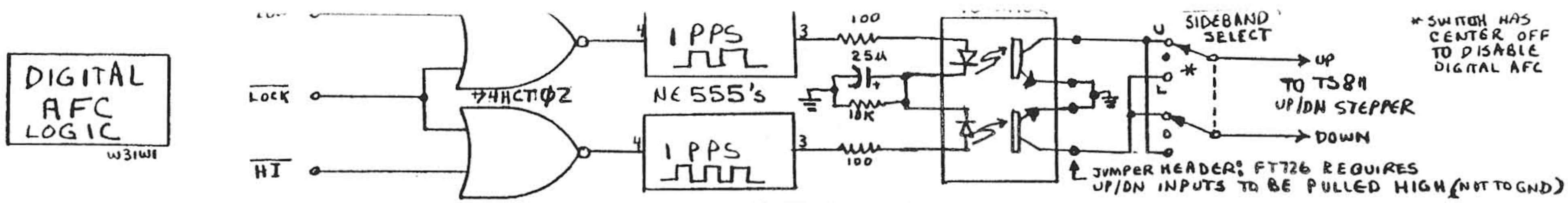
Fig 3—Schematic diagram of the PSK demodulator.

(NOTE: M1 & M2 REPLACED WITH LM3914 LED INDICATORS)

* U3 SHOULD BE PREMIUM LOW OFFSET DEVICE (e.g. TLC 0274)

** VARIABLE RESISTOR TO OPTIMIZE DIGITAL AFC WINDOW

(ADDED NOTES BY W3IWI OCTOBER '86)



Circuit Description

The circuit presented is an adaptation of the Costas loop. Its merits include:

- A frequency lock range up to ±200 Hz
- A lock indicator
- A sense indicator of the received frequency shift
- Output of the sense indicator drives the receiver VCO (if an input port is available) to automatically track the received signal

Fig 1 shows a block diagram of the Costas loop. The multipliers labeled I-, Q- and third form a phase lock loop (PLL) circuit. A carrier signal is applied to the I- and Q-multiplier with a phase difference of 90° to each other. The two outputs connect through the low-pass filters and are introduced to the third multiplier. Its output is then applied to the variable crystal oscillator (VCO) through the loop filter. The data signal to the terminal node controller (TNC) is obtained from the I-multiplier.

It is necessary to receive some indication that the PLL is in a lock condition. While the Costas loop's output does not contain signal amplitude information, the main loop circuit should be designed to include a PLL indicator. The modified circuit operates with applied carrier signals showing a phase difference of ±45°.

The Circuit

Fig 2 shows a block diagram of the demodulator circuit and Fig 3 is the schematic diagram. The multipliers consist of an LM324 op amp (U1) and a 4066 analog switch (U8). The 4046 VCO generates a frequency eight times that of the carrier. This signal frequency is divided by eight and applied to the shift register (U11) to obtain the phase differences of 45° each.

Once the circuit wiring is complete, place a jumper (W1) between points A and B; this makes U9 a voltage follower. Adjust the VCO frequency to read 12.8 kHz, keeping its input reference voltage at 8 volts. 5

VCO Indicator

If your receiver has the means of driving the VCO from an external source, the following process will go easily.

When the received frequency gets higher than the 1600-Hz carrier, the signal indicator (DOWN) shows its status and delivers a corresponding output signal voltage. This allows control of the RF receiving frequency and UP signal. Both of the signals (UP and DOWN) appear on the indicator panel when the frequency deviates over ±100 Hz. When the receiving frequency is correct, the LOCK LED shows this.

UP and DOWN indicate the deviation sense only of the input signal frequency of the demodulator and not of the receiver frequency. UP and DOWN will invert according to the sideband being used.

The meter (M1) at U9 is a lock indicator and is important for frequency tuning. Scale this within ±5 volts.

A level indicator aids in setting a proper receiver audio level. Because the Doppler shift of JAS-1 is larger than the lock range of the circuit, this indicator might be necessary. Any indicator such as an LED will suffice.

It is better for the UP, DOWN and LOCK signals to be arranged for an RS-232-C format. The 12-V power supply should be well regulated. Current drain is less than 30 mA.

This circuit is small enough (no larger than a standard postcard) to fit inside a TNC. If this is where the circuit will reside, add a switch to the modem to select PSK or FSK.

Automatic Tracking

Perfect auto-tracking of the received signal will be impossible in a band full of interference and noise. First, capture the PSK signal manually. The auto-tracking system can take over once the Doppler shift is noticeable. When the circuit unlocks, try to manually access the satellite one more time. This is a good exercise to determine sensing—whether the frequency shift during lock is going to be up or down. Remember, the circuit has no searching function.

Testing the Circuit

If you own a TNC, construct a PSK signal generator that works with your equipment. A PSK-modulated signal can be generated by the circuit shown in Fig 4. Here, the audio frequency PSK signal is obtained by applying a 1600-Hz carrier signal to the Manchester encoder of the circuit. The PSK signal is used to examine the demodulator at audio frequencies, and the signal can also be applied to the mic terminal of a transceiver to check the PSK demodulator at RF.

Mode selection is easy if you are familiar with your TNC. Work with your system further by using test tapes.

Further development of the PSK demodulator circuit is expected. For additional information contact JAS-1 Committee, c/o Technical Institute, JARL, Sugamo 1-14-2, Toshima-ku, Tokyo, 170 Japan.

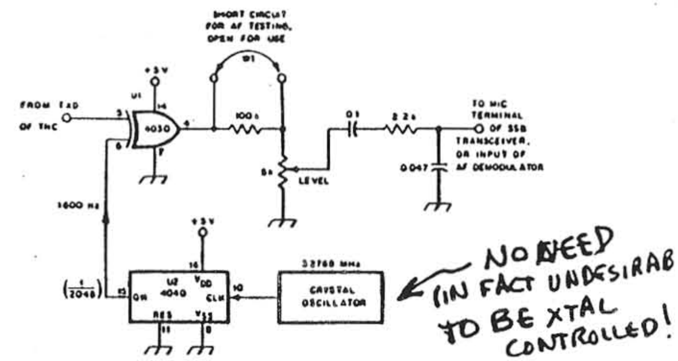


Fig 4—Audio frequency PSK modulation circuit for testing the PSK demodulator.

147

The Flight of JAS-1

By Shozo Hara, JA1AN
c/o JARL

Project JAS-1 has been in the works since 1983. Flight Models FM-1 and FM-2 were completed in March and November of 1985, respectively, for the August 1 flight. Both models were prepared for launch in the chambers of the NEC Corp near Tokyo.

On June 21, a vehicle with air-suspended wheels transported FM-2 to Tanegashima. Various test and measuring equipment accompanied the satellite on its journey.

The island of Tanegashima is located in southern Japan and is historically famous to the Japanese as the place the matchlock was introduced by drifted Portuguese people more than 400 years ago. In 1986, it was the launch site of JAS-1.

The Japanese National Space Agency launch vehicle, the NASDA H-1, consisted of a two-stage rocket. The propellant of the second stage rocket, that which carried JAS-1 into orbit, was liquid oxygen and hydrogen. The booster is capable of launching 3,968 pounds to an altitude of 932 miles with an inclination of 50°.

Instead of sending a dummy payload on the first H-1 test flight, three missions were onboard: EGP, the experimental geodetic payload, JAS-1 and the magnetic bearing flywheel experiment. About one hour after launch, the second stage rocket flew over South America, where two payloads separated from the rocket sequentially.

The satellite's power supply was activated at the moment of separation from the rocket. The University of Chile agreed to provide assistance and was the first to receive the satellite's signals. About 20 minutes later, JAS-1 flew northward over England. There, the staff at the University of Surrey waited to check the health of the newborn satellite.

JAS-1 transmits its telemetry in CW using the analog transponder, Mode JA. During the initial period, the solar condition of the satellite will be examined. It is requested that listeners do nothing more than this until the operating schedule is announced.

Major Specifications of the Satellite

Orbit: Circular, 1500 km altitude
Period: 116 minutes
Inclination: 50°
Life expectancy: 3 years
Weight: 110.23 lbs
Configuration: Polyhedron of 26 faces covered by solar cells
Size: 15.75 inches (diam) × 18.50 inches (height)
Power generation: 8 W initially

Transponders

Analog (JA—linear)
Input: 145.9 to 146.0 MHz (100-kHz bandwidth)
Output: 435.9 to 435.8 MHz (inverted sideband)
Required uplink EIRP: 100 W
Transponder EIRP: 2-W P-P

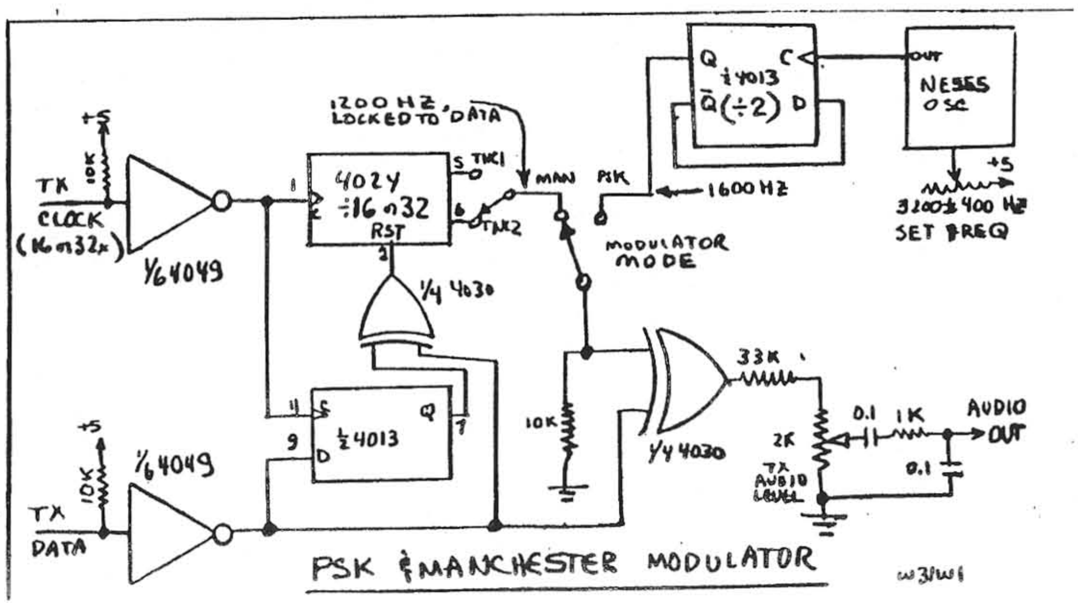
Digital (JD)
Input: Four channels—145.85, 145.87, 145.89, 145.91 MHz
Output: 435.91 MHz (one channel)
Required uplink EIRP: 100 W
Transponder EIRP: 1-W RMS
Signal format: 1200-baud PSK, store and forward

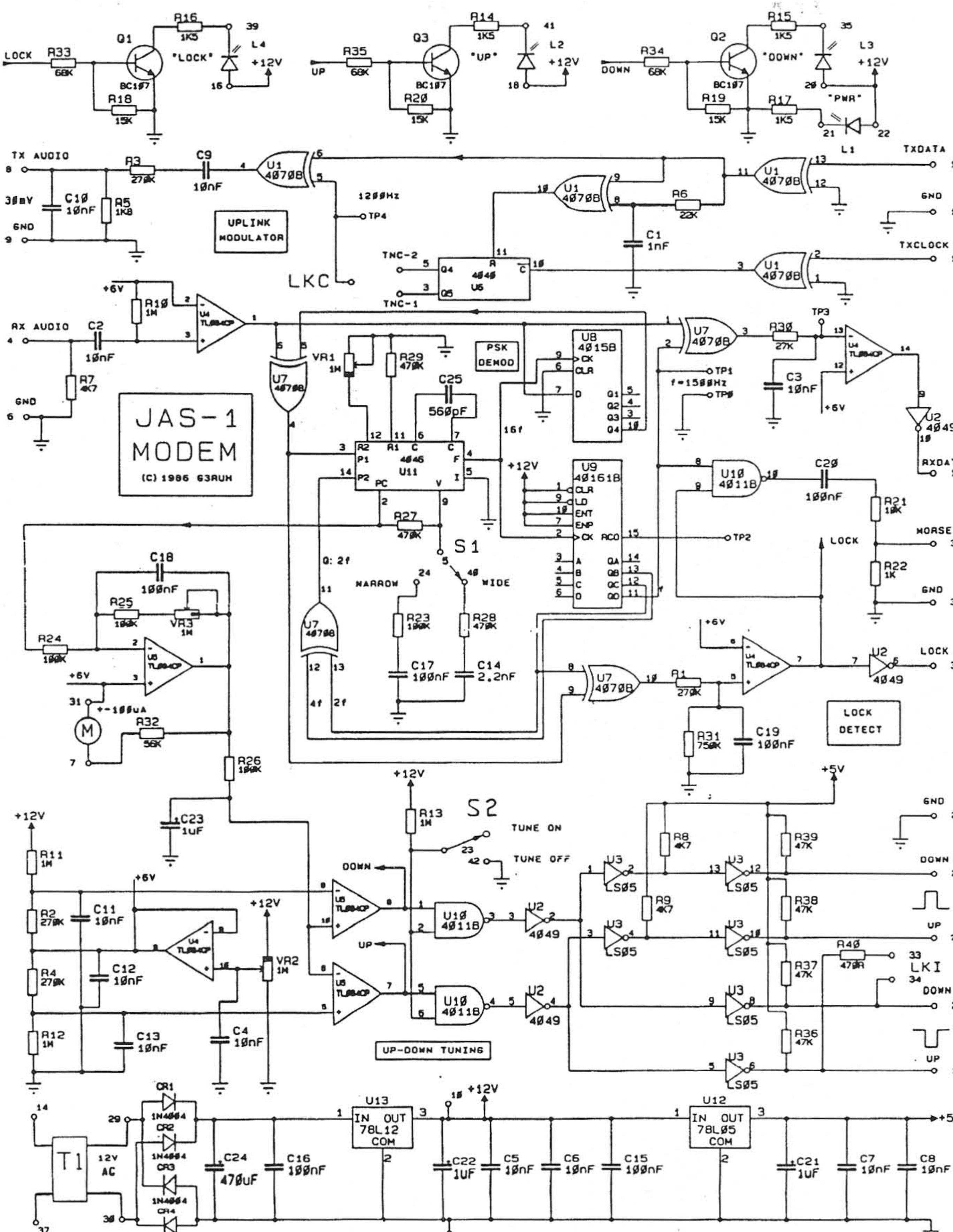
Beacon and Telemetry

JA beacon: 435.795 MHz, 100 mW CW or PSK
JD telemetry: 435.910 MHz, 1 W PSK

Orbit Parameters

Epoch: 1986-07-31, 21h 32m 07.20s UT
Semimajor axis: 7879.562 km
Eccentricity: 0.000140656
Inclination: 50.0039°
RA of ascending node: 237.456°
Argument of perigee: 2.155°
Mean Anomaly: 330.248°





Note: Integrated circuits U1, U2, U3, U6 use the +5 volt supply.
The meter, switches and LEDs are not mounted on the PCB.

