QEX

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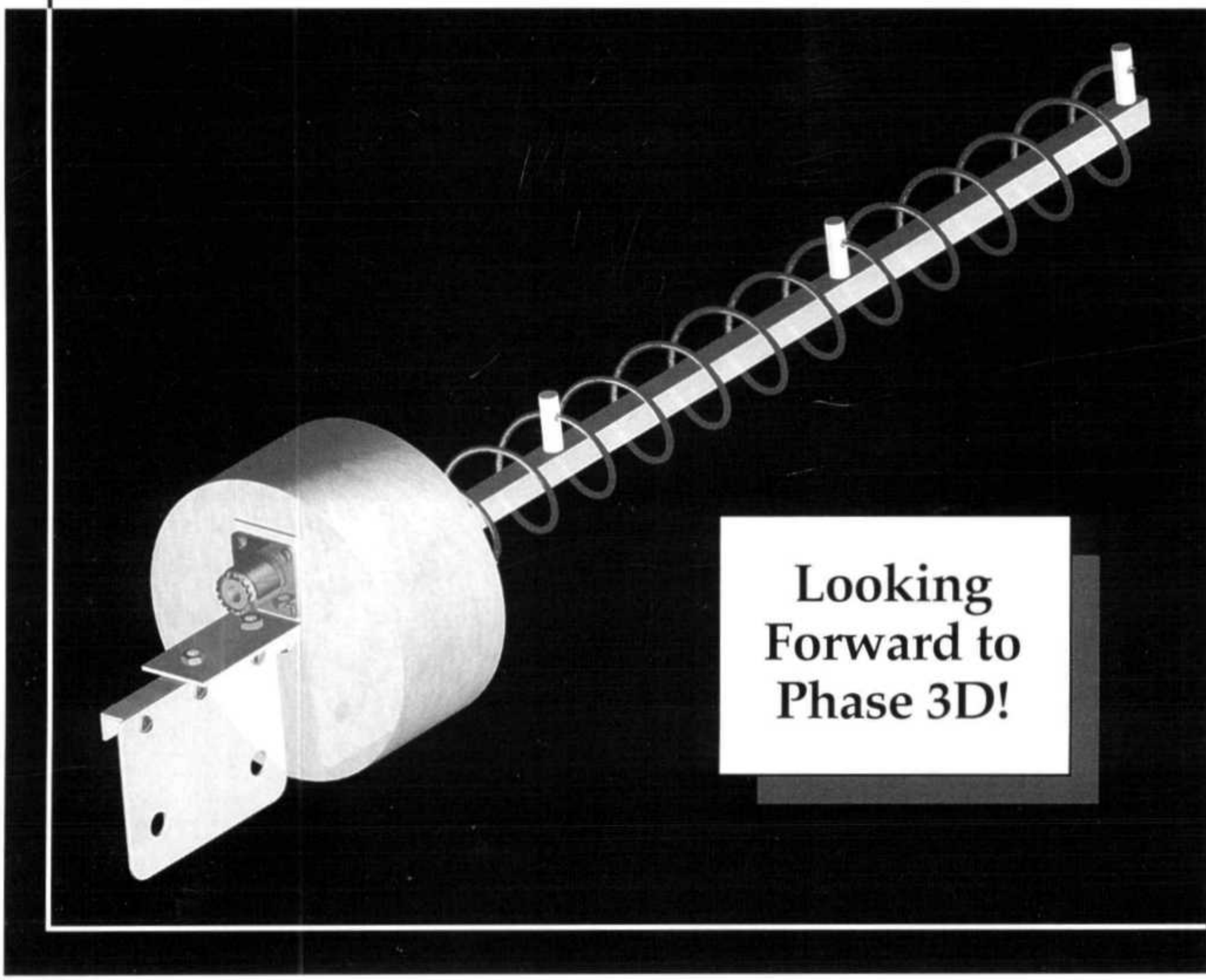
ARRL Experimenter's Exchange

September 1997



QEX: The ARRL
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American Radio Relay League
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QEX

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About the Cover

Need simple and practical ideas for P3D ground station? W1VT has some great ideas.

Features

Columns

September 1997 QEX Advertising Index

Empirically Speaking

Response to the *QEX* Restart

Just before we restarted *QEX*, we sent out a letter to all subscribers apologizing for the missing issues and offering to refund the outstanding balance to anyone who wanted to cancel. Well, we haven't had to send much money back. Instead what we received was a flood of enthusiastic support and encouragement. It is clear that you want this magazine to continue. That of course puts us (the Editor and all the support crew) squarely on the hot seat—we have to produce! Fortunately we have received some good material for future articles and we are processing it as quickly as possible to get future issues out on time. However, a periodical is a hard mistress that demands constant attention. Keep the material coming!

QEX is not just a place to find technical articles; it's an experimenter's forum. Although in the past there has been no regular section for letters to the Editor and comments on articles, we believe such correspondence would add to *QEX*. We will include at least some letters in future issues, experimentally.

Finally, this column has traditionally been a place to give you short bits of information of general interest. Help!!! I need input to help me fill this space.

Many of you would like to see more articles in *QEX*. Assuming that you start sending more articles our way, there's still the problem of economics. Some of you have suggested that we shift to a bimonthly—or even quarterly—schedule to cut costs, provide issues with more "meat", and perhaps make it easier to stay on track. We have an opportunity to switch to bimonthly or quarterly publication at the end of 1997. Rather than the monthly 24- to 32-page *QEX* you're used to seeing, we'd produce a 48- to 64-page bimonthly or a 72- to 96-page quarterly magazine. From our perspective, going to less than 12 issues per year is attractive because it would allow us to bring you more articles, reduce the burden on the staff, and allow *QEX* to come closer to breaking even financially. What do you think? By all means, drop me line and let me know your feelings on this. A change of regime is always an opportunity for experimentation.

Besides a new Editor, a new Managing Editor, Bob Schetgen, KU7G, has joined the crew to keep *QEX* moving at headquarters. In the past, and thankfully for the future, the day-to-day work of keeping *QEX* going has been done by Assistant Editor Maty Weinberg. She wields the whip to keep us all moving along smartly.

This Month in *QEX*

At this writing Phase 3D is scheduled for launch and hopefully all has gone well and the satellite is in a vacuum not an aquatic environment. Zack Lau, W1VT, and Ed Krome, K9EK, have provided two thought-provoking articles on ground stations and antennas for P3D. This should get you off and running to use this new satellite. It looks to me as though we will have to get some good dope on 5.7 GHz-and-up gear for future issues.

Direct-conversion receivers are always a popular topic but the time has come to start implementing digital technology for direct conversion. Peter Traneus Anderson, KC1HR, has provided a series of articles for *QEX* on this subject and this month ties them all together in a new article. To fully comprehend this latest article you should dig out your past issues to see how all this has developed.—*Rudy Severns, N6LF e-mail:* ***n6lf@arrl.org***

A Simple Synchronous-AM Demodulator and Complete Schematics for the DDC-Based Receiver

KC1HR adds AM reception to his digital-downconverter-based (DDC) receiver.

By Peter Traneus Anderson, KC1HR

This direct-conversion receiver is for signals from 10 kHz to 12 MHz.[1,2,3,4,5] Using an alias response adds coverage from 13 MHz to 22 MHz. Frequency conversion occurs digitally, giving performance impossible in conventional analog receivers. The dynamic range is not as good as that of the best analog receivers, but the filter skirts are sharper than those of analog receivers. For casual listening, the receiver performs very well.