149

* JAS-1 Operating Frequencies and Procedures *

The uplink for JAS-1 Mode JA is: 145.900 through 146.000 MHz. The corresponding downlink band is: 435.900 through 435.800 MHz. The bandplan provided by JARL recommends CW users in the lower third of the passband from 435.800 through 435.835 MHz. SSB users should use the upper third from 435.865 to 435.900 MHz. Mixed SSB and CW Voice are welcome in the center third.

To maximize passband usefulness, JARL recommends you control your uplink frequency to maintain a constant downlink frequency as heard at your QTH. The reasons for this are fairly subtle but seemed to work on AO-8, Mode J.

Differences in Doppler shift between occupants of the passband can can cause some occupants to move across the downlink passband faster than others. The result is that "collisions" between QSOs are more likely than on other current satellites. COequently, it is recommended that the same procedure used on AO-8, Mode J be used on JO-12, Mode J. That is, once you have found a clear spot in the downlink passband, try to remain there by adjusting your UPLINK frequency only.

Mode JD, the digital Mode J, could be activated in a few weeks.

JAS-1/JO-12 MODEM PRINTED CIRCUIT BOARD

by James Miller G3RUH

To use the JAS-1 (OSCAR-12) satellite's digital Mailbox you need an AX.25 Terminal Node Controller (TNC) system with an External Modem replacing the standard TNC's Bell 202 internal modem. (See Oscar News No 60, July 1986. p.30). Automatic doppler shift tracking is also virtually essential.

The complete circuit of a suitable modem is shown on the next two pages. Full instructions (8 pps) are available separately now - see below. We will automatically release the PCB when live tests via OSCAR-12 confirm that mode JD is operational. But ...

Presently we have over 50 confirmed advance orders for boards. When this figure tops 100 we will make and despatch the boards immediately anyway, even if mode JD is still untested. (Dated 1986 Aug 28)

Modem PCB Specification

* MODEM: DOWNLINK; Input 50mv to 5 v RMS RX audio. PSK demodulator to TTL digital, 1200 bps. UPLINK; 1200 bps Manchester encoding modulator to Mic level (about 30 mV pk-pk) TX audio. RX carrier LOCK LED indication. Selectable loop bandwidth. Morse code regenerator.

* CONNECTs to AX.25 TNC "modem disconnect" jack. Suitable for TNC-1 or TNC-2, (and any other provided the internal modem can be bypassed). Four extra digital connections needed: TXdata, RXdata, TXclock, Gnd.

* DIGITAL AFC: tracks changing doppler shift via the Up/Down signal lines of your RX rig. Designed for all known ICOM, TRIO and YAESU standards, Adjustable for 10 - 100 Hz/step. Positive pulses, negative pulses and Icom bi-level. Tracking ON/OFF switch. Manual tuning indication by LEDs and centre-zero meter.

* SET-UP Three preset pots - for PLL frequency, local 6v supply, and up/down tuning gain.

* POWER: AC mains PSU built-in OR 12v AC input OR 12 to 14v DC, 40 ma.

* PCB: High quality 160 x 100 mm (single eurocard) double side, plated through, legended, with full alignment and installation instructions. Standard CMOS and LSTTL used. No hard-to-get parts.

* PCB Obtainable from AMSAT-UK, LONDON E12 5EQ, England. PCB price £16.50 post paid UK/Europe, £17.50 airmail elswhere. Instructions only, send SAE or 2 IRC. AMSAT groups with orders of 10 or more should contact G3RUH direct for a bulk price:

James R Miller G3RUH, 3 Benny's Way, COTON, Cambridge, CB3 7PS, England

Optimal Two-Impulse Orbital Transfer between Inclined Elliptical Orbits with Applications to Phase IIIC and Phase IV.

by Bob McGwier, N4HY

Success of most if not all of the missions being planned by **AMSAT-NA** in conjunction with it's mission partners requires the use of complex maneuvers to place the satellite of interest into the final orbit needed to meet our primary mission objectives. These maneuvers are required because we simply cannot afford a launch where the delivery system (the rocket) places us in the proper orbit without our "active" participation in the propulsion of our satellite. We also carry about several very real constraints. We have a tank on board our spacecraft and these tanks do not have an unlimited capacity for us to muck about the earth in orbit. We must make "OPTIMAL USE" of that fuel so that we may achieve our goals. In the Phase III program it is to go from a geostationary transfer ellipse given by the Ariane vehicle to a Molniya type orbit, one which is highly inclined, highly eccentric, with inclination chosen so as to zero out the first order perturbations on the argument of perigee. It should be clear that these are complex calculations, requiring carefully designed models, and full understanding of the sensor apparatus on board the spacecraft for determining spacecraft attitude so that we may use the thrust to give us the correct change of orbit at the time it is needed. We wish to describe here the derivation of a model under which we will study the orbital transfer maneuver facing us in our continuing satellite program. This paper details a study of a two-impulse process between an initial orbit with known orbital elements, and a final orbit with elements given by design of the mission. We will do this by first deriving some analytical results and then doing an exhaustive search over the possible parameters of the problem given the constraints placed on the parameter set derived from our analytical investigation.

GLOSSARY OF SYMBOLS

$a =$ semimajor axis

$e =$ eccentricity

$i =$ inclination

$p =$ semiparameter

$r =$ magnitude of satellites position vector

$t =$ time

$\Delta\theta =$ transfer angle (true anomaly angle in transfer orbit)

$\mu =$ gravitation constant

$\phi_1 =$ angle from reference axis to departure point in initial orbit

$\phi_2 =$ angle from reference axis to arrival point in initial orbit

$\omega =$ argument of perigee

$\Omega =$ right ascension of ascending node

$\alpha =$ angle between r_2 and $r_2 - r_1$

$\beta =$ angle between r_1 and $r_1 - r_2$

$\Psi_1 =$ functional form of 1st orbit changing velocity increment

$\Psi_2 =$ functional form of 2nd orbit changing velocity increment

$I =$ functional representation of impulse

$e_j =$ orbit shape and orientation vector

$r_1 =$ vector from reference pos to point of departure initial orbit

$r_2 =$ vector from reference pos to point of arrival on final orbit

$W =$ unit vector directed along orbits's angular momentum vector

$V_{tj} =$ velocity vectors in transfer orbit

$V_j =$ velocity vectors in initial and final orbit

$U_j =$ unit vectors in dirction of radius vectors r_j

$N, M, W_2 =$ unit vectors in Cartesian coordinates defining the ref. plane

A technique originally developed by Stark[1] does some preliminary development of a geometrical method for analyzing the two-impulse orbital transfer problem. The first paper to use this technique was one by McCue[2], (the notation used above and throughout this paper are identical to the paper by McCue) but it does not take the analysis far enough for our purposes and makes simplifying assumptions that are not true in all of our transfer problems. My favorite celestial mechanic Pedro Escobal[3] uses this technique on problems of optimal two impulse transfer between non coplanar circular orbits. Here we generalize this work and apply the technique to noncoplanar elliptic orbits. Normally we need $a, e, i, \Omega,$ and, ω to describe the geometry of an orbit. Here we may make several simplifying assumptions and have no loss of generality in our idealized model. That is, we can safely assume that line of intersection is a common reference point on the two orbits and thus **RAAN** (Ω), is not needed in our set, and we assume that one has inclination zero. We need only correct the latter for non-sphericity perturbations after the burn, since before and after the burn the integrator used will take into full account zonal,tesseral,drag,Lunar, Solar and major planetary perturbations for the longer term stability studies. It is very easy to carry all these perturbations when you have the best possible integrator algorithm for this problem and the computational complexity which would normally make this procedure prohibitively expensive is mollified by the speed of a Cray he round off problem is minimized by being able to do 128 bit floating point arithmetic. For shorter range studies, where the total input of the minor perturbations is insignificant, we do the work on our AT at home and leave off those perturbations which are overwhelmed by round off error in the paltry 80 bit arithmetic in Microsoft MS-C^{tm} and Microsoft MS-Fortran^{tm} for intermediate results and 64 bits used to store the results of arithmetic operations. We make another simplifying assumption which will almost certainly be true, and that is we will only make "short" transfers. That is we will always take the "short path" rather than the "long path" onto an orbital plane as the latter is an ostentatious usurper of propellant. Thanks to Phil Karn's efforts we have a suite of programs used by the government in producing ephemeris and will be testing it for long term accuracy as it also attempts to do a perturbation analysis, but it is a general perturbation technique, i.e. it models the secular changes in the orbital elements rather than integrates the gradient of the potential as we are doing for this study. This is technique used in the now famous W3IWI tracking program and it's derivatives such as ORBITS and QUIK-TRAK. The integrator we use here is based on a technique known as Burlisch-Stoer and uses Richardson's extrapolation and is the premier ordinary differential equation technique in terms of speed/accuracy when the vector field is very smooth as it is in gravitational field problems for earth satellites.

Let W_i be a unit vector along the initial orbits angular momentum vector; W_t, and W_f will be the same quantity for the transfer or intermediate orbit and the final orbit respectively. Whenever you do a burn, if this were the ideal case of an impulse as in our model, the orbit before the burn lies in a plane, and the orbit after the burn lies in another plane which intersects the initial orbital plane in a line. This line is a simple geometric object to derive mathematically it has a natural unit vector associated with it given by

(1)
$$N = \frac{W_2 \times W_1}{\mid W_2 \times W_1 \mid}.$$

$W_i, W_t,$ and, W_f are unit vectors normal to initial, transfer, and final orbital planes and will prove useful in our analysis. Let $e_i, e_t,$ and, e_f be vectors whose lengths are the eccentricities of the respective orbits, and who point at the perigee of the orbit from which it is derived. Let the interval (mod 2π) traversed in the transfer orbit in true anomaly be $\Delta\theta$. This interval is easy to determine from

(2)
$$cos(\Delta\theta) = (U_1 \cdot U_2).$$

No ambiguity arises here as we have restricted ourselves to short transfers so we may hold the angle here to be in the first two quadrants.

For any two elliptical orbits, let r_1 and r_2 be the vectors from the reference position on the line of intersection to the departure and arrival points, respectively. The angle as we have already said is $\Delta\theta$. By forming $r_2 - r_1$, a triangle is made of the three vectors in the transfer orbit plane.

Let

(3)
$$\beta = \frac{arcsin \mid r_2 \mid sin(\Delta\theta)}{\mid r_2 - r_1 \mid},$$

(4) $$\alpha = \pi - (\beta + \Delta\theta).$$

Consider the collection of all possible velocity vectors that can act upon the point defined r_1, and trace a conical orbit path that goes through the point defined by r_2. This ensemble defines all possible conic transfer orbits between the two points, since a particular orbit is uniquely determined by its velocity vector at a given position. For our problems, these collections will consist only of elliptical (or circular) orbits as we have not enough fuel on board to take a hyperbolic trajectory between orbits. They are conical in nature because we suppose an ideal impulsive velocity change then the vehicle goes back to it's "free fall" orbit shape determined by the new velocity.

The velocity vector of any transfer orbit at the particular point r_1 is given by (see Escobal[3])

(5) $$V_{t1} = v + zU_1$$

where

(6) $$v = \frac{(\mu p)^{\frac{1}{2}}(r_1 - r_2)}{\mid r_1 \times r_2 \mid}$$

(7) $$z = \left(\frac{\mu}{p}\right)^{\frac{1}{2}} tan\left(\frac{\Delta\theta}{2}\right)$$

where p is the semiparameter of the transfer orbit. Then as a function of p

(8) $$V_{t1}(p) = \left(\frac{\mu}{p}\right)^{\frac{1}{2}} \left[\frac{p \mid r_2 - r_1 \mid}{\mid r_1 \times r_2 \mid} m + tan\left(\frac{\Delta\theta}{2}\right) U_1\right]$$

where m is a unit vector in the direction of $r_1 - r_2$. Every value of p great than zero defines a transfer orbit whose velocity vector at r_1 has components in the direction m and U_1.

The set of points in a Cartesian coordinate system such that the product of the coordinates is a constant forms a hyperboloid with the axes as the asymptotes. Since the product of the magnitudes of the components in the m direction and the U_1 direction is independent of p, we arrive at the following equation

(9) $$\left[\frac{(\mu p)^{\frac{1}{2}} \mid r_1 - r_2 \mid}{\mid r_2 \times r_1 \mid}\right] \left[\left(\frac{\mu}{p}\right)^{\frac{1}{2}} tan\left(\frac{\Delta\theta}{2}\right)\right] = \frac{\mu\ tan(\Delta\theta/2) \mid r_2 - r_1 \mid}{\mid r_1 \times r_2 \mid}$$

gives a hyperbola from the formulation of V_{t1} with oblique axes m and U_1 as aymptotes. The collection of all possible velocity vectors leaving r_1 and arriving at r_2 on a conic path forms a hyperbola. Likewise at r_2, the velocity vector for any transfer orbit (depending upon the semiparameter) is given by

$$V_{t2} = v - zU_2. \tag{10}$$

This is another hyperbola that represents the collection of all possible transfer orbits leaving r_1 and arriving at r_2. The drawing included here is taken from McCue's[2] paper. Note there is one point on on each of these hyperbolae for each p that represents the transfer orbit. In this figure V_1 and V_2 are vectors defining the initial and final orbits and this is a coplanar transfer. V_1 and V_2 are defined by

$$V_1 = \left(\frac{\mu}{p}\right)^{\frac{1}{2}} W_1 \times (e_1 + U_1) \tag{11}$$

$$V_2 = \left(\frac{\mu}{p}\right)^{\frac{1}{2}} W_2 \times (e_2 + U_2) \tag{12}$$

which must have magnitudes less than

$$V_{\mathrm{par}} = \left(\frac{2\mu}{r}\right)^{\frac{1}{2}} \tag{13}$$

From geometrical considerations it is clear that the vectors V_1 and V_2 emanate from r_1 and r_2 and must lie within a certain radius containing all elliptical orbits or defined by the maximum possible impulse given your system.