The receiver operates in various modes: synchronous AM (SAM) with a –3 dB audio passband of 6836 Hz, upper sideband (USB) with a –3 dB passband of 1709 Hz, lower sideband (LSB) with a –3 dB passband of 1709 Hz and CW with –3 dB passbands of 1709 Hz, 427 Hz and 107 Hz.

The –102 dB passband is 1.4 times the –3 dB passband. For SAM mode, the –102 dB passband is 9570 Hz either side of the carrier, so an adjacent-station carrier 10 kHz away is not heard.

For the LSB and USB modes, the –102 dB passband is 2393 Hz, so SSB stations could be placed at 2400 Hz spacing, assuming the transmitters had the same passband as this receiver. For the CW modes, the –102 dB passbands are 2393 Hz, 598 Hz and 150 Hz.

In this DDC-based receiver, USB and LSB modes pass audio frequencies between 671 Hz and 2380 Hz for a total bandwidth of 1709 Hz. The recovered audio is very intelligible and the passband is narrower than the passband of narrowband voice modulation (NBVM).[6,7]

Receiver frequency, mode and gain settings are controlled by a personal computer (PC) through the PC's printer port. Preselector tuning and synchronous-AM control loop on-off are manually controlled.

The receiver uses Weaver's method for reception of SSB signals.[8,9] Weaver's method is also used for single-signal reception of CW signals. Synchronous-AM detection is used to receive strong AM signals. Weak AM signals or those with interference are best received in USB or LSB mode.

The heart of the receiver is the Harris HSP50016 digital downconverter (DDC).[10] Fig 1 shows a block diagram of the DDC, and Fig 2 shows the DDC pin arrangement for the 48-lead pin-grid array (PGA) package.

[1]Notes appear on page 8.

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The DDC is also available in a cheaper 44-lead plastic leaded-chip-carrier (PLCC) package. I used the PGA because the PLCC was not available in the fall of 1993. Keep in mind that this is an entirely digital device.

Analog Devices[11] and Graychip also make DDCs, but their 70 dB dynamic ranges are not suitable for this receiver. Also, the Analog Devices part is not yet real, and the Graychip part is prohibitively expensive in small quantities.

The high-frequency oscillator (HFO) has a complex output (two components 90° apart in phase).[12] The HFO is a direct digital synthesizer (DDS), also called a numerically controlled oscillator (NCO). The HFO frequency is the clock frequency multiplied by the ratio of two integers. The numerator of the ratio is loaded into the DDC by the PC. The denominator is fixed at 2^{33}.

The numerator can be set to values between zero and $(2^{32}) - 1$, giving HFO frequencies between zero and one-half the clock frequency.

The first pair of multipliers multiply the real input radio-frequency (RF) signal by the complex HFO sine wave. The resulting frequency-shifted signal is low-pass filtered to set the receiver passband: only RF signal frequencies close to the HFO frequency get through the filters.

The complex low-pass filter outputs (I and Q signals) contain frequencies from minus half the passband width to plus half the passband width. A given frequency component shows up in both I and Q, with a phase difference of 90° between I and Q. Positive and negative frequencies are distinguished by whether the phase difference is plus or minus 90°.[13]

In a conventional direct-conversion receiver, the I component alone drives the speaker. This gives the well-known double-signal effect: a given CW station can be heard at two settings of the HFO (HFO above and below the station frequency).

To get single-signal reception, the I and Q complex signal is multiplied by a second complex oscillator, the Weaver oscillator (WO). The real part of the result is taken as the audio signal for SSB and CW operation. This adds the WO frequency to the frequencies in the passband. The phase relationships and the precise digital math ensure that frequency components show up only where they should.

The WO frequency is fixed at a little more than half the passband width. This gives an audio passband starting a bit above zero and extending upward in frequency. The overall effect is that input RF components are shifted a constant amount in frequency to the output audio passband.

Fig 3 shows the receiver's front end. A double-tuned preselector (L1, L2 and the dual variable capacitor) drives a wide band amplifier (U16) with a gain of 10. The amplifier output drives a 12-bit analog-to-digital (A/D) converter (U14). The Burr-Brown ADS801U[14] is a reasonably good

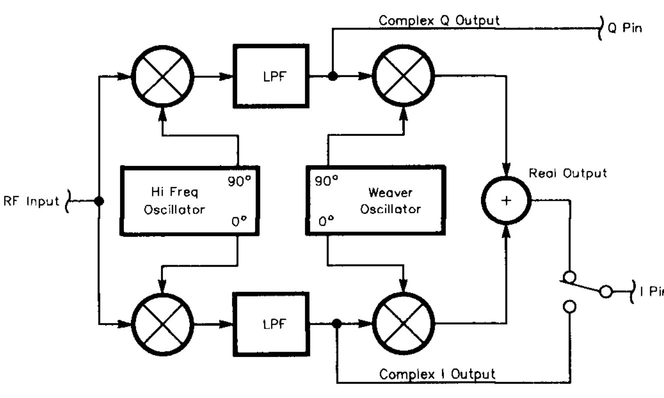

Fig 1—Block diagram of the Harris HSP50016 digital downconverter (DDC).

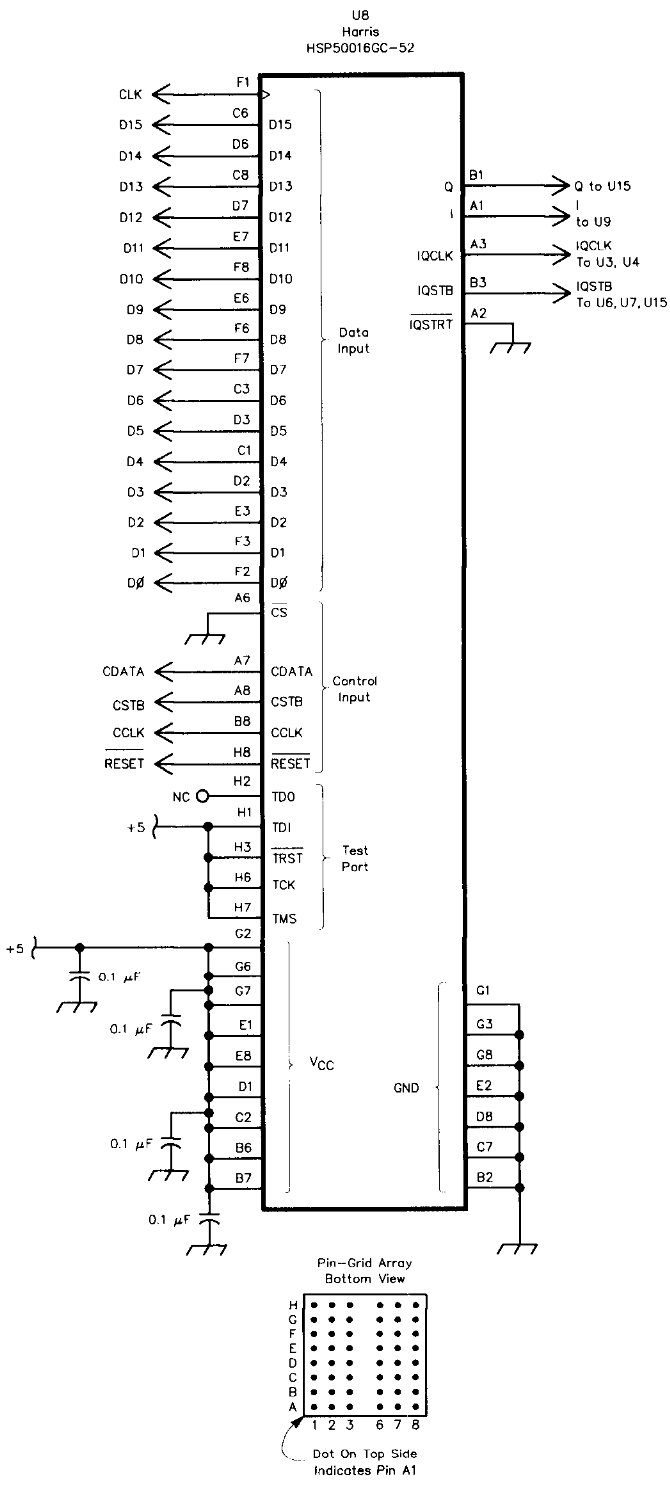

Fig 2—The digital downconverter (DDC).

12-bit A/D that is easier to use than some and is available from Digi-Key. The preselector uses plug-in coils for band changing.

I use miniature RF chokes for L1 and L2 and place the chokes close together for inductive coupling. For low-frequency listening, I use an untuned circuit consisting of a $10\,k\Omega$ resistor in place of L2, and a $0.1\,\mu F$ capacitor from the RF input to the hot end of the resistor. With this network, I have heard WWVB on 60 kHz and various stations from 100 kHz to 400 kHz.

For medium-wave broadcast-station listening, I use either the untuned circuit or a loopstick (from an old AM radio) in place of L2.

Recall that the DDC HFO frequency can be tuned from 0 to $^1/_2$ the DDC clock frequency. If you set the frequency to zero in one of the CW modes, you will hear a loud carrier at 0 Hz: You are listening to the dc offset in the A/D converter. My software limits the low end at 10 kHz to avoid this loud noise.

The DDC has only a product detector; so—by itself—it is incapable of conventional envelope-detection of AM signals. Instead, I use synchronous double-sideband product detection, with the DDC's HFO phase-locked to the AM-signal carrier frequency.

For SAM, the DDC is used in the complex mode, with the WO off and the low-pass filter I and Q outputs used directly. The I output of the DDC provides the demodulated audio to the D/A converter, and the Q output of the DDC is used to build a simple phase-locked loop (PLL) to synchronize the HFO to the incoming AM signal carrier. The circuitry added to create the PLL is shown in Fig 4.

The DDC passband is widened to 13672 Hz, to give an audio passband of 0 to 6836 Hz, to maximize audio fidelity while keeping the over-sampling ratio a power of two.

The PLL forces the dc component of the Q output to be zero. This puts the I component of the HFO in phase with the incoming carrier so that the I output has the demodulated audio.

A basic PLL contains a reference frequency source, a voltage-controlled oscillator (VCO), a phase detector, a low-pass filter (loop filter) and an amplifier (to provide loop gain). In this PLL (as in most PLLs in radios), there is also a digital frequency changer between the VCO and the phase detector. The frequency changer is conventionally a digital divider. In this case, the frequency changer is the HFO in the DDC.

The PLL reference frequency source is the incoming AM signal's carrier. The reference is digitized by the A/D converter (U14 in Fig 3) and sent to the DDC (U8 in Fig 2) along with the modulation sidebands and any other signals that get past the preselector.

The PLL VCO is the clock oscillator, U12 in Fig 3. The 10Ω resistor in

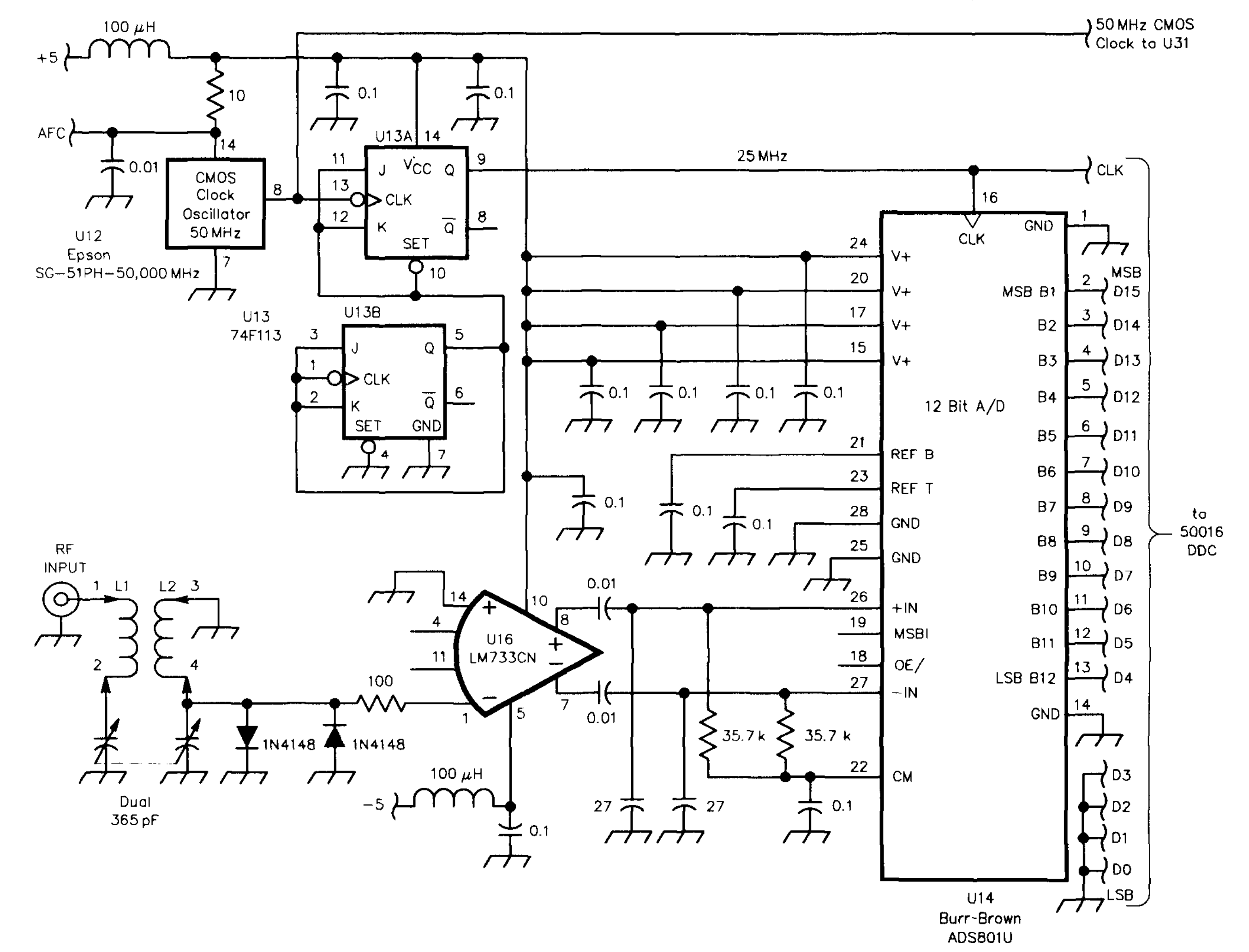

Fig 3—Preselector, preamp and A/D converter.

series with the oscillator supply pin permits the supply voltage to be lowered a few tenths of a volt, but not enough to take the voltage below the specified operating range. This varies the frequency of the oscillator over a 50-Hz range. The oscillator runs nominally at 50 MHz, so the variation available is 1 part per million (1 ppm).