In finding the minimum velocity increment solution for this two-impulse case, the function to be minized is

$$I(p) = \Psi_1 + \Psi_2 \tag{14}$$

where

$$\Psi_1(p) = \mid V_{t1}(p) - V_1 \mid \tag{15}$$

(16) $$\Psi_2(p) = \mid V_2 - V_{t2}(p) \mid .$$

Once again these equations are valid ONLY for short transfers there are sign changes if you take the long transfer. In the diagram, our optimization code requires that the sum of the distances from V_1 and V_2 to the respective transfer loci be minimized. For every semiparameter, there is ONE AND ONLY ONE point on each hyperbola corresponding to the transfer orbit. The distances marked I_{1p} and I_{2p} represent simply a particular transfer orbit chosen for illustrative purposes. Our search technique is a combination of both finesse and brute force. Given this geometric technique we can find the minima GIVEN $\mathbf{r}_1$ and $\mathbf{r}_2$. We must then search exhaustively over the ensemble of possible values for departure and arrival points. This is not strictly true, but close, some economies may be taken but it is still exhaustive search. For this problem, we would not want to use adhoc or gross approximations as we need to be absolutely certain of our calculations. Let us solve the analytic problem from the geometry in "Escobal style" (indeed he did this for circular orbits, i.e. Hohmann transfers, Bielliptic transfers). We will find an eigth degree polynomial whose zero's will contain the solution GIVEN the terminal points. We wish to minimize the function given in equation (14). This is a function of the semiparameter (among other things). As every student of calculus knows to minimize the function you take it's first derivative and set it equal to zero.

(17) $$\frac{\partial I}{\partial p} = \frac{\partial \Psi_1}{\partial p} + \frac{\partial \Psi_2}{\partial p} = 0$$

(18) $$\begin{aligned}\Psi_1(p) &= [(V_{t1}(p) - V_1) \cdot (V_{t1}(p) - V_1)]^{\frac{1}{2}} \\ &= [(v(p) + z(p)\,U_1 - V_1) \cdot (v(p) + z(p)U_1 - V_1)]^{\frac{1}{2}} \\ &\equiv [f(p)]^{\frac{1}{2}}\end{aligned}$$

where

(19) $$\begin{aligned}f(p) = v(p) \cdot v(p) &+ z^2(p) + V_1 \cdot V_1 - \\ &2z(p)V_1 \cdot U_1 - 2V_1 \cdot v(p) + 2z(p)v(p) \cdot U_1 \\ &= Ap + 2Bp^{\frac{1}{2}} + G - 2Cp^{-1/2} - Dp^{-1}.\end{aligned}$$

Similarly,

$$\Psi_2(p) \equiv [g(p)]^{\frac{1}{2}} \tag{20}$$

where

$$g(p) = Ap + 2Ep^{\frac{1}{2}} + H - 2Fp^{\frac{-1}{2}} - Dp^{-1}. \tag{21}$$

The coefficients A-H are given in table I. For the impulse to be an extremum,

$$\frac{\partial \Psi_1}{\partial p} + \frac{\partial \Psi_2}{\partial p} = \frac{1}{2\Psi_1}\frac{\partial f}{\partial p} + \frac{1}{2\Psi_2}\frac{\partial g}{\partial p} = 0. \tag{22}$$

Cross multiplying gives

$$\frac{\Psi_1(p)}{\Psi_2(p)} = -\frac{\partial f/\partial p}{\partial g/\partial p} \tag{23}$$

Since $\Psi_1(p)$ and $\Psi_2(p)$ are always positive (otherwise it is a one impulse maneuver and negative impulses are not allowed) it easy to see from this equation that $\partial f/\partial p$ and $\partial g/\partial p$ must be of opposite sign for an extremum. This crucial observation allows us to do our Escobalesque and easily identify the extraneous in the polynomial we are about to derive. Taking derivatives of (19) and (2) we get

$$\frac{\partial f}{\partial p} = A + Bp^{-\frac{1}{2}} + C^{-\frac{3}{2}} + Dp^{-2} \tag{24}$$

$$\frac{\partial g}{\partial p} = A + Ep^{-\frac{1}{2}} + F^{-\frac{3}{2}} + Dp^{-2}. \tag{25}$$

Before we can get a meaningful expression we must square (23). Upon doing so and using (19) and (20) we get

$$\frac{f(p)}{g(p)} = \frac{(\partial f/\partial p)^2}{(\partial g/\partial p)^2}. \tag{26}$$

and

$$f(p)\left(\frac{\partial g}{\partial p}\right)^2 - g(p)\left(\frac{\partial f}{\partial p}\right)^2 = 0 \tag{27}$$

Multiplying out this equation and using the identities derived above and substituting

(28) $$s = p^{\frac{1}{2}}$$

we get an eigth degree polynomial in s

(29) $$\phi_1 s^8 + \phi_2 s^7 + \phi_3 s^6 + \phi_4 s^5 + \phi_5 s^4 + \phi_6 s^3 + \phi_7 s^2 + \phi_8 s^1 + \phi_9 = 0$$

as the necessary condition for an extremum (and therefore for a minimum). The coefficients are in table 2. We have introduced possible extraneous roots by the squaring we did to get equation (26). These are easily discarded by factoring (27) into the sum time the difference of two quantities. Using (19) and (20) these factors are

(30) $$\Psi_1(p)\frac{\partial g}{\partial p} \pm \Psi_2(p)\frac{\partial f}{\partial p} = 0$$

The roots of (29) which are real and satisfy (30) with the plus sign are extrema and the roots of (29) that satisfy (30) with the negative sign are extraneous. We have another necessary condition that we have not made use of and that is the partials of f and g with respect to p must be of opposite sign. The boundary values of these partials are $-\infty$ limiting on zero from the right and A (see the coefficient table 1) for the limiting as p goes to ∞. Therfore since these are continuous functions by the intermediate value theorem there must be a zero for each of them. Further the region where they are not both negative or both positive is bounded. Therefore the boundaries in which all minima in the impulse function must lie for our problem are given by the least positive value of p and the greatest positive of p for which either

(31) $$\partial f/\partial p = 0 \text{ or } \partial g/\partial p = 0$$

If $s = p^{1/2}$ as we have stated then $\partial f/\partial p = 0$ where

(32) $$As^4 + Bs^3 + Cs + D = 0$$

and $\partial g/\partial p = 0$ where

(33) $$As^4 + Es^3 + Fs + D = 0.$$

These two quartics may be easily solved using formulas like the old quadratic formula many of you may know (a great deal more complicated).

In numerical practice, we solve these these equations by standard numerical factorization routines. These values of the semiparameter for the transfer orbit which in the case of two impulse maneuver determines all the other parameters in the transfer between two known orbits are then stored for the r_1 and r_2 pair. The process is then repeated. In actual implementation, we solve the equations the painful way ONLY when necessary. That is when we start up and when a root dissappears. That is a bifurcation point in the dynamical picture. The rest of the time we use the old values and Newton's method for the finding the zeros of nonlinear functions. We will give the coefficients in the tables that follow. Look for the results of the numerical runs to appear in some print media that AMSAT is associated with in the near future. I would like to thank Phil Karn for allowing me to rip off some of his routines he used for sun angle calculations to take into account solar perturbations in the dynamical model used here. This model is over kill for this local short time burn scenario but will be very useful when studying long term stability of orbits to predict necessary propellant for station keeping. I would like to thank the members of the Phase IV study team and the management of AMSAT for asking to work so hard and for paying me so well. 73 de BOB.

Table I. Coefficients in f and g.

$$
\begin{aligned}
A &= \mu \frac{| r_2 - r_1 |^2}{| r_1 \times r_2 |^2} \\
B &= -\frac{\mu}{(p_1)^{1/2} \, | r_1 \times r_2 |} [(r_2 - r_1) \cdot (W_1 \times (e_1 + U_1))] \\
C &= \frac{\mu \, tan\,(\Delta\theta/2)}{(p_1)^{1/2}} [U_1 \cdot (W_1 \times e_1)] \\
D &= -\mu \, tan^2 \left(\frac{\Delta\theta}{2}\right) \\
E &= \frac{\mu}{(p_2)^{1/2} \, | r_1 \times r_2 |} [(r_2 - r_1) \cdot (W_2 \times (e_2 + U_2))] \\
F &= \frac{-\mu \, tan\,(\Delta\theta/2)}{(p_2)^{1/2}} [U_2 \cdot (W_2 \times e_2)] \\
G &= \frac{\mu}{p_1} [W_1 \times (e_1 + U_1)]^2 + \frac{2\mu \, tan(\Delta\theta/2)}{| r_1 \times r_2 |} [U_1 \cdot (r_2 - r_1)] \\
H &= \frac{\mu}{p_2} [W_2 \times (e_2 + U_2)]^2 - \frac{2\mu \, tan(\Delta\theta/2)}{| r_1 \times r_2 |} [U_2 \cdot (r_2 - r_1)]
\end{aligned}
$$

Table 2 Coefficients in eigth degree polynomial

$$
\begin{aligned}
\Phi_1 &= A^2(G - H) + A(E^2 - B^2) \\
\Phi_2 &= A^2(4F - 4C) + A(2EG - 2BH) + 2E^2B - 2EB^2 \\
\Phi_3 &= A(8BF - 8EC + 2EF - 2BC) + E^2G - HB^2 \\
\Phi_4 &= A(4BD - 4ED + 2FG - 2CH) + 4BEF - 2CE^2 - 4BCE + 2FB^2 \\
\Phi_5 &= D(2AG - 2HA - E^2 + B^2) + A(F^2 - C^2) - 2BCH + 2GEF \\
\Phi_6 &= D(4FA - 4AC + 2EG - 2BH) + 4FBC - 4CEF + 2BF^2 - 2EC^2 \\
\Phi_7 &= D(8BF - 8EC + 2BC - 2EF) + F^2G - C^2H \\
\Phi_8 &= D^2(4B - 4E) + D(2FB - 2HC) + 2FC^2 - 2CF^2 \\
\Phi_9 &= D^2(G - H) + d(C^2 - F^2)
\end{aligned}
$$

Bibliography

(1) Stark, ,Optimal Two Impulse Transfer Maneuver

(2) G.A. McCue, "Optimal Two-Impulse Transfer and Rendezvous between Inclined Elliptical Orbits", *AIAA Journal*, August 1963.

(3)Pedro Escobal, *Methods of Astrodynamics*, John Wiley and Sons, 1968, Chapter 3.

(4)Pedro Escobal, *Methods of Orbital Determination*, John Wiley and Sons, New York, 1965.

(5) G. Leitman, *Optimization Techniques*, Academic Press, New York, 1962, Chapter 1.

S-BAND ANTENNA DESIGN AND CONSTRUCTION

FOR AMSAT PHASE 3C

*Hans van de Groenendaal ZS6AKV**

*Hennie Rheeder ZS6ALN***

SUMMARY

In 1981, SA AMSAT took the decision to become involved in satellite construction. Various projects were considered and practical experiments were carried out using balloon flights.

When Phase 3C projects were discussed, SA AMSAT was allocated the design and construction of the S-band antenna. Several designs were considered, built and tested:

1. Planar antenna.
2. Combination helix with S-band helix inside L-band helix.
3. Broad-band helix for both S and L-band.
4. Single S-band helix.

The paper discusses each design, construction and test results.

INTRODUCTION

At the Annual General Meeting of SA AMSAT held in Cape Town in October 1981, it was decided that SA AMSAT should get involved in the development of amateur satellites. The then President, Greg Roberts ZS1BI, approached various universities and industry for support of the idea. The main interest in the project came from members of the Amateur Radio Club at the University of Pretoria, ZS6TUK, and the Head of the Department of Electronic Engineering, Prof. Louis van Biljon.

In July 1984, Gordon Hardman ZS1FE/KE3D produced a memorandum setting out proposals for SA AMSAT's involvement in the PACSAT project. He proposed that SA AMSAT be responsible for the development of the ground station.

After some initial ground work, VITA, the sponsors of the project decided that, for control purposes, it would be better if the project was contained within the confines of North America.

SA AMSAT was without a satellite project!

**President SA AMSAT, P.O. Box 13273, Northmead 1511, South Africa.*

***Satellite Project Engineer, SA AMSAT, P.O. Box 13273, Nortmead 1511, South Africa.*

To keep enthusiasts occupied and involved, the BACAR project was developed by Dave Woodhall ZS6BNT. BACAR is the acronym for BALLOON CARRYING AMATEUR RADIO. Radio amateurs from all over Southern Africa were and still are involved in the BACAR project. Various transponders were developed and tested at 70 to 80 thousand feet above sea level. Mode A, reverse Mode A, Mode B and a Store and Forward Mode (Parrot - 2 metre FM) units were built and tested. The major effort with these launches is in the recovery of the equipment. We are not always lucky!

BACAR is an ongoing project, the current plan is to fly Packet Radio.

CHELTENHAM, ENGLAND 1984

In June, 1983, a meeting of various satellite groups was held in Cheltenham, England.

At the meeting it was agreed that South Africa would contribute the S-band antenna and the electronics for the control of the propulsion motor.

Once a full analysis was carried out, it turned out to be impractical to develop electronics 10 000 km from where the motor is manufactured. Finally, it was agreed that SA AMSAT would be responsible for the S-band antenna.

SPECIFICATIONS

At first little specifications were available, so the design team under the leadership of Hennie Rheeder ZS6ALN agreed to work to the following specification:

S-band Antenna Specification

Centre frequency	:	2,4 GHz
Gain	:	To match an 8 turn helix.
Size	:	As small as possible.
Position on SC	:	Around the 145 and 435 MHz omni antennas in the centre of the spacecraft.

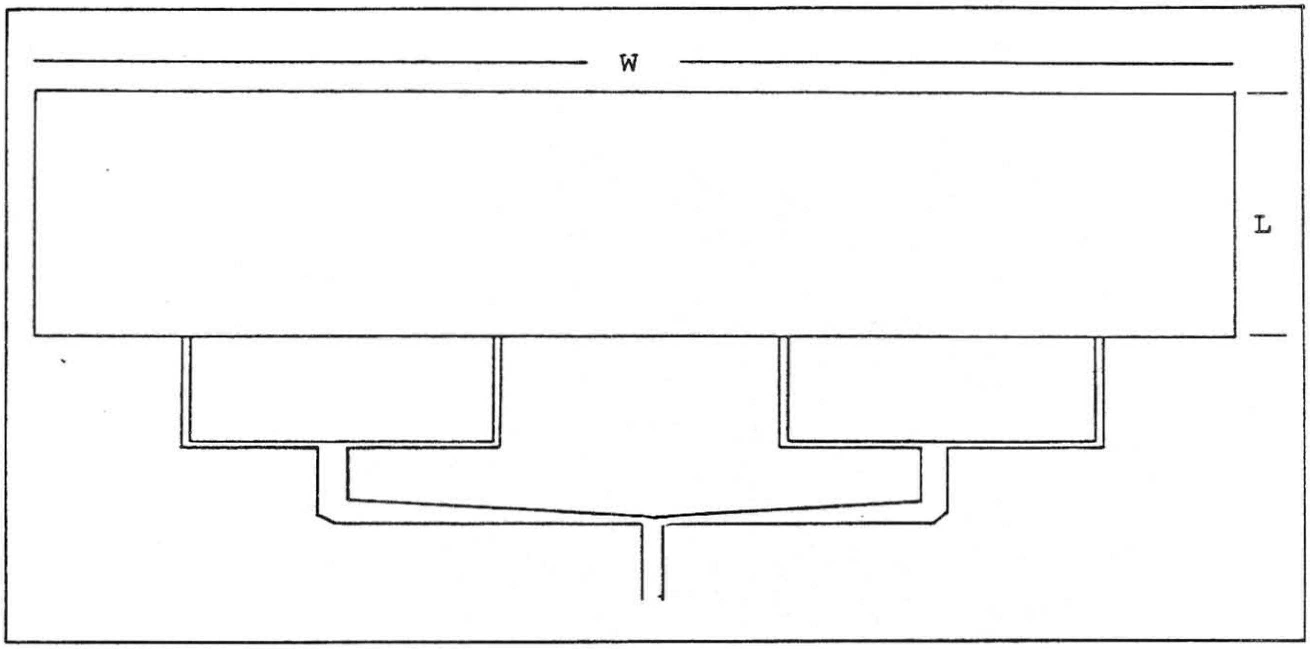
THE PLANAR ANTENNA

The design team discussed several ideas. The helix was reviewed in detail, but as it is a standard antenna, the team decided to look for something more unusual.