The PLL phase detector is the multiplier in the DDC. The low-pass filter in the DDC provides part of the loop filter, removing out-of-passband signals from the loop.

The Q output is hard-limited to provide the loop gain needed. Flip flop U15 in Fig 4 captures the sign bit of the Q output of the DDC. U15 pin 9 goes high to clock the sign bit into U15B.

The Q output of U15B, pin 5, is used as a 1-bit D/A converter. U15 is a CMOS part, to provide rail-to-rail output swing. The Q output of U15B, pin 6, drives a pair of LEDs to give a visual indication of tuning frequency error and loop lock.

The loop filter is a single-pole RC low-pass filter using a 1000 Ω resistor and a 100 µF capacitor.

The PLL is manually turned off by switching from the 1000 Ω resistor to a series pair of 2200 Ω resistors. Thus, when the loop is off, the error signal is fixed at midrange. The 4700 Ω resistor between U15B pins 2 and 6, is an attempt to provide a computer-controlled PLL on-off function. The PLL is turned off by "tristating" the Q output. Unfortunately, this also turns off the LED tuning indicator, so I added a manual switch.

The 2N3906 PNP emitter follower provides current gain to drive the supply pin of oscillator U12, via the 68 Ω resistor. A 4 V swing on the base provides a 0.5 V swing to U12.

To tune in a strong AM station, first put the receiver in synchronous-AM mode with the PLL turned off. The beat between the AM carrier and the HFO will be audible in the speaker, and visible in the LEDs turning on and off alternately. Tune the HFO in 1 Hz steps until the beat is slowest, then turn on the loop. The speaker audio will clear, and the two LEDs will be equally bright on average (with much blinking in response to the audio).

The available lock range is about 1 ppm of the signal frequency, or 1 Hz of lock range per MHz of signal frequency. Thus, for a medium-wave broadcast station at 1000 kHz, the lock range is only 1 Hz. For a shortwave broadcast station at 6000 kHz, the lock

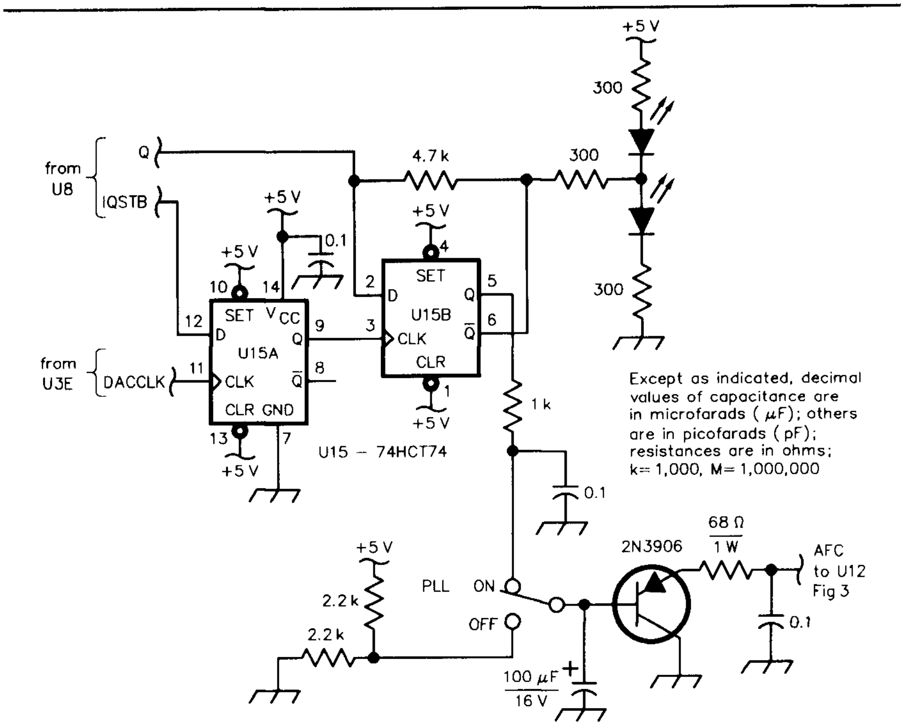

Fig 4—AM carrier synchronizer.

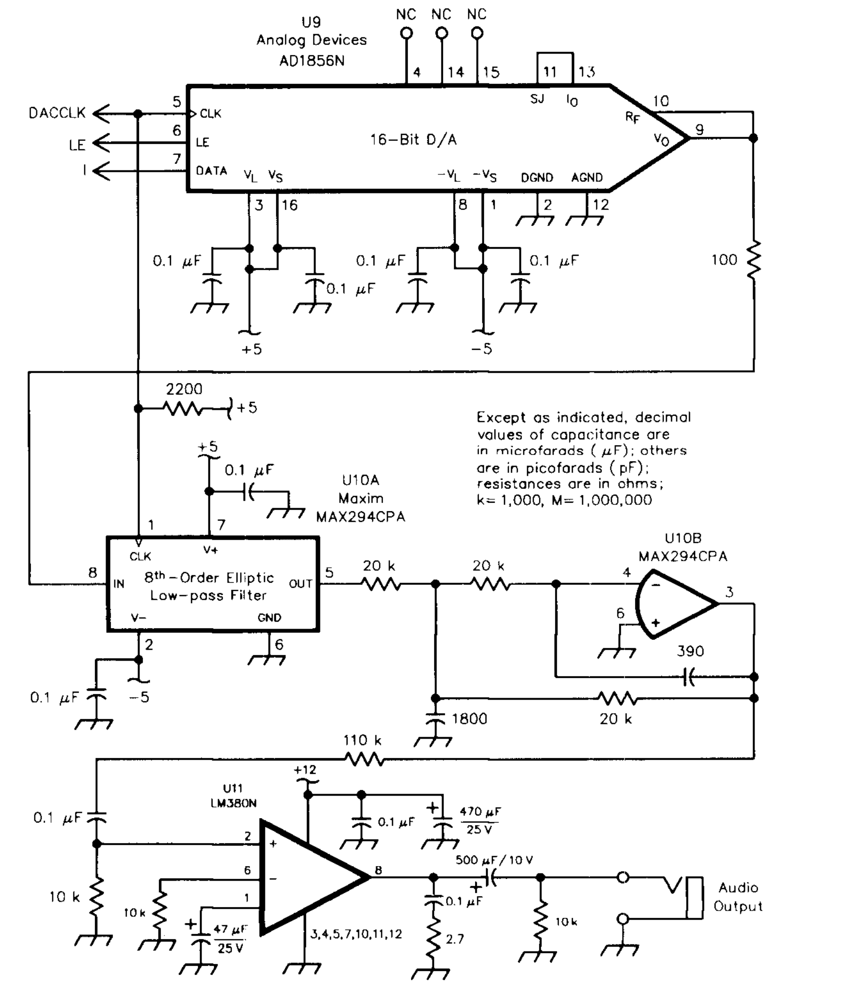

Fig 5—D/A converter, low-pass filter and audio amplifier.

range is 6 Hz. Many broadcasters operate a few Hertz away from their nominally assigned frequencies.

The unlocked AM mode will work on distant AM stations, as the sideband phases and amplitudes are distorted by the ionosphere, reducing the severity of the audio beats. If an AM signal is too weak to lock, it may be best to use the USB or LSB mode.

Fig 2 shows the DDC connections. The serial digital audio is taken from the I output. The I output is converted to analog audio to drive a speaker by the circuitry in Fig 5. The I output drives a two's-complement serial-input audio digital-to-analog (D/A) converter, U9.