The planar antenna was agreed on. The planar antenna is a microstrip constructed from high quality printed circuit board. By mounting two to four antennas flat on the satellite surface and interconnecting them with a suitable matching harness, the required gain and a circular polarization pattern could be achieved.

The first planar antenna built measured 280 x 100 mm. A second model measured 205 x 100 mm.

Fig. 1 shows the design.



1) $L = \frac{\lambda_o}{2}$

Where λ_o = wavelength taking velocity factor into account.

2) $\text{Gain} \doteqdot \frac{0{,}9 \times 8W}{\lambda_o}$ for $\frac{W}{\lambda_o} \gg 1$

Where the 0,9 factor represents 90% efficiency.

Gain dB = 10 Log 10 (Gain)

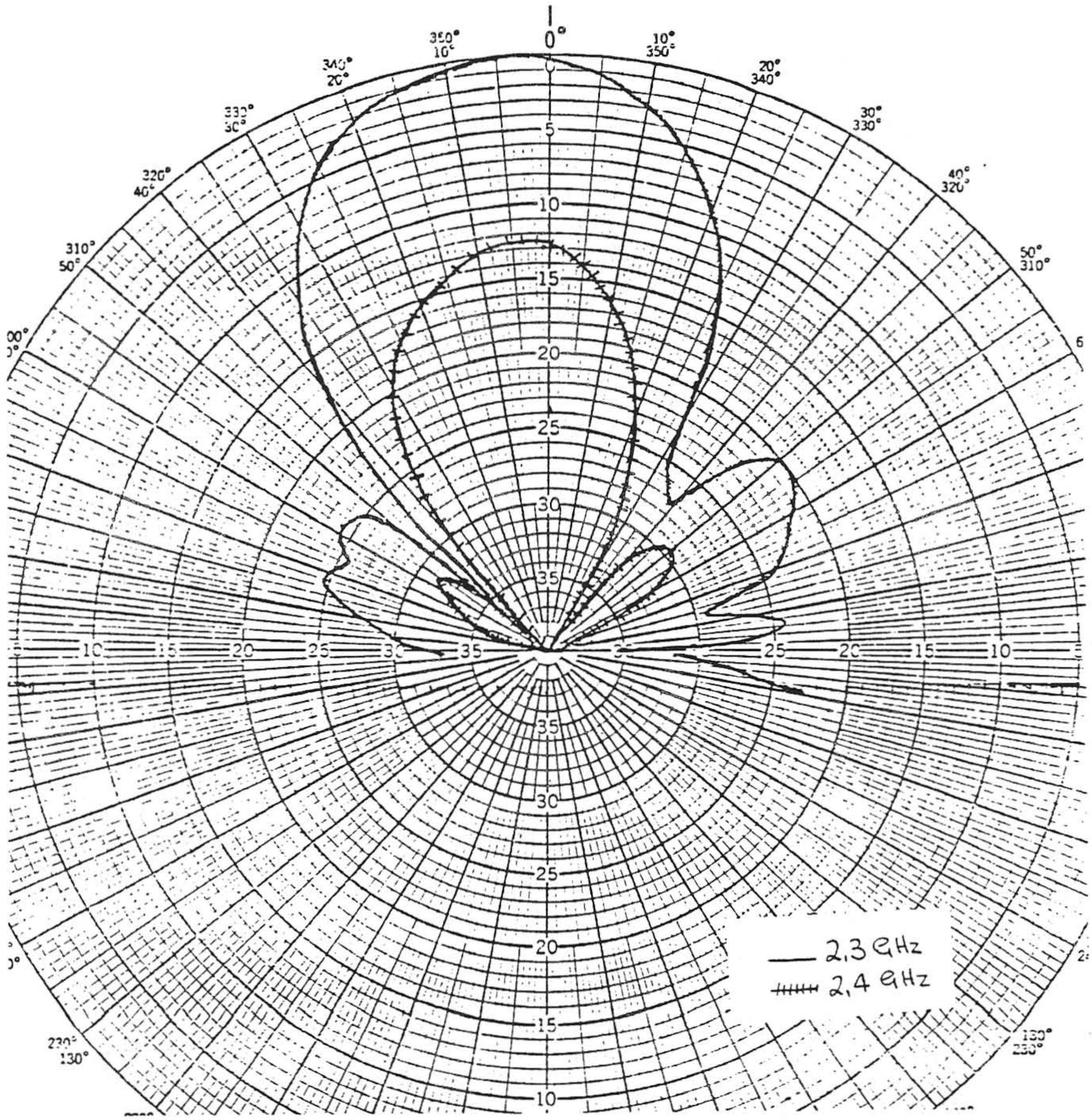
Fig. 1 - Planar Antenna

TEST RESULTS

Max. gain : 10,2 dBi at 2;33 GHz

VSWR : 1,42:1 at 2,32 GHz

-3dB bandwidth : 60 MHz



The antenna performed well. We were not concerned with the slightly higher resonant frequency, as with experimentation the design parameters would be modified to meet the correct specification.

The S-band team in Boulder reviewed the concept and tabled one major area of concern: Would the micro-strips adversely affect the spacecraft's thermal constraints?

An extensive search was instituted for materials with high heat transfer conductivity. No suitable material was found; generally no test results to determine the PC board's influence on temperature control were available.

It was agreed to shelve the idea and to change direction. Work on the planar antenna will, however, continue as part of the BACAR project.

DESIGN OPTION 2

S-band helix inside a L-Band helix

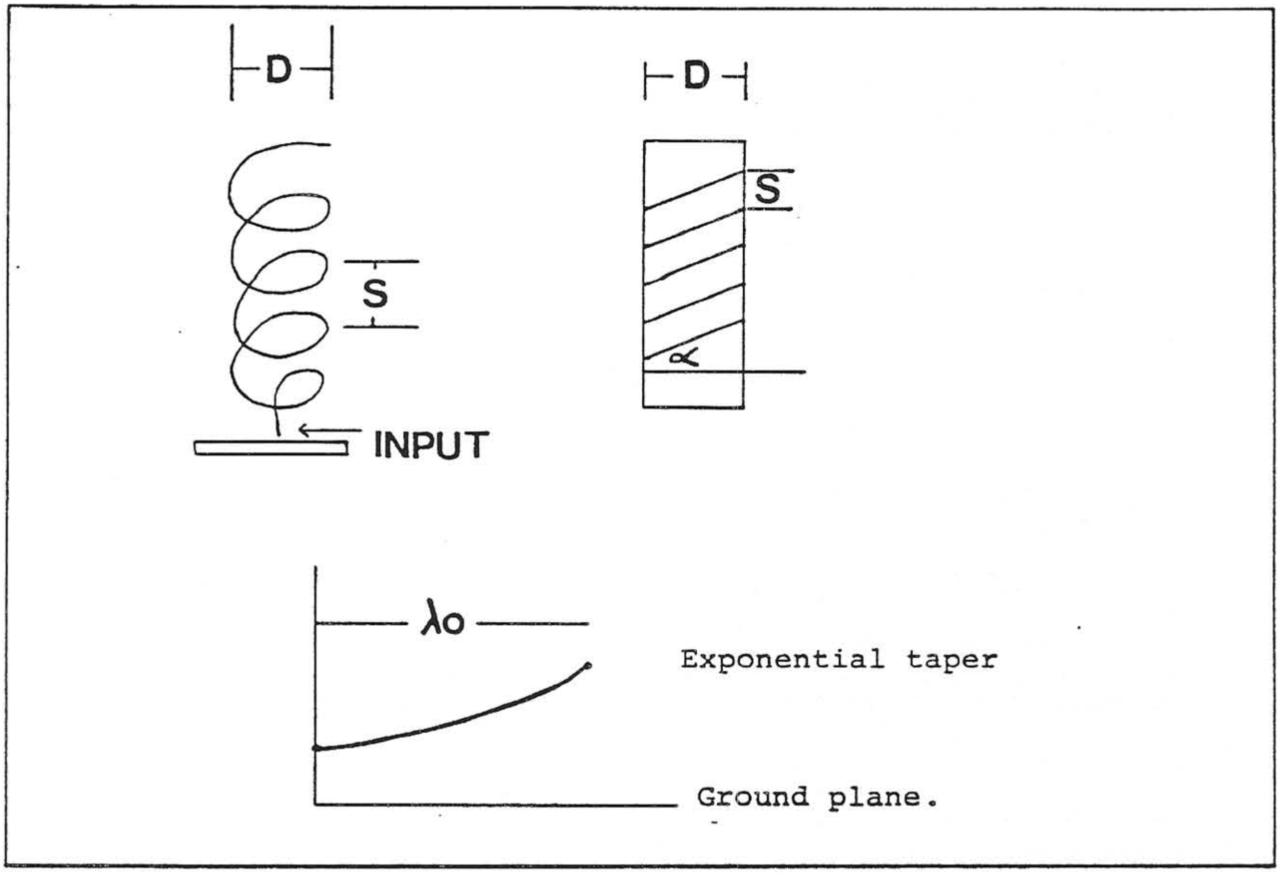
After careful discussion and consideration of the various factors involved, it was decided to design a combination S-band and L-band antenna, two helices, one inside the other.

The idea sounded simple and logical. Despite an extensive literature search, no reference to two helices, one inside the other, could be found. The team set to work and produced a design. From a theoretical point of view the antennas should meet the required specifications. The construction of this configuration was further complicated by the omni-directional antenna, which is mounted in the centre of the two helices. It was decided to first build a model of the two helices.

A test model was made using the following materials:

- Two rectangular pieces of fibreglass material 80 mm in width and 500 mm in length 2 mm thick with slots cut lengthwise, epoxied together, offering a figure x coil-former with diameter of 80 mm.
- Two rectangular pieces of polycarbonate 15 mm by 6 mm by 10 mm thick epoxied to the x coil-former as base.
- 10 turns of copper wire with diameter of 1 mm to form two helices with diameters of 40 mm and 75 mm and elngths of 250 mm and 480 mm respectively, wound through pre-drilled holes.
- Two SMA connectors offer separate feedpoints for the exponential pitch matching sections of the first copper wire turns respectively.
- 300 mm square sheet aluminium offers the ground plane attached to the polycarbonate base tapped for 3 mm diameter bolts.

Fig. 2 shows the design formulae:



1) Input impedance $\doteq$ 150 ohm

2) Tapered line is used for matching to 50 ohm on first turn length of λo.

3) $\pi D = \lambda o$.

4) Gain $= 15 \left(\frac{\pi D}{\lambda o}\right)^2 \frac{N.S}{\lambda o}$ N = Number of turns

$6° < \alpha < 12°$

Axial ratio $= \frac{2N+1}{2N} \doteq 1$ for ciruclar polarisation

5) Half-power beam width $= \frac{52°}{\left(\frac{\pi D}{\lambda o}\right)\sqrt{\frac{NS}{\lambda o}}}$

Where o = wavelength taking velocity factor into account.

TEST RESULTS

L-Band

Max. gain	:	14 dBic at 1,18 GHz (< 1dB ripple with antenna checked against a rotating linearly polarised antenna)
Gain	:	12,3 dBic at 1,27 GHz
VSWR	:	1,37:1 at 1,269 GHz
-3dB bandwidth	:	> 300 MHz

S-Band

Gain : The gain measurement was interrupted by unexpected rain and prevented readings.

Relative gain :

Frequency	Vertical Polarisation	Horizontal Polarisation
2,45 GHz	+ 8,3 dB	+ 9,6 dB
2,4 GHz	0 dB	0 dB
2,34 GHz	+ 9,5 dB	+ 8,9 dB

VSWR	:	1,66:1 at 2,4 GHz
-3 dB bandwidth	:	Not definable.

The antenna gain at frequencies representing best performance appears to be adequate, as does the majority of sidelobe levels, which are generally suppressed 10 dB or more. The problem, however, is the vast fluctuation found mainly on the S-band helix. It is suspected that this is due to interaction between the two antennas at resonant and near resonant frequencies. The effect is like that of a transformer.

The fact that the two helices were wound in the opposite direction, did not seem to make any difference.

The coupling between the two helices was less than 20 dB, as measured with a network analyser.

DESIGN OPTION 3

At this stage, time became a major factor. After reviewing the option, it was agreed to tackle the project on a parallel basis:

(a) Continue with experiments to construct a combination antenna.

(b) Construct a single S-band antenna.

S-Band Helix

As this is our first attempt at building an antenna to fly in space (BACAR 60 000 feet flights cannot be regarded as space), extensive investigations were carried out to select the core material. For the main core Tufnol (whale brand) was selected. A solid block of material was machined. The grooves were accurately determined to a close tolerance of 10 micron. The base was machined from B51S aluminium and treated with an alodyne finishing process. Bolts and nuts were used to attach the base to the core and the final turn of the winding are stainless steel. The winding was done with 1 mm diametre copper wire.

The connectors are gold-plated SMA, forced crimped and soldered.

TEST RESULTS

S-Band only Helix

Gain : 11,3 dBic at 2,41 GHz

VSWR : 1,3:1 at 2,4 GHz

Frequency/gain variation: : 10 dBic for both 2,31 GHz and 2,45 GHz

See attached polar diagram.

Although the S-band antenna performed well, it was felt that optimum results were not achieved. The antenna was shipped to the Boulder team for evaluation and as a possible standby, should an urgent requirement arise.

Favourable comments were received and suggestions noted for consideration in the construction of the final S-band antenna.

The Boulder team's main concern was the weight and suggested that the core be constructed in a honeycomb fashion. This could be achieved by drilling a series of holes in the structure.

L-Band and S-Band Single helix

Because of the tremendous bandwidth of a helix antenna, it was decided to design and build one helix capable of resonating at both S-band and L-band.

The practical results were disastrous. The radiation pattern was totally useless.