The analog signal is filtered by an eighth-order switched-capacitor clock-tunable low-pass filter, followed by a two-pole active analog low-pass filter, both in U10, to remove unwanted audible aliases. The filter clock is varied to set the cutoff frequency as needed. Usually the cutoff is set just above the upper audio band edge. For the 107-Hz CW bandwidth, the cutoff can be set higher to intentionally pass aliases that are more audible to my ears than the low-frequency primary tone.

The audio amplifier, U11, is a LM380 running at 12 V, to provide more audio output than the original LM386 provided. The analog gain is set so that the LM380 overloads at $^1/_3$ full scale in the D/A. The overall gain of the receiver is varied by the digital gain setter shown in Fig 6. The D/A converter requires a load pulse to tell the D/A when to latch data from the serial I output of the DDC. The digital gain setter derives the load pulse from the DDC IQSTB output. Counter U5 stores the gain setting. Counters U6 and U7 set the time of the load pulse, depending on the setting of U5. This sets the number of bits the I serial data is left-shifted when latched into the D/A.

The DDC is configured to output 32-bit two's-complement serial data, most-significant bit (MSB) first. With zero shift (U5 outputs set to all ones), the high 16 bits of the data are latched into the D/A. Decrementing the count in U5 shifts the D/A data left one bit by making the latch pulse occur one clock later. Each bit of shifting gives a (voltage) factor of two, or 6 dB of numerical gain.

The CW demodulator, Fig 7, is a full-wave rectifier followed by a threshold comparator, low-pass filter and output transistor. The signal level is controlled by the gain setter (Fig 6) so that the threshold can be set as needed for a given signal. U21A captures the MSB of the serial data loaded into the D/A. U20B full wave rectifies the serial data. U21B is set when the signal is instantaneously more than $^1/_{32}$ of full scale. U23 stretches high levels so that the transistor is continuously on when a signal is present.

Fig 8 shows the transmitter VFO. U31 contains a DDS and a D/A, and is used to drive a straight-through CW transmitter on 80 and 40 m. U32 buffers the D/A output. The antialias filtering is in the transmitter. Since the VFO frequency is software-controlled, many other transmitters could be used.

This particular DDS, the Analog Devices AD7008, contains a quadrature amplitude modulator, which is not used here.[11] This modulator is capable of generating SSB signals.

The receiver is controlled (except for preselector tuning and PLL on/off functions) from an x86 PC-compatible computer. The PC interface, Fig 9, is configured to look to the computer like a parallel printer. U1 buffers all signals to or from the computer, to protect the rest of the receiver. U3 and U4A provide delays so the STB, BUSY, ACK handshake works properly.

A simple *C* program to control the receiver is shown in Fig 10. I wrote the program in Microsoft *Quick C*, and it may require changes in the I/O functions for other *C* compilers. As written, the program runs on DOS PCs from 8088s to 586s.

A good way to understand and debug the program, is to connect a printer to the PC's printer port. Run the program and see what the program prints for

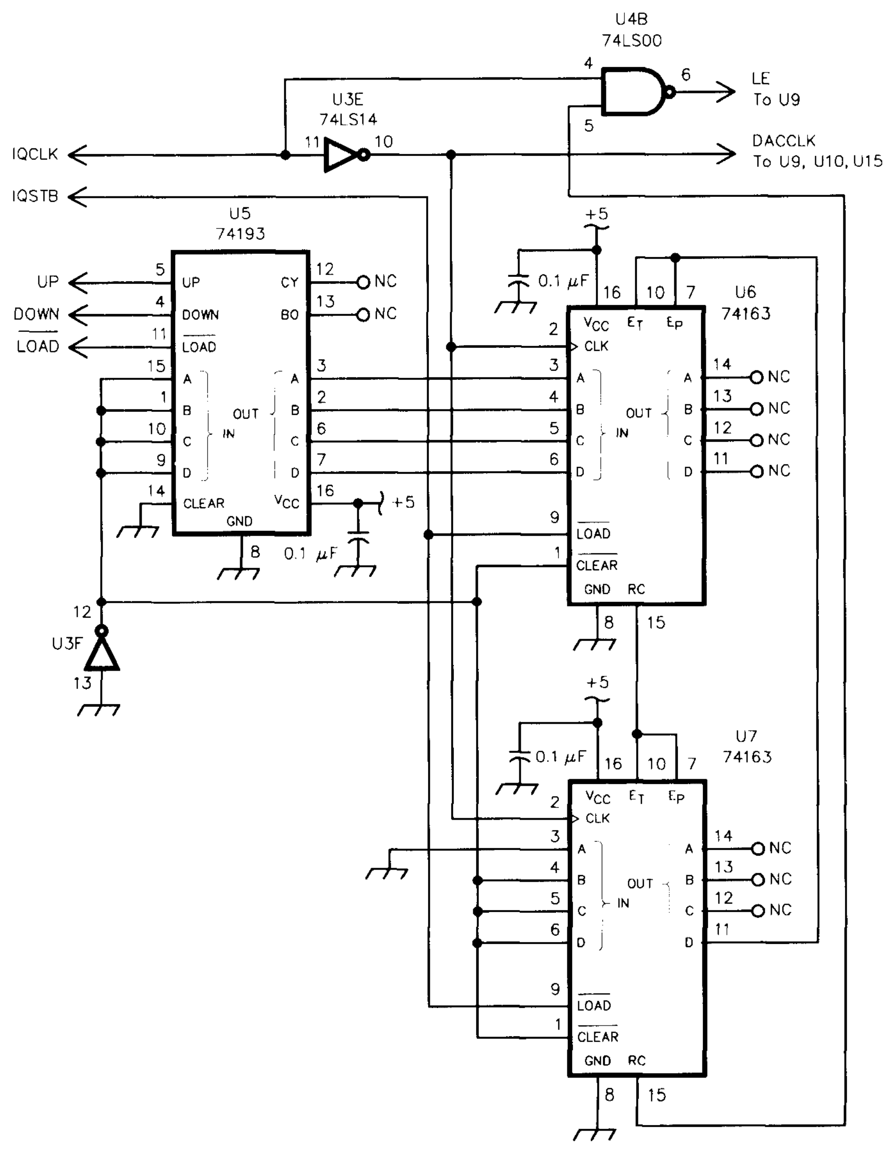

Fig 6—Digital gain setter.

the various commands.

Use MSDOS without Microsoft *Windows* 3.X running, as the Windows printer driver changes the printed text to improve the appearance on an actual printer. The changes garble the receiver operation. I have not tried *Windows95* or NT. An old floppy-based 8088 PC makes a good dedicated controller for this receiver.

I ported the control program to *Linux*. I had to change the I/O function calls to get it to work, because the printer device stdprn and the input functions getch and cscanf do not exist in standard *C*.

Much of this article was typed in *Emacs* under *Linux*, while listening to classical music on the receiver running in synchronous-AM mode, controlled by the Linux version of the control program running in another window.

I have included my calculations of parameters used to set up the DDC in Fig 11. Most of the parameter names are those used in the 50016 data sheet.

The decimation ratio, R, must be exactly a power of two to eliminate the center-of-passband spurious tone that is well known in analog Weaver receivers.[9] The tone is 102 dB down from full-scale output; so it is within the 50016 specification. The tone is probably due to the rounding that occurs at the seventeenth bit of the scaling multiplier in the 50016. When R is a power of two, the scaling multiplier gain is set to exactly unity and no rounding is needed.