VSWR : 1,7:1 at 1,269 GHz

: 1,3:1 at 2,4 GHz

CONCLUSION

Although the S-band antenna project was a relatively small one, it has created new enthusiasm and has led to the establishment of committees of excellence. Meetings will primarily be arranged on the air.

Some of these committees of excellence will be dedicated to the Phase 4 projects.

References:

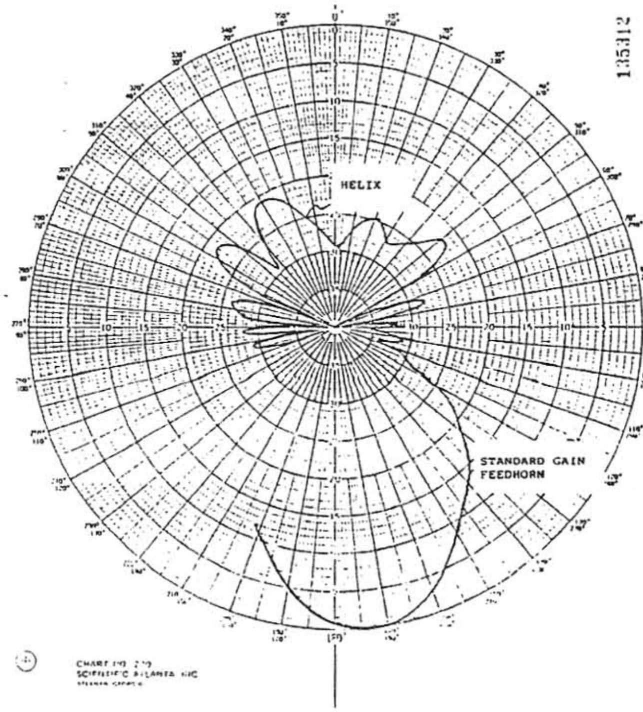
Bahl: Build microstrip antennas with paper thin dimensions. Microwaves - October 1979.

Martin Davidoff : The ARRL Satellite Experimenter's Handbook - ARRL 1985.

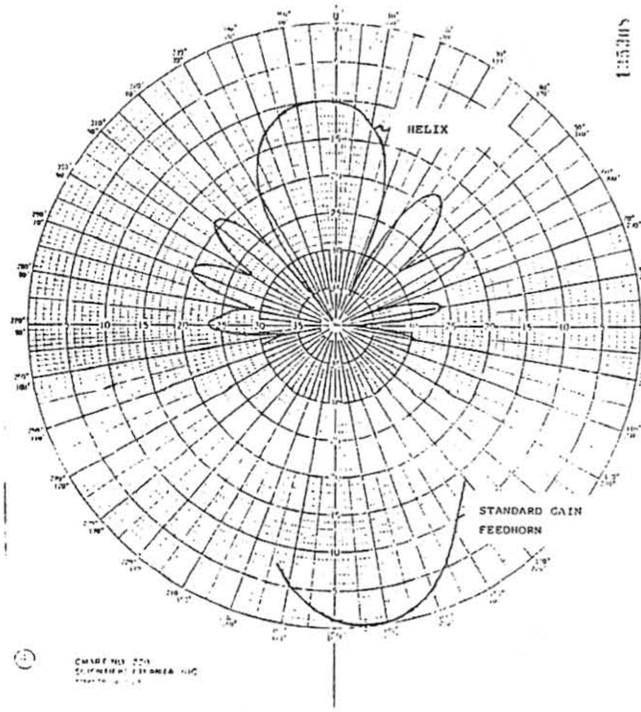
Stutzman & Thiele - Antenna theory and design - John Wiley 1981.

Personal communication with various experts on antennas.

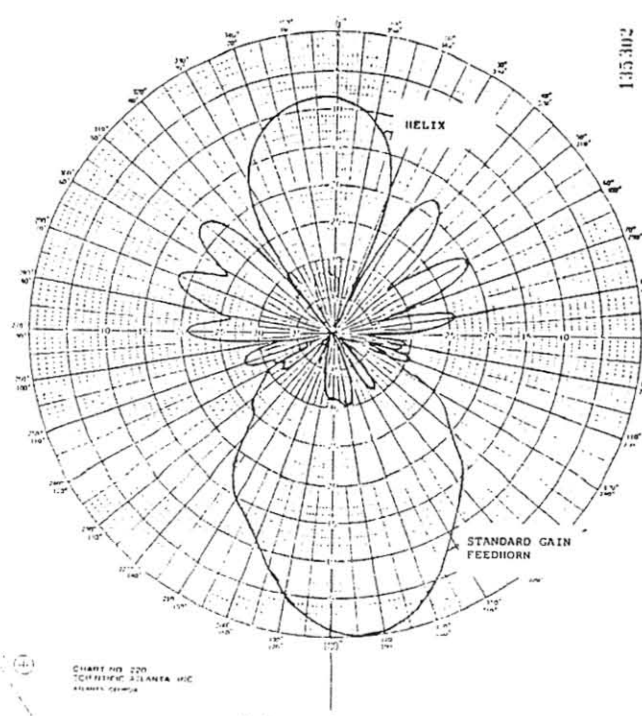
S-Band team in Boulder.



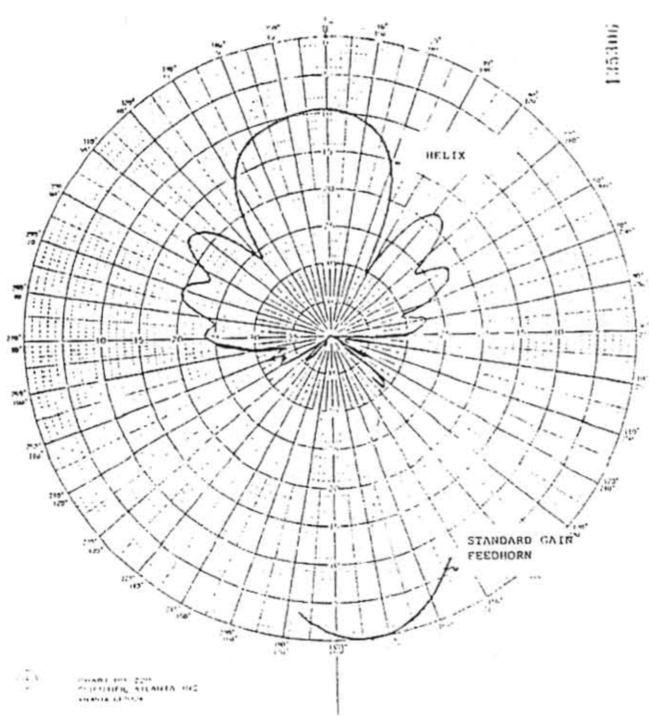
WIDE-BAND S AND L BAND HELIX PATTERN AT 2.4 GHz



S-BAND HELIX 2.45 GHz



S-BAND HELIX 2.41 GHz



S-BAND HELIX 2.31 GHz

AMSAT MODE-S TRANSPONDER

by

WILLIAM D. McCAA Jr., KØRZ

October 11, 1986

Background

It is hoped that the addition of an S-band transponder on Phase-3C will help the transition of the average amateur satellite user into the microwave frequencies. The ready availability of good low cost crystal controlled receiving equipment in the MDS (215Ø-216Ø MHz.) service can find immediate application in receiving a Phase-3C transponder in the 24ØØ-245Ø MHz. band.

Introduction

The S band output, Mode-S, transponder described herein has been developed for flight in the AMSAT Phase-3C satellite which is scheduled for launch in Mid 1987, on the first flight of the Arienne 4 launcher. Since this transponder is an add on to a Phase-3 type satellite, the power consumption and physical size had to be held to the constraints of the satellite's origional design. Thus power efficiency and size became major design considerations. The transponder's current drain from the satellite's 14.Ø VDC buss is Ø.54 Amps.

The transponder will operate either in the PSK (4ØØ baud) beacon mode or transponder mode, 3Ø kHz. bandwidth, usable for both NBFM and SSB and have an EIRP of +17 dBW. The spacecraft S band antenna is a left hand circular 15 turn helix.

The Mode-S transponder uses a portion of the Mode-B transponders receiver. A buffered output at 53 MHz. is taken from the Mode-B receivers first IF after AGC. The Mode-S transponder thus can be operated only when the mode-B receiver is active, while the Mode-S beacon can be operated at any time. The uplink power at 435 MHz. required for access will be the same as that required for mode-B (about 1ØØØ Watts EIRP max.).

Transponder Construction Status

The Mode-S transponder is completed. It has undergone Thermal-vacuum testing in the Phase-3C spacecraft in May, 1986, and has completed over 1ØØØ hours operation and burn-in.

Path Calculations at 2.4 GHz.

Transmitter output power at antenna	+Ø dBW
Spacecraft antenna gain (15 turn helix)	+17 dBic
Spacecraft EIRP	+17 dBW
Free space path loss (4Ø,ØØØ km @ 2.4 GHz.)	-192 dB
Signal level at receive antenna	-175 dBW
Receive antenna gain (1 meter dish @ 5Ø%)	+25 dBic
Signal level at receiver	-15Ø dBW
Receiver sensitivity (75K, 2Ø kHz.BW)	-16Ø dBW
Received signal to noise ratio	+1Ø dB

INPUT AND OUTPUT FREQUENCIES

The following details the frequencies used in the Mode-S transponder.

INPUT FREQUENCY TO THE S BAND TRANSPONDER (Fin)	435.625 MHz.
Input frequency from Mode-B transponder	53.3Ø5 MHz.
Local crystal controlled oscillator (LO1)	42.6Ø5 MHz.
Local crystal controlled oscillator (LO2)	41.93Ø MHz.
IF frequency including filter (IF=Fin-LO1-382.32)	1Ø.7ØØ MHz.
IF FILTER BANDWIDTH	3Ø KHz.
Beacon injection oscillator (BO)	1Ø.63Ø MHz.
3XLO2 injection frequency	125.79Ø MHz.
1st upconversion frequency (FI=3XLO2+IF)	136.49Ø MHz.
18X3XLO2 injection frequency	2264.22Ø MHz.
2nd upconversion frequency (Fout=54XLO2+FI)	24ØØ.71Ø MHz.
OUTPUT FREQUENCY FROM THE S BAND TRANSPONDER (Fout=Fin+56XLO2-382.32=57XLO2+IF)	24ØØ.71Ø MHz.
BEACON OUTPUT FREQUENCY (FB=57XLO2+BO)	24ØØ.64Ø MHz.

Modulation

The transponder is a soft limiting type that will be suitable for use by one or two NBFM signal or four simultaneous SSB signals. The nonlinearity introduced by the amplifier and limiter does not limit its usefulness to CW or FM only. Since the received signal to noise ratio will be less than 2Ø dB, SSB can be used thru the transponder as the intermod products are generally below 2Ø dB and thus below the received noise level. This technique is being used sucessfully in the Mode-L transponder on OSCAR-1Ø.

General Comments On The Transponder Use

It is necessary to point out that this transponder is intended for purely experimental and educational purposes. Through using it, it is hoped that the satellite users will gain operational and technical experience in receiving microwave frequencies from an amateur radio satellite.

The transponder can be used for normal voice and data communications via narrow band FM, CW or SSB modulation. Doppler shifts can be quite significant, up to 5Ø KHz. depending where the satellite is in its orbit. Doppler should be a minimun at apogee, and it is planned that the transponder or beacon will operate only at apogee.

Receiving SSB and CW requires less receiver bandwidth than NBFM. With reduced bandwidth, the required receiver sensitivity or antenna size decreases for a given signal to noise ratio. However, SSB and CW reception at 24Ø1 MHz. requires excellent receiver frequency control via a crystal controlled converter. With NBFM modulation, the ground station receiver could use AFC to overcome receiver drift and doppler.

Mechanical Packaging

The transponder is packaged in two separate housings.

PACKAGE 1   S-TX

This module contains the following:
S-Band mixer, S-Band amplifier, and 18X multiplier. It is mounted at the arm end next to Mode-B receiver. Package size is 10.0" X 2.23" X 3.00".

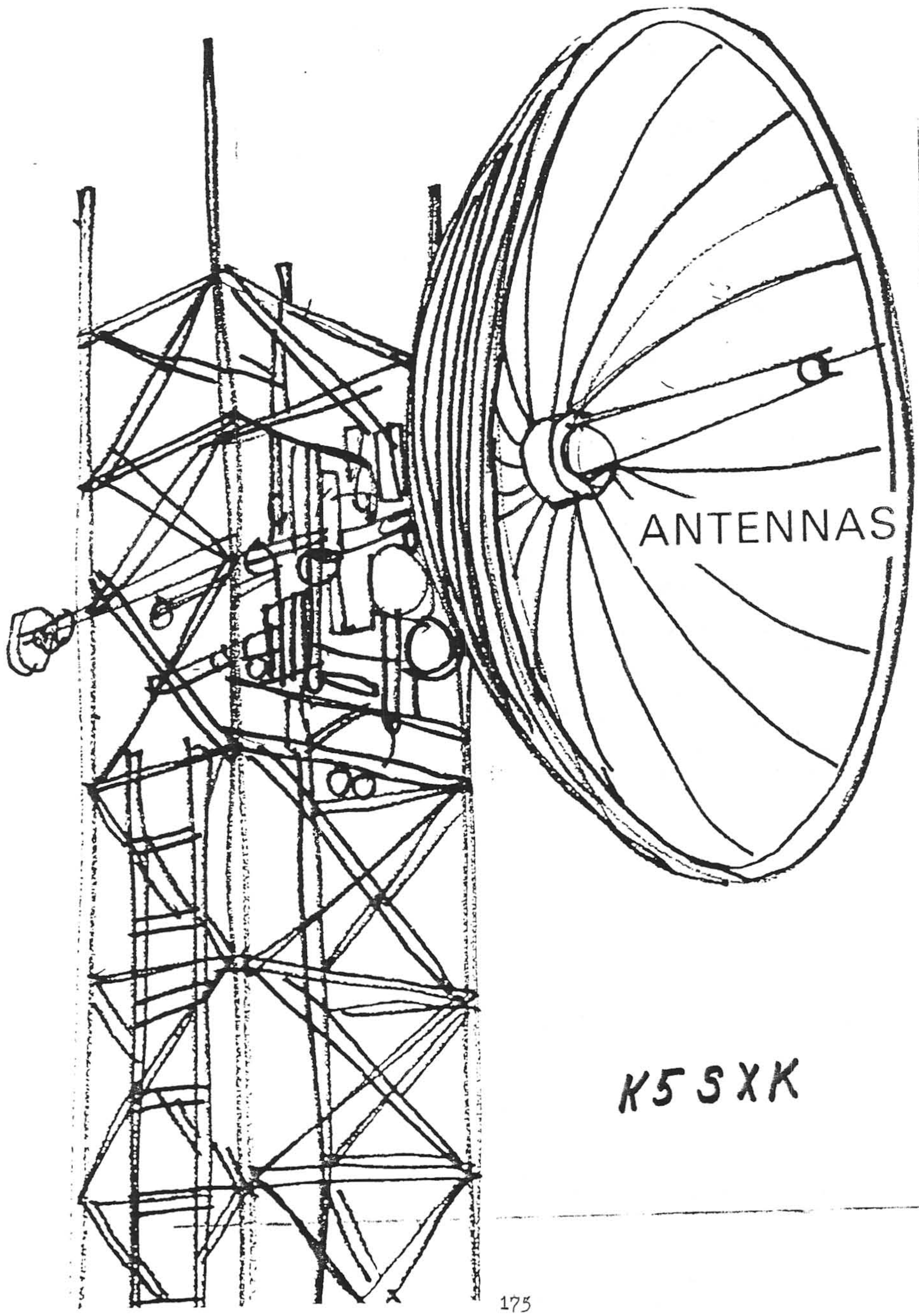
PACKAGE 2   S-IF

This module contains the following:
VHF stages, 10VDC converter, Beacon generator, 42 MHz. oscillators, 3X multiplier, and IHU interface. It is mounted on top of the Mode-B transmitter. Package size is 13.85 X 4.12" X 1.5".

Development Team

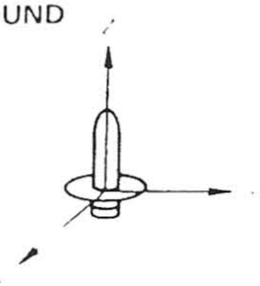
The development of this Mode-S transponder has been shared among many amateurs. The specific task leaders are listed below:

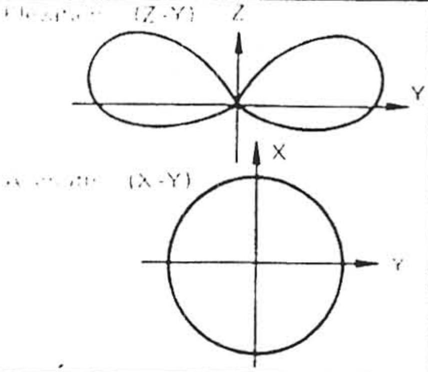
TASK AREA	RESPONSIBLE PERSONS	
Project Coordination, Construction	Bill McCaa,	K0RZ
S-Band Housing	Ray Uberecken,	AA0L
S-Band Miltiplier, and Mixer	Steve Ernst,	WB0WED
Local Oscillators and 3X Mulitplier	Chuck Hill,	KY0S
VHF Mixers, IF Amp, Control,	Gordon Hardman,	KE3D
Placement, Spacecraft Interface	Jan King,	W3GEY
S-Band RF Power Amplifier	Chip Angle,	N6CA
S-Band Antenna	Hans Van de G.	ZS6AKV


ANTENNAS
K5SXK

ANTENNA TYPE	RADIATION PATTERN	CHARACTERISTICS

QUARTER-WAVE MONOPOLE OVER SMALL GROUND PLANE





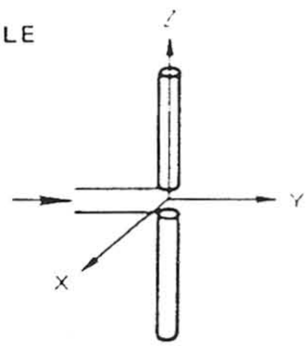
POLARIZATION
Linear

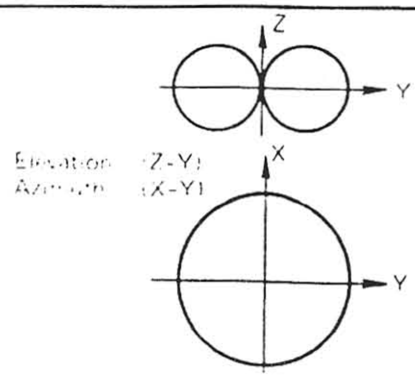
TYPICAL HALF-POWER BEAMWIDTH
50° x 360°

TYPICAL GAIN
5 dB

BANDWIDTH
15%

DIPOLE





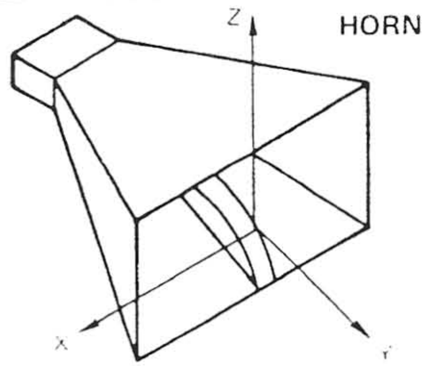
POLARIZATION
Linear

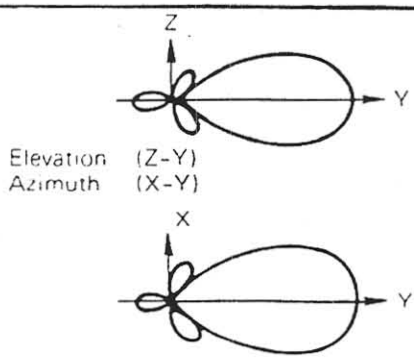
TYPICAL HALF-POWER BEAMWIDTH
80° x 360°

TYPICAL GAIN
2 dB

BANDWIDTH
10%

HORN





POLARIZATION
Linear

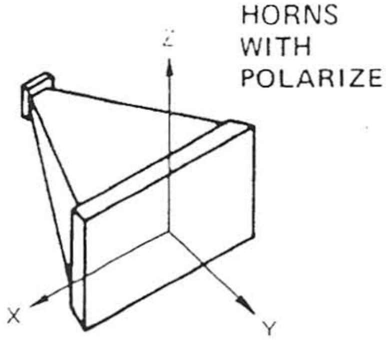
SYMMETRIC TYPICAL HALF-POWER BEAMWIDTH
40° x 40°

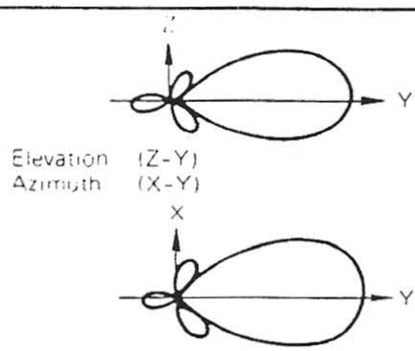
ASYMMETRIC BEAMWIDTH
20° x 60°

TYPICAL GAIN
5 to 20 dB

BANDWIDTH
4:1

HORNS WITH POLARIZER





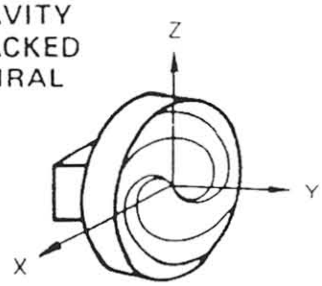
POLARIZATION
Circular

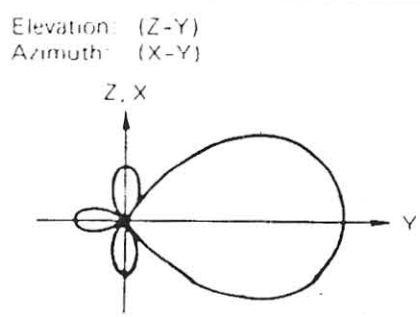
TYPICAL HALF-POWER BEAMWIDTH
40° x 40°

TYPICAL GAIN
5 to 10 dB

BANDWIDTH
2:1

CAVITY BACKED SPIRAL



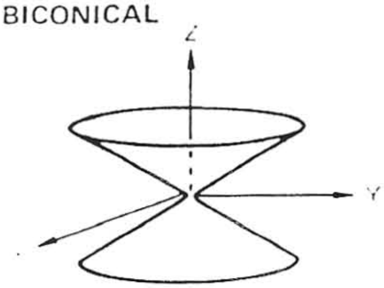
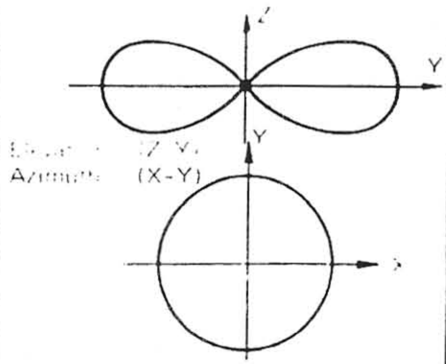
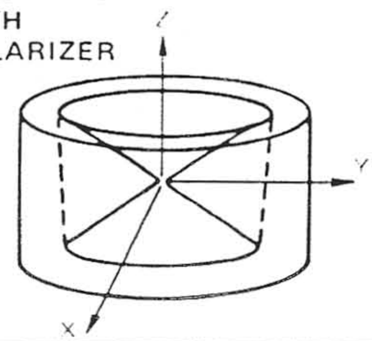
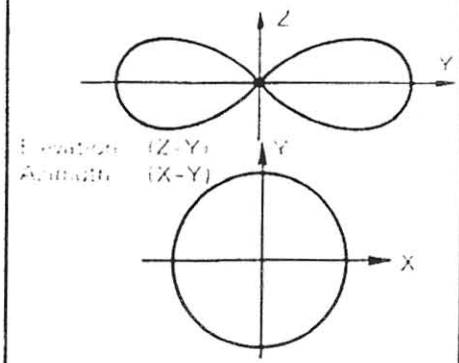
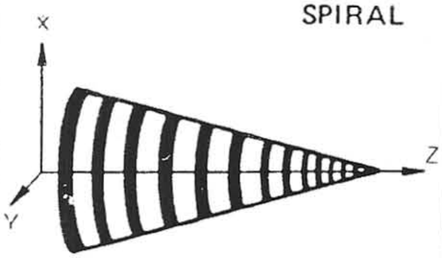
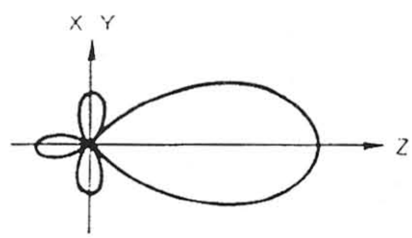
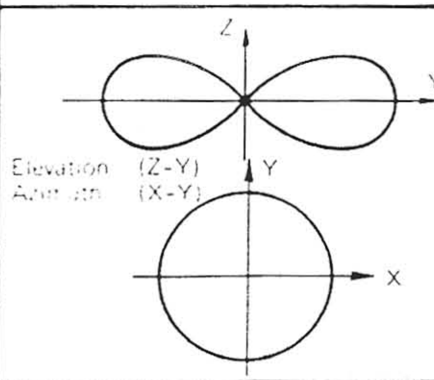
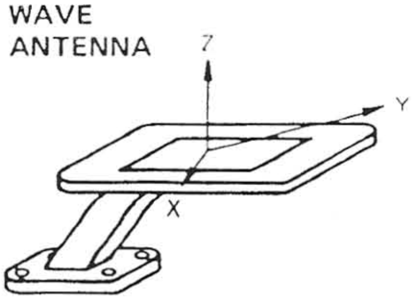
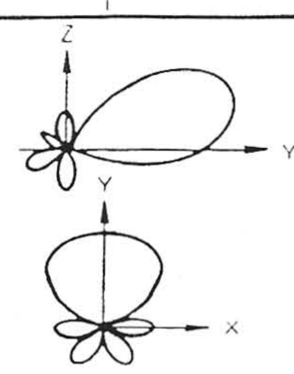


POLARIZATION
Circular

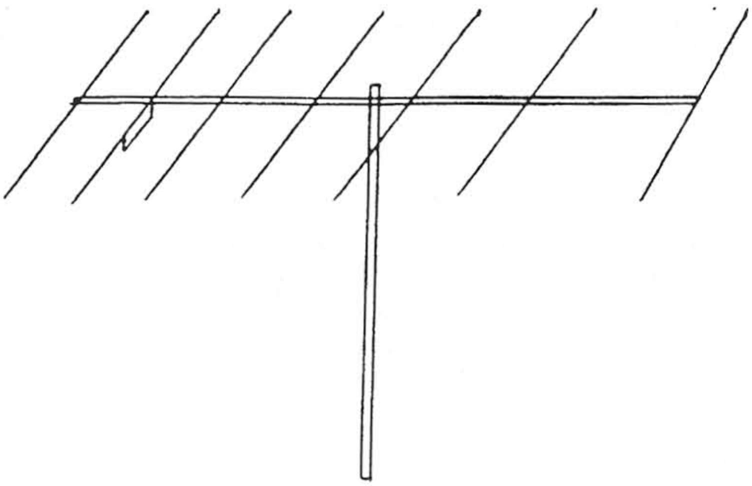
TYPICAL HALF-POWER BEAMWIDTH
80°

TYPICAL GAIN
-3 to +4 dB

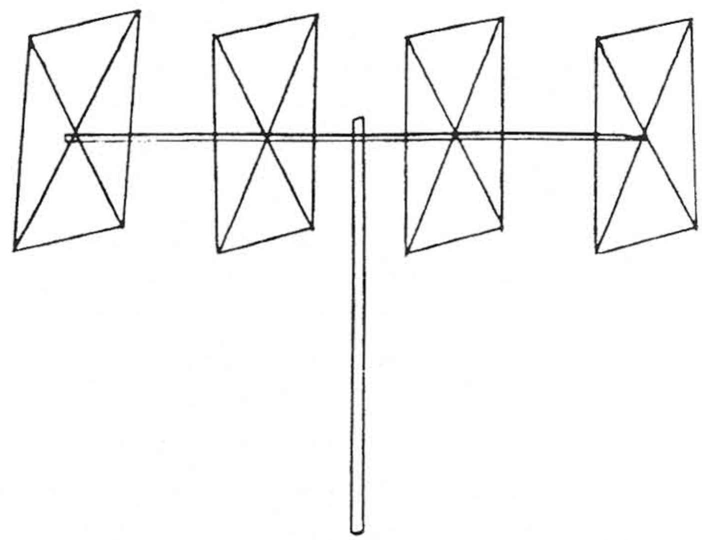
BANDWIDTH
40:1

<table>
<tr><th>ANTENNA TYPE</th><th>RADIATION PATTERN</th><th>CHARACTERISTICS</th></tr>
<tr><td>BICONICAL
</td><td></td><td>POLARIZATION
Linear
TYPICAL HALF-POWER BEAMWIDTH
20° 100° x 360°
TYPICAL GAIN
[illegible]
BANDWIDTH
[illegible]</td></tr>
<tr><td>BICONICAL WITH POLARIZER
</td><td></td><td>POLARIZATION
Circular
TYPICAL HALF-POWER BEAMWIDTH
20°–100° x 360°
TYPICAL GAIN
0 to 4 dB
BANDWIDTH
3 1</td></tr>
<tr><td>CONICAL SPIRAL
</td><td>Elevation (Z-X)
Azimuth (Z-Y)
</td><td>POLARIZATION
Circular
TYPICAL HALF-POWER BEAMWIDTH
60° x 60°
TYPICAL GAIN
5 to 6 dB
BANDWIDTH
4 1</td></tr>
<tr><td>4-ARM CONICAL SPIRAL
</td><td></td><td>POLARIZATION
Circular
TYPICAL HALF-POWER BEAMWIDTH
50° x 360°
TYPICAL GAIN
0 dB
BANDWIDTH
4 1</td></tr>
<tr><td>SURFACE WAVE ANTENNA
</td><td>Elevation (Z-Y)
Azimuth (X-Y)
</td><td>POLARIZATION
Linear
TYPICAL HALF-POWER BEAMWIDTH
25° x 60°
TYPICAL GAIN
12 dB
BANDWIDTH
20%</td></tr>
</table>