For those who would prefer to use a serial-port interface, Fig 12 shows a simple serial-to-parallel converter using a Harris CDP6402CE 40-pin DIP universal asynchronous receiver transmitter (UART). This chip is pin-compatible with the original UART chip. The original UART was PMOS, and required −12 V on pin 2. The CDP6402 is CMOS, and pin 2 is left open. The UART is pin-programmed, rather than register-programmed, so the UART can be used as a stand-alone device. The baud-rate clock is 16 times the desired baud rate and is provided by a crystal-oscillator and pin-programmable frequency-divider chip from Digi-Key. Warning: I have not built this interface, although I have used the UART before in a number of designs over the last 20 years.

I have described a simple AM/SSB/CW receiver using a digital downconverter. The dynamic range is not as good as that of the best analog receivers, but the filter skirts are better than those of analog receivers. This receiver is a good signal source for DSP-based demodulators and is easily controlled from a computer. As always, this design is intended as a basis for further improvements and development.[15]

Notes

[1]Anderson, P. T., "A Simple SSB Receiver Using a Digital Down Converter," *QEX*, Mar 1994, pp 3-7.

[2]Anderson, P. T., "A Better A/D and Software for the DDC-Based Receiver," *QEX*, Nov 1994, pp 11-15.

[3]Anderson, P. T., "A Simple CW Demodulator for the DDC-Based Receiver," *QEX*, Feb 1995, pp 6-10.

[4]Anderson, P. T., "A Simple CW Transmit VFO for the DDC-Based Receiver," *QEX*, Jan 1996, pp 20-25.

[5]Anderson, P. T., "A Better and Simpler A/D for the DDC-Based Receiver," *QEX*, Aug 1996, pp 21-24.

[6]Narrowband voice modulation (NBVM) passes two bands of audio frequencies: 176 Hz to 626 Hz, and 1251 Hz to 2500 Hz. The higher band is shifted in frequency to be next to the lower band, giv-

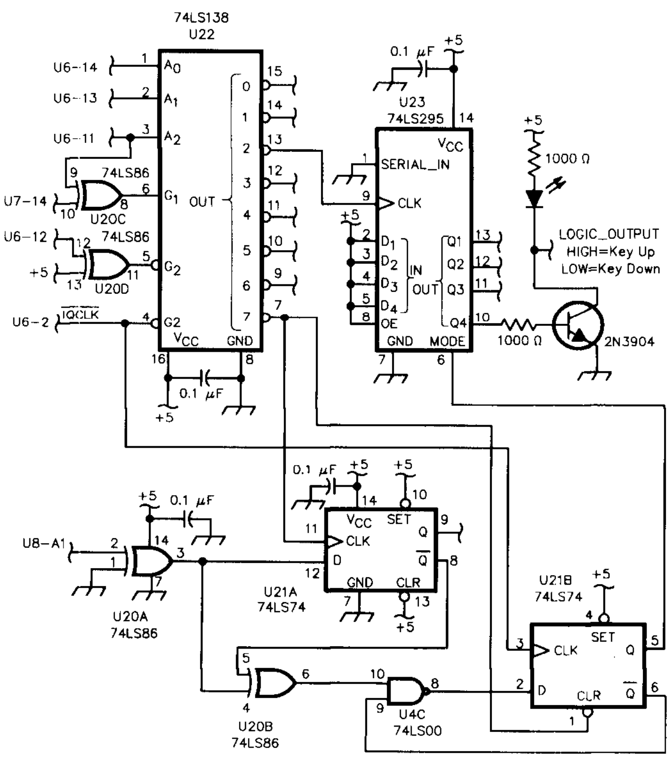

Fig 7—CW demodulator.

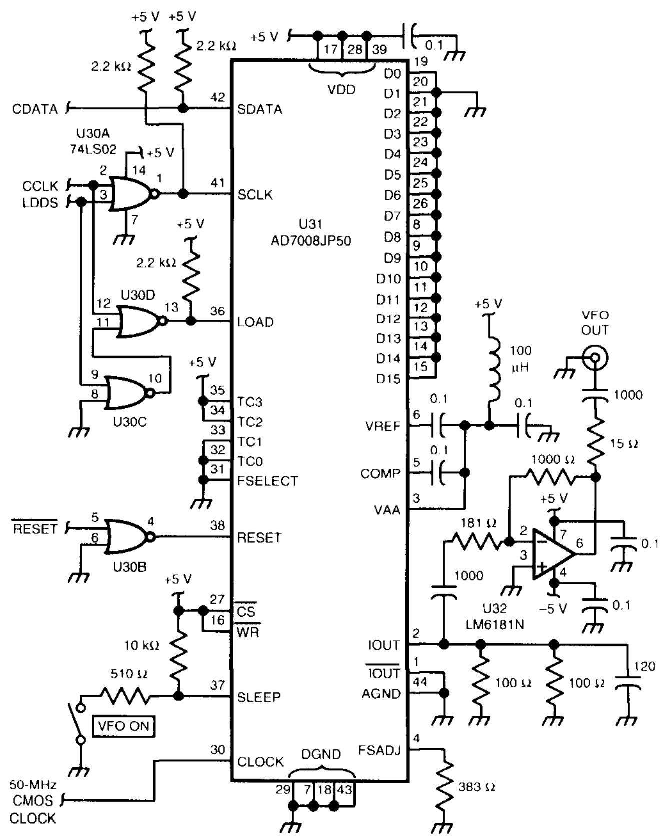

Fig 8—Transmit VFO.

ing a single band 1799-Hz wide. The frequency shifting makes NBVM incompatible with standard SSB signals.[7]

[7]Ash, J., Christensen, F., and Frohne, R., "DSP Voice Frequency Compandor for use in RF Communications," *QEX*, Jul 1994, pp 5-10.

[8]Weaver, D. K., "A Third Method of Generation and Detection of Single-Sideband Signals," *Proceedings of the IRE*, Dec 1956.

[9]Anderson, P. T., "A Different Weave of SSB Receiver," *QEX*, Sep 1993, pp 3-7.

[10]HSP50016 data sheet, Harris Semiconductor, 1301 Woody Burke Rd, Melbourne, FL 32902; tel 407-724-3000. You can get the data sheet from Harris's AnswerFAX 407-724-7800 or from **http://www.semi.harris.com**.

[11]Analog Devices, One Technology Way, PO Box 9106, Norwood, MA 02062-9106; tel 617-329-4700; **http://www.analog.com**.

[12]Bloom, J., "Negative Frequencies and Complex Signals," *QEX*, Sep 1994, pp 22-27.

[13]When the DDC is operated in complex mode, its I and Q outputs together contain all the signal information in the passband, so an external digital signal processor (DSP) could implement any demodulation method, including AM, FM and PM. I am not using a DSP, as I can get the receiver functions I need without the hardware and software complexity of a DSP.

[14]ADS801U data sheet, Burr-Brown, PO Box 11400, Tucson, AZ 85734; tel 520-746-1111. For immediate product information, call 800-548-6132.

[15]Special thanks to my cat, Nooper, who kept my lap warm during cold winter nights of typing.