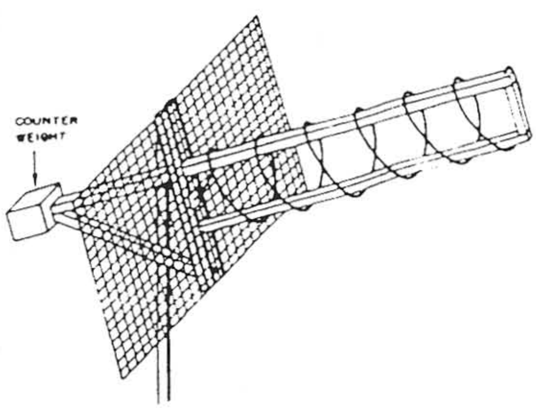
YAGI



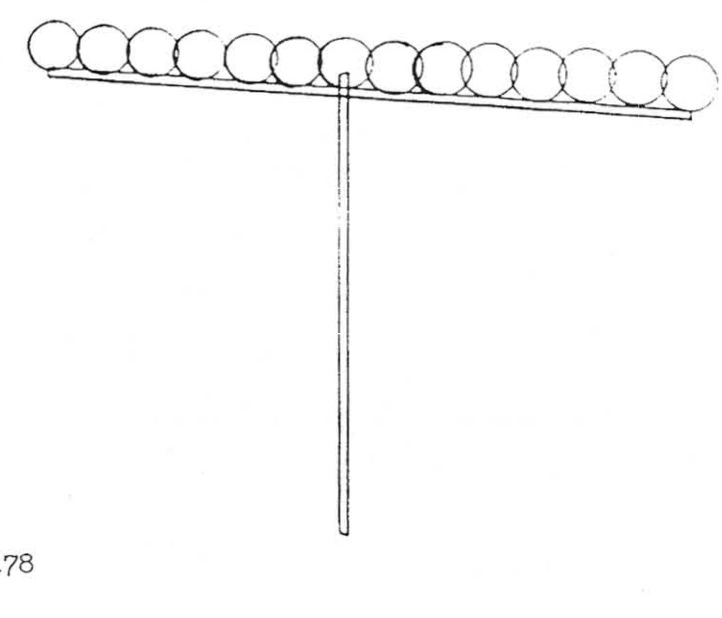
QUAD



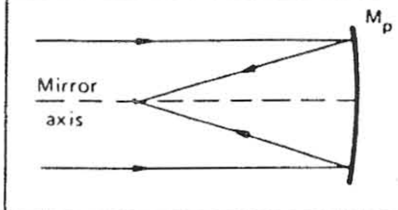
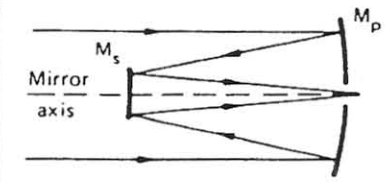
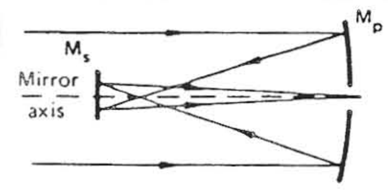
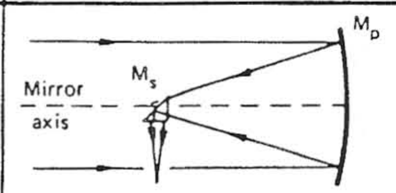
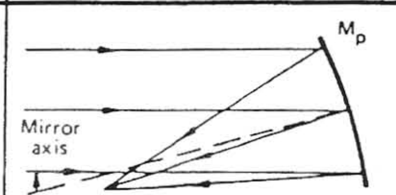
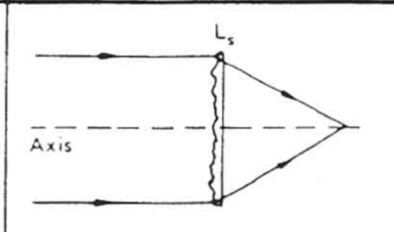
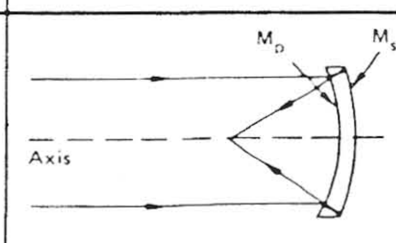
HELIX



LOOP-YAGI



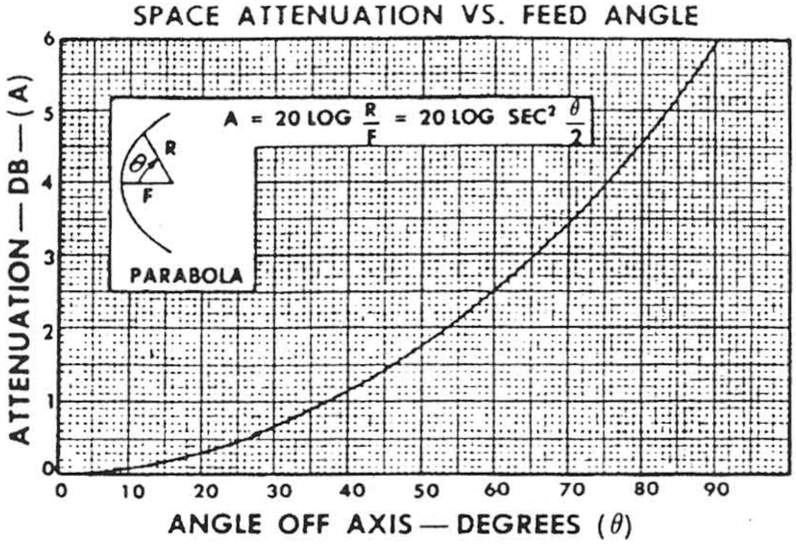
Quasi-Optical Apertures

TYPE	RAY DIAGRAM	OPTICAL ELEMENTS	PERTINENT DESIGN CHARACTERISTICS
PARABOLOID		Reflective M_p = Paraboloidal mirror	1. Free from spherical aberration. 2. Suffers from off-axis coma. 3. Available in small and large diameters and f/numbers. 4. Low IR loss (Reflective). 5. Detector must be located in front of optics.
CASSEGRAIN		Reflective M_p = Paraboloidal mirror M_s = Hyperboleidel mirror	1. Free from spherical aberration. 2. Shorter than Gregorian. 3. Permits location of detector behind optical system. 4. Quite extensively used.
GREGORIAN		Reflective M_p = Paraboloidal mirror M_s = Ellipsoidal mirror	1. Free from spherical aberration. 2. Longer than cassegrain. 3. Permits location of detector behind optical system. 4. Gregorian less common than cassegrain.
NEWTONIAN		Reflective M_p = Paraboloidal mirror M_s = Reflecting prism or plane mirror	1. Suffers from off-axis coma. 2. Central obstruction by prism or mirror.
HERSCHELIAN		Reflective M_p = Paraboloidal mirror inclined axis	1. Not widely used now. 2. No central obstruction by auxiliary lens. 3. Simple construction. 4. Suffers from some coma.
FRESNEL LENS		Refractive L_p = Special fresnel lens	1. Free of spherical aberration. 2. Inherently lighter weight. 3. Small axial space. 4. Small thickness reduced infrared absorption. 5. Difficult to produce with present infrared transmitting materials.
MANGIN MIRROR		Refractive-reflective M_p = Spherical refractor M_s = Spherical reflector	1. Suitable for IR Source systems. 2. Free of spherical aberration. 3. Most suitable for small apertures. 4. Covers small angular field. 5. Uses spherical surfaces.

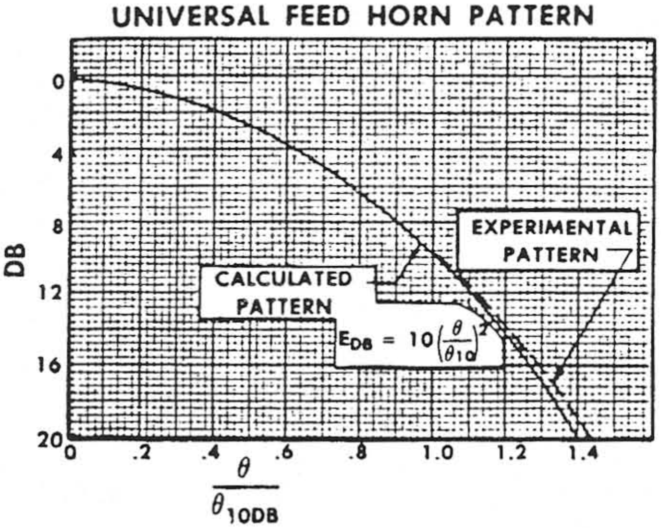
PARABOLIC ANTENNA

FEED DESIGN

SPACE ATTENUATION VS. FEED ANGLE



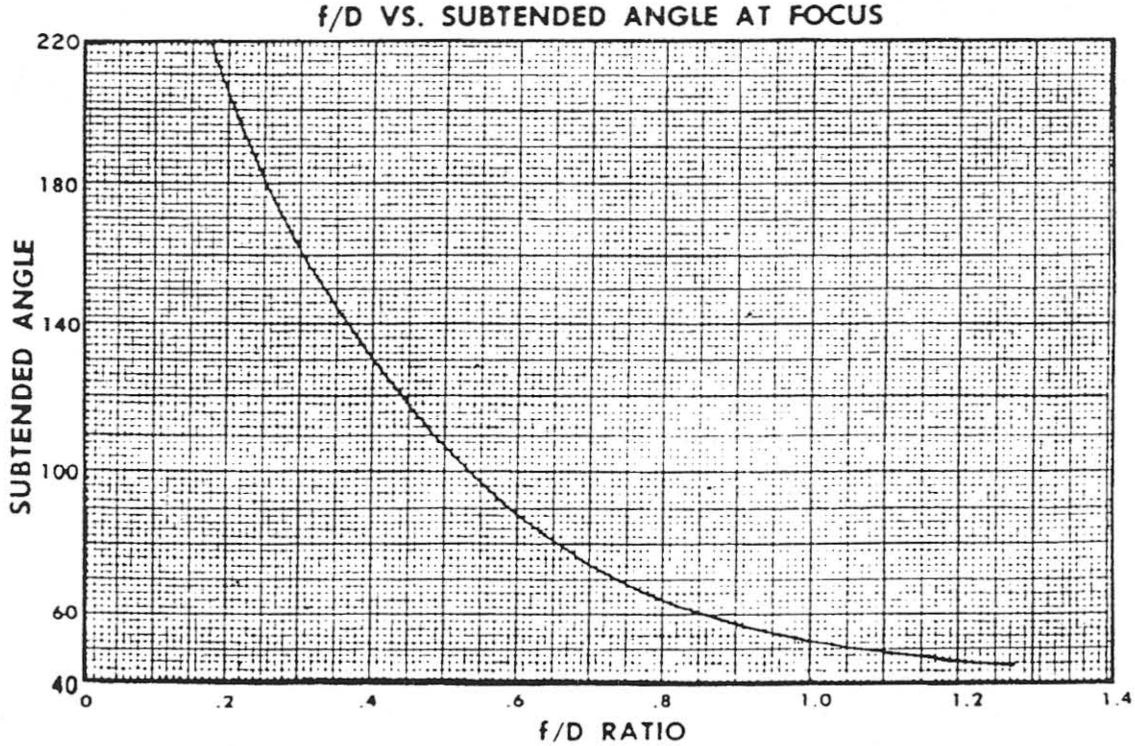
UNIVERSAL FEED HORN PATTERN



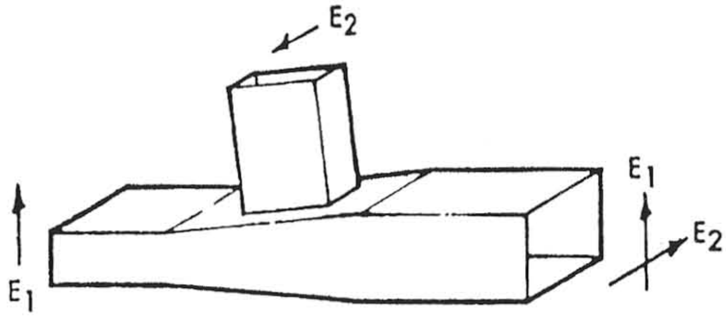
TO USE:

1. Start with aperture edge illumination & f/D.
2. Find feed angle using f/D.
3. Find space attenuation using feed angle.
4. Subtract space attenuation from desired edge illumination to get feed taper.
5. Find feed 10 db beamwidth using feed taper.