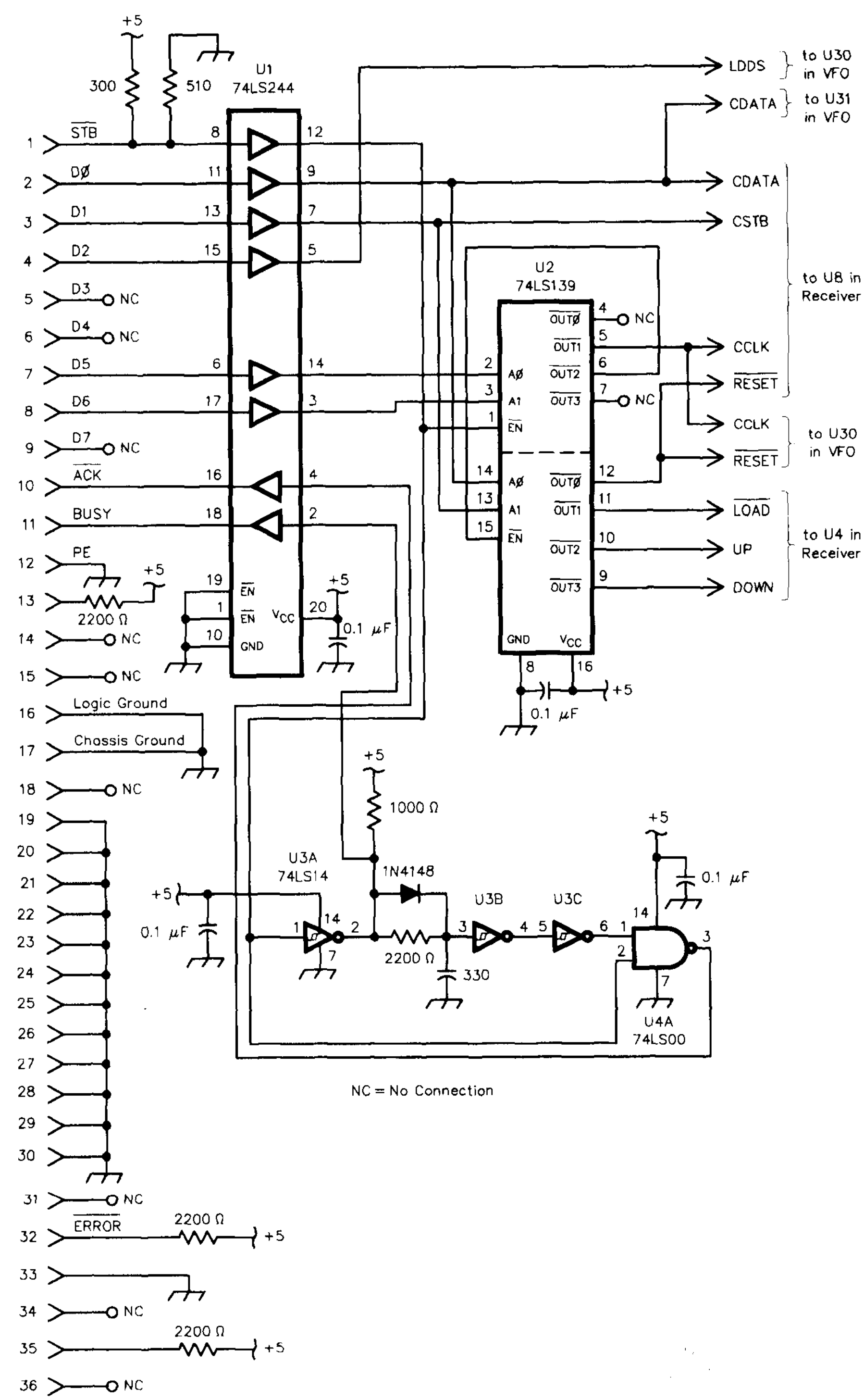

Fig 9—PC printer-port interface.

Fig 10—Control software *C* source listing.

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
/* PC control program for 50016 receiver @ 25 MHz and 7008 VFO @ 50 MHz */
/* RX25N.C 9mar97 PTAnderson KC1HR */

main()
{  int tempint = 0;
   int gain_state = 0;
   int j = 0;
   int c = 'm';
   int exit_char = '!';
   char preamble[] = "20011";
   char postamble[] = "000001";
   char ph_inc_string[] = "20011011001100101110101010001011110010001";
   long maxfreq = 12000000;
   long freq = 6175000;
   float tempfloat = 0.0;
   double freq_offset = 0.0;
   double dfreq = 0.0;
   double rxkhz = 0.0;  double txkhz = 0.0;
   double alkhz = 0.0;
   double dph_inc = 0.0;
   long ph_inc = 0;
/* 50016 clock frequency is nominally 25000000.0, my osc is a little low */
   double fclock = 24999900.0;
   double two_up32_over_fclock = 0.0;
   two_up32_over_fclock = 4294967296.0 / fclock;

/* initialize receiver to minimum gain */
   fprintf(stdprn,"@A\n");

/* initialize control registers 2 and 3 (same data for DSB or SSB or CW) */
   fprintf(stdprn,"2010000000000000000000000000000000000000\n");
   fprintf(stdprn,"2011000000000000000000000000000000000000\n");

/* print help table */
   printf("\nSimple SSB/CW/synchronous_AM receiver RX25 9mar97 PTAnderson");
   printf("\nFrequency range 10 to 12500 kHz");
   printf("\nAlias frequency range 24990 to 12500 kHz");
   printf("\n");
   printf("\nRF passband center = frequency (-,+ 1.526 kHz for lsb,usb only)");
   printf("\n");
   printf("\nexit to DOS:  set DDC clock kHz:   set frequency kHz:");
   printf("\n !            #                 =");
   printf("\n");
   printf("\nup frequency:");
   printf("\n q=1MHz w=100kHz e=10kHz r-5kHz t=1kHz y=100Hz u=10Hz i=1Hz");
   printf("\n");
   printf("\ndown frequency:");
   printf("\n a=1MHz s=100kHz d=10kHz f=5kHz g=1kHz h=100Hz j=10Hz k=1Hz");
   printf("\n");
   printf("\ngain:                    set VFO = passband center: W");
   printf("\nz=up x=dn c=min");
   printf("\n");
   printf("\naudio bandwidth Hz , mode:     ?=107cw without audio alias");
   printf("\n      b=6836am n=1709usb m=1709lsb ,=1709cw .=427cw /=107cw");
   printf("\n");
   printf("\nlast command, gain, alias, VFO, rx frequencies in kHz now are:");
   printf("\n");
   printf("\n");

/* while not exit char */
   while(c-exit_char){

     /* set preamble and postamble to update 50016 phase increment */
```

You can download this source code from the ARRL "Hiram" BBS (tel 860-594-0306), or the ARRL Internet ftp site: **oak.oakland.edu** (in the **pub/hamradio/arrl/qst-binaries** directory). In either case, look for the file DDCSRC.TXT in 97QEX09.ZIP.