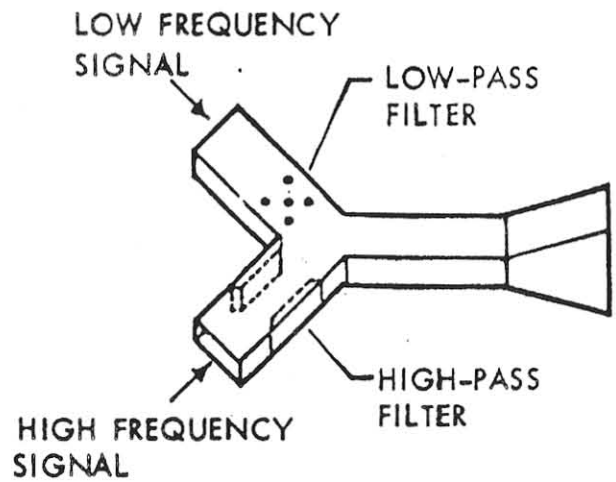
f/D VS. SUBTENDED ANGLE AT FOCUS



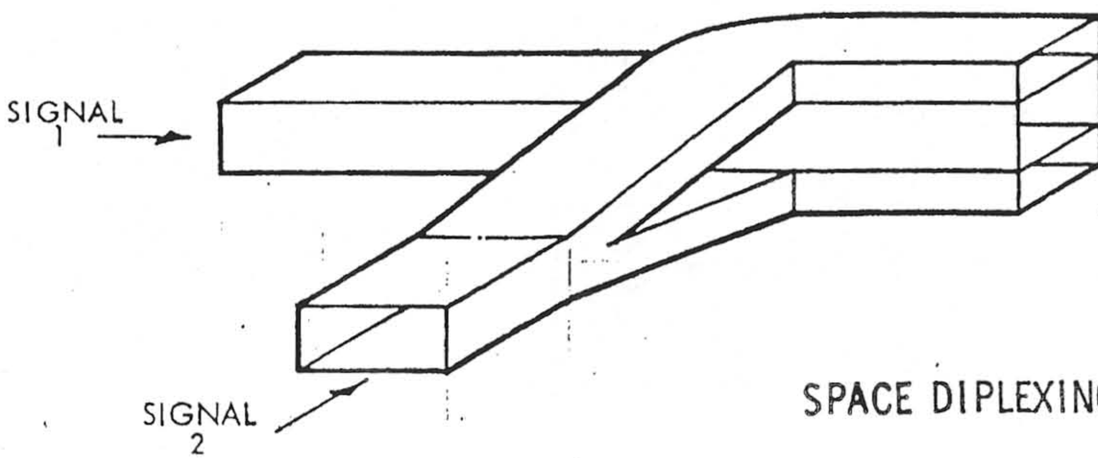
MULTIPLE FEED TECHNIQUES



POLARIZATION DIPLEXING

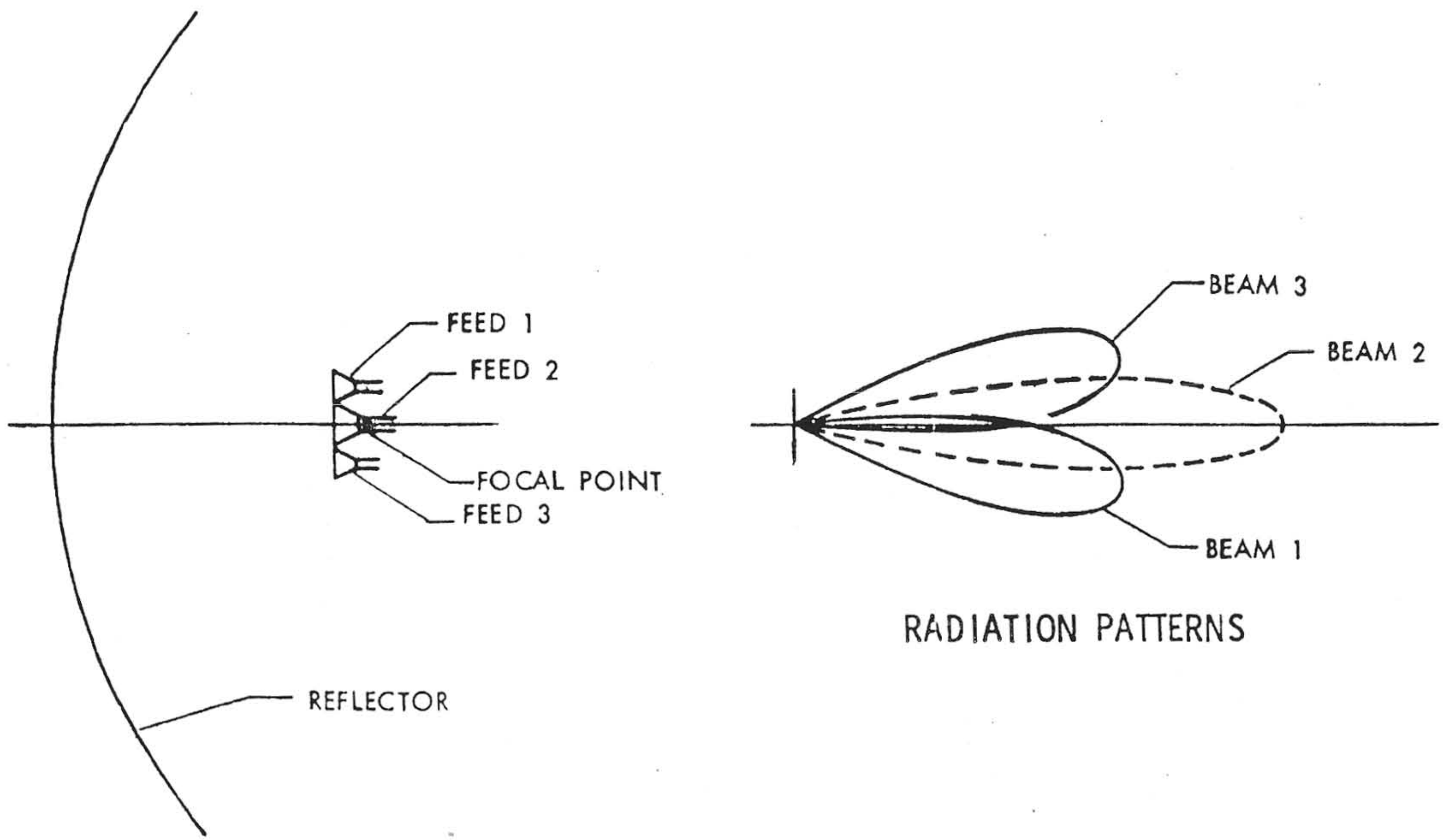


FREQUENCY DIPLEXING

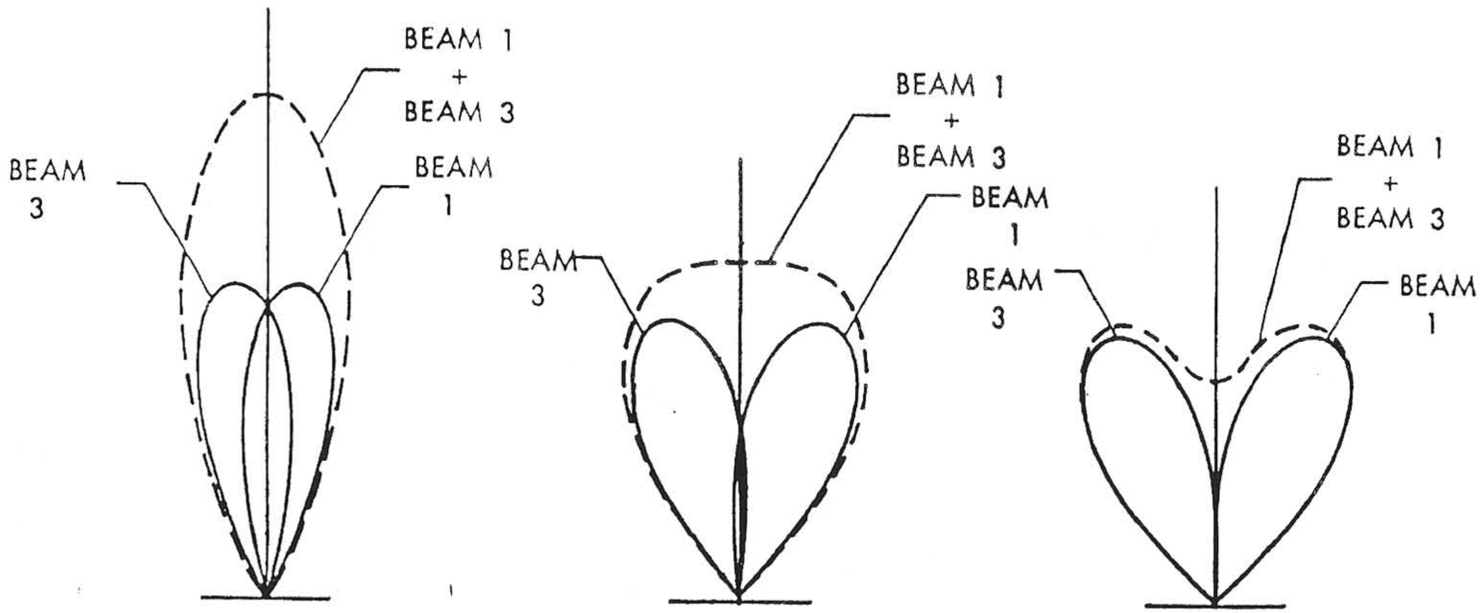


SPACE DIPLEXING

SPACE DIPLEXING TECHNIQUE



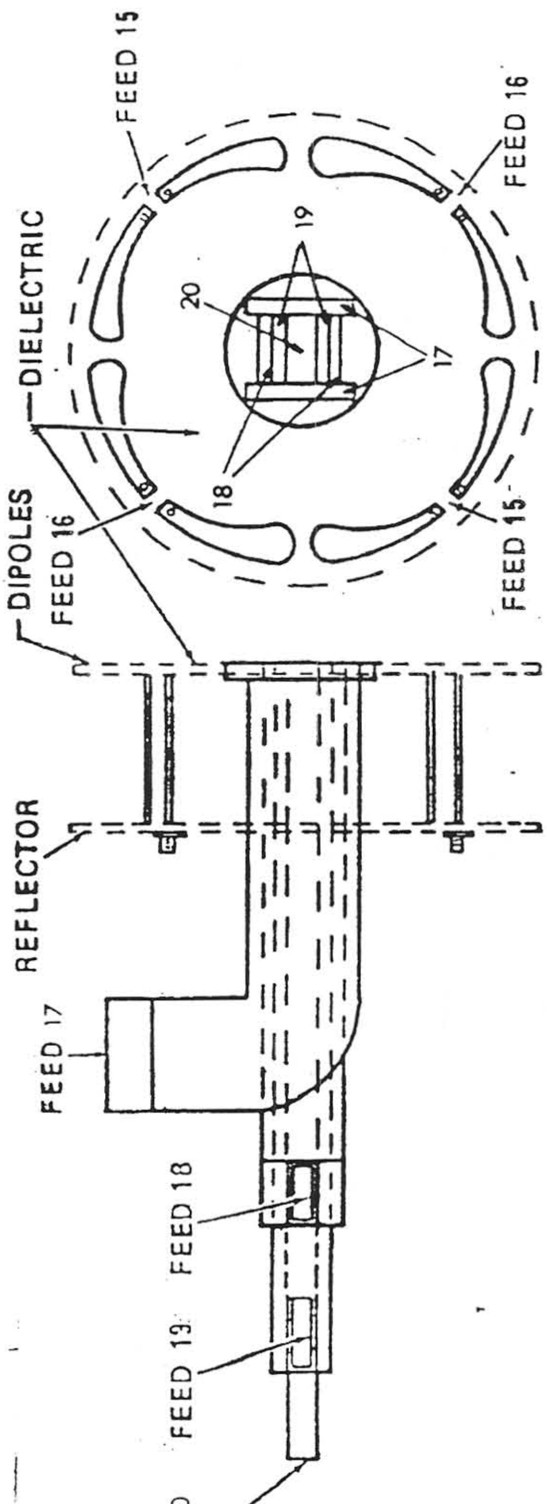
PATTERN COMBINATION

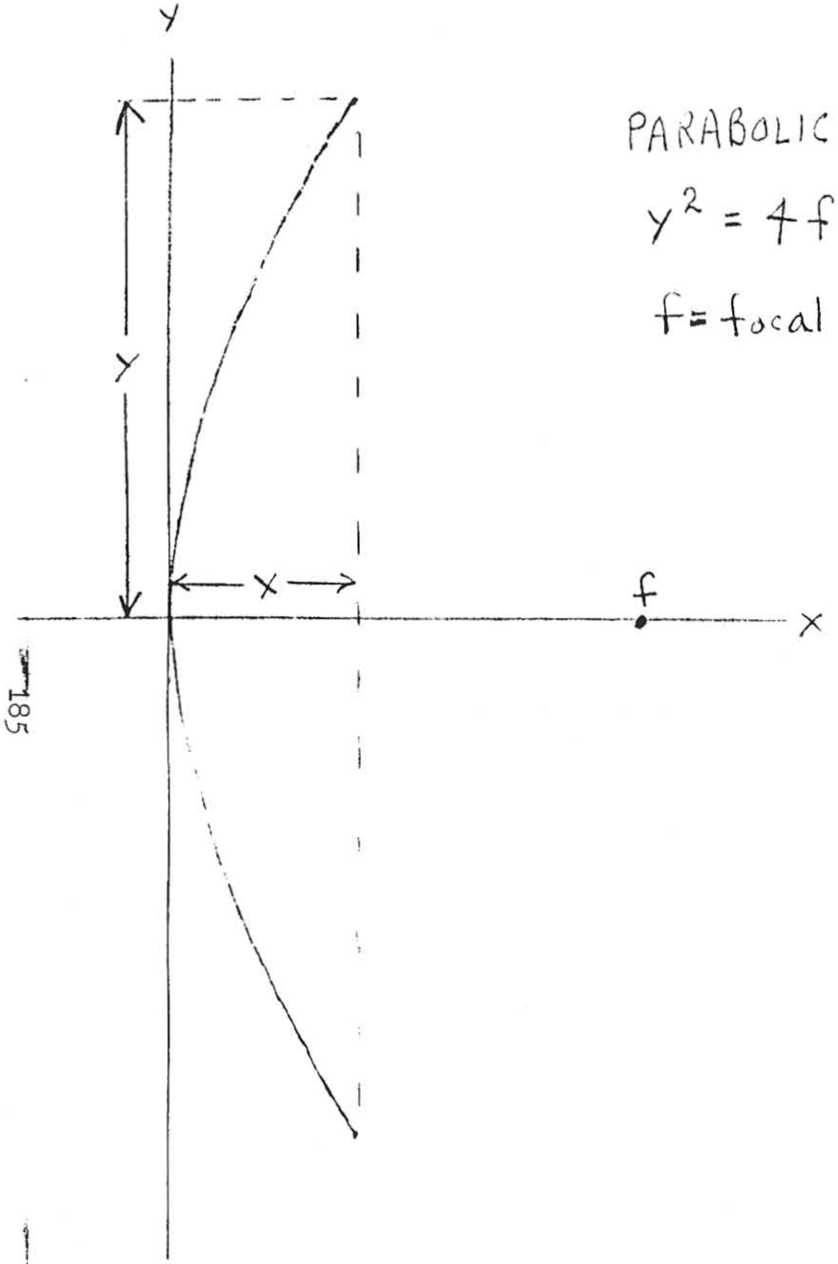


LESS THAN CRITICAL SEPARATION

CRITICAL SEPARATION

GREATER THAN CRITICAL SEPARATION


FEED 15
FEED 16
DIELECTRIC
19
20
17
18
DIPOLES
FEED 16
FEED 15
REFLECTOR
FEED 17
FEED 18
FEED 19
FEED 20



PARABOLIC SHAPE

$y^2 = 4fx$

f = focal Length

$$\text{FAR FIELD} = 2\frac{D^2}{\lambda}$$

OR

$$\text{FAR FIELD (ft.)} = 2\, D^2(\text{ft.})\, f(\text{GHz})$$