```
strcpy( preamble,"20011" );
strcpy( postamble,"000001" );

switch (c)
{
  case 'z':       /* up gain */
   if( gain_state > 14 )
     gain_state = 15;
    else
    {
      gain_state = gain_state + 1;
       fprintf(stdprn,"C");
    }
    break;
case 'x':       /* dn gain */
  if ( gain_state < 2 )
  {
     gain_state = 0;
     fprintf(stdprn,"A");
  }
  else
  {
    gain_state = gain_state - 1;
    fprintf(stdprn,"B");
  }
  break;
case 'c':       /* min gain */
  gain_state = 0;
  fprintf(stdprn,"A");
  break;
case '=':       /* set freq in kHz*/
  printf("\rfreq kHz ");
  cscanf( "%f", &tempfloat );
  freq = 1000.0 * tempfloat;
  tempint = getch();
  break;
case '#':       /* set fclock in kHz */
  printf("\rclock kHz ");
  cscanf( "%f", &tempfloat );
  fclock = 1000.0 * tempfloat;
  two_up32_over_fclock = 4294967296.0 / fclock;
  tempint = getch();
  break;
case 'b':       /* 6836 Hz bandwidth synchronous am */
  fprintf(stdprn,"210000000000000000000000000000000001000110\n");
  fprintf(stdprn,"210100000000111111111000000000000000000101\n");
  fprintf(stdprn,"211000000000111010101001001000000000011010\n");
  freq_offset = 0;
  break;
case 'n':       /* 1709 Hz bandwidth usb */
  fprintf(stdprn,"210000000100000000000000000000000000101000\n");
  fprintf(stdprn,"210100000111111111110000000000000000000101\n");
  fprintf(stdprn,"211000000000111010101001000000000001011010\n");
  freq_offset = -1526;
  break;
case 'm':       /* 1709 Hz bandwidth lsb */
  fprintf(stdprn,"210000000100000000000000000000000000101001\n");
  fprintf(stdprn,"210100000111111111110000000000000000000101\n");
  fprintf(stdprn,"211000000000111010101001000000000001011010\n");
  freq_offset = 1526;
  break;
case ',':       /* 1709 Hz bandwidth cw */
  fprintf(stdprn,"210000000100000000000000000000000000101001\n");
 fprintf(stdprn,"210100000111111111110000000000000000000101\n");
  fprintf(stdprn,"211000000000111010101001000000000001011010\n");
  freq_offset = 0;
  break;
case '.':       /* 427 Hz bandwidth cw */
  fprintf(stdprn,"210000000100000000000000000000000000010101\n");
```

```
    fprintf(stdprn,"21010001111111111111000000000000000000101\n");
    fprintf(stdprn,"21100000000011101010100100000000111001000\n");
    freq_offset = 0;
    break;
  case '/':       /* 107 Hz bandwidth cw with audio alias */
    fprintf(stdprn,"21000000100000000000000000000000000000001\n");
    fprintf(stdprn,"21010111111111111111000000000000000000101\n");
    fprintf(stdprn,"21100000000011101010100100000000001011010\n");
    freq_offset = 0;
    break;
  case '?':       /* 107 Hz bandwidth cw without audio alias */
    fprintf(stdprn,"21000000100000000000000000000000000000001\n");
    fprintf(stdprn,"21010111111111111111000000000000000000101\n");
    fprintf(stdprn,"21100100000011101010100100000011100100011\n");
    freq_offset = 0;
    break;
  case 'W':       /* TX frequency = RX frequency */
    txkhz = rxkhz;
    /* set preamble and postamble to update 7008 DDS phase increment */
    strcpy( preamble,"00000" );
    strcpy( postamble,"400000" );
    break;
  case 'i':       /* up 1Hz */
    freq = freq + 1 ;
    break;
  case 'k':       /* dn 1Hz */
    freq = freq - 1 ;
    break;
  case 'u':       /* up 10Hz */
    freq = freq + 10 ;
    break;
  case 'j':       /* dn 10Hz */
    freq = freq - 10 ;
     break;
  case 'y':       /* up 100Hz */
    freq = freq + 100 ;
    break;
  case 'h':       /* dn 100Hz */
    freq = freq - 100 ;
    break;
  case 't':       /* up 1kHz */
    freq = freq + 1000 ;
    break;
  case 'g':       /* dn 1kHz */
    freq = freq - 1000 ;
    break;
  case 'r':       /* up 5kHz */
    freq = freq + 5000 ;
    break;
  case 'f':       /* dn 5kHz */
    freq = freq - 5000 ;
    break;
  case 'e':       /* up 10kHz */
    freq = freq + 10000 ;
     break;
  case 'd':       /* dn 10kHz */
    freq = freq - 10000 ;
    break;
  case 'w':       /* up 100kHz */
freq = freq + 100000 ;
    break;
  case 's':       /* dn 100kHz */
    freq = freq - 100000 ;
    break;
  case 'q':       /* up 1MHz */
    freq = freq + 1000000 ;
    break;
  case 'a':       /* dn 1MHz */
    freq = freq - 1000000 ;
```

```
      break;
    default:
      break;
  }
  if ( freq > maxfreq )
    freq = maxfreq;
  if ( freq < 10000 )
    freq = 10000;
  dfreq = freq;
  rxkhz = 0.001*dfreq;
  alkhz = 0.001*(fclock-dfreq);
  dph_inc = (dfreq-freq_offset) * two_up32_over_fclock;
  ph_inc = dph_inc;
  dph_inc = ph_inc;
  printf("\r%c %2.2u %9.3f %9.3f %9.3f      ",
     c, gain_state, alkhz, txkhz, rxkhz);
  strcpy( ph_inc_string, preamble );
  /* convert thirty bits of ph_inc to ASCII string */
  for( j = 0; j < 30; j = j + 1 )
  {
    ph_inc = ph_inc << 1;
    if( ph_inc < 0 )
      strcat( ph_inc_string, "1" );
    else
      strcat( ph_inc_string, "0" );
  }
  strcat( ph_inc_string, postamble );
  /* send forty-one-character string to transceiver on printer port */
  for( j = 0; j < 41; j = j + 1 )
  {
    fprintf(stdprn,"%c", ph_inc_string[j]);
  }
  /* send newline characters to keep printer happy */
  fprintf(stdprn,"\n");
  c = getch();
 }
}
```

nominal_audio_bandwidth	=	6836	1709	427	107 Hz
output_mode	=	complex	real	real	real
fclk = fs	=	25000000	25000000	25000000	25000000 Hz
HDF_decimation_ratio = R	=	256	2048	8192	32768
f' = fs/R	=	97656.25	12207.03	3051.76	762.94 Hz
FIR_decimation_ratio = f'/f"	=	4	2	2	2
audio_sample_rate = f"	=	24414.06	6103.52	1525.88	381.47 Hz
fw = f"/4_or_0	=	0	1525.88	381.46	95.37 Hz
-3dB_RF_bandwidth = 0.14*f'	=	13671.88	1708.98	427.25	106.81 Hz
-3dB_AF_bandwidth	=	6835.94	1708.98	427.25	106.81 Hz
AF_lo_bandedge = fw-0.07*f'_or_0	=	0	671.39	167.85	41.96 Hz
AF_hi_bandedge = fh = fw+0.07*f'	=	6835.94	2380.37	595.09	148.77 Hz
AF_hi_stopedge = fhs = fw+0.1*f'	=	9765.63	2476.58	686.64	171.66 Hz
-102dB_RF_bandwidth = 0.2*f'	=	19531.25	2441.41	610.35	152.59 Hz
AF_lowest_alias = f" – fhs	=	14648.43	3356.94	839.24	209.81 Hz
log_2(R)	=	8	11	13	15
5*log_2(R)	=	40	55	65	75
Ce = Ceiling[5*log_2(R)]	=	40	55	65	75
Shift = 75-Ce	=	35	20	10	0
Scale_factor =2^Ce/R^5	=	1.000000	1.000000	1.000000	1.000000
f_audio_antialias_filter_corner	=	9259.26	2747.25	551.88	136.76 Hz
fIQCLK = f_antialias_filter_clk	=	925926	274725	55188	13676 Hz
IQCLKRATE = (fclk/fIQCLK)+1	=	26	90	452	1827
IQCLK_clocks/sample = fIQCLK/f"	=	37.9	45.0	36.2	35.9
IQCLKRATE to pass aliases	=	—	—	—	90

Fig 11—Calculations of various parameters used to set up the DDC.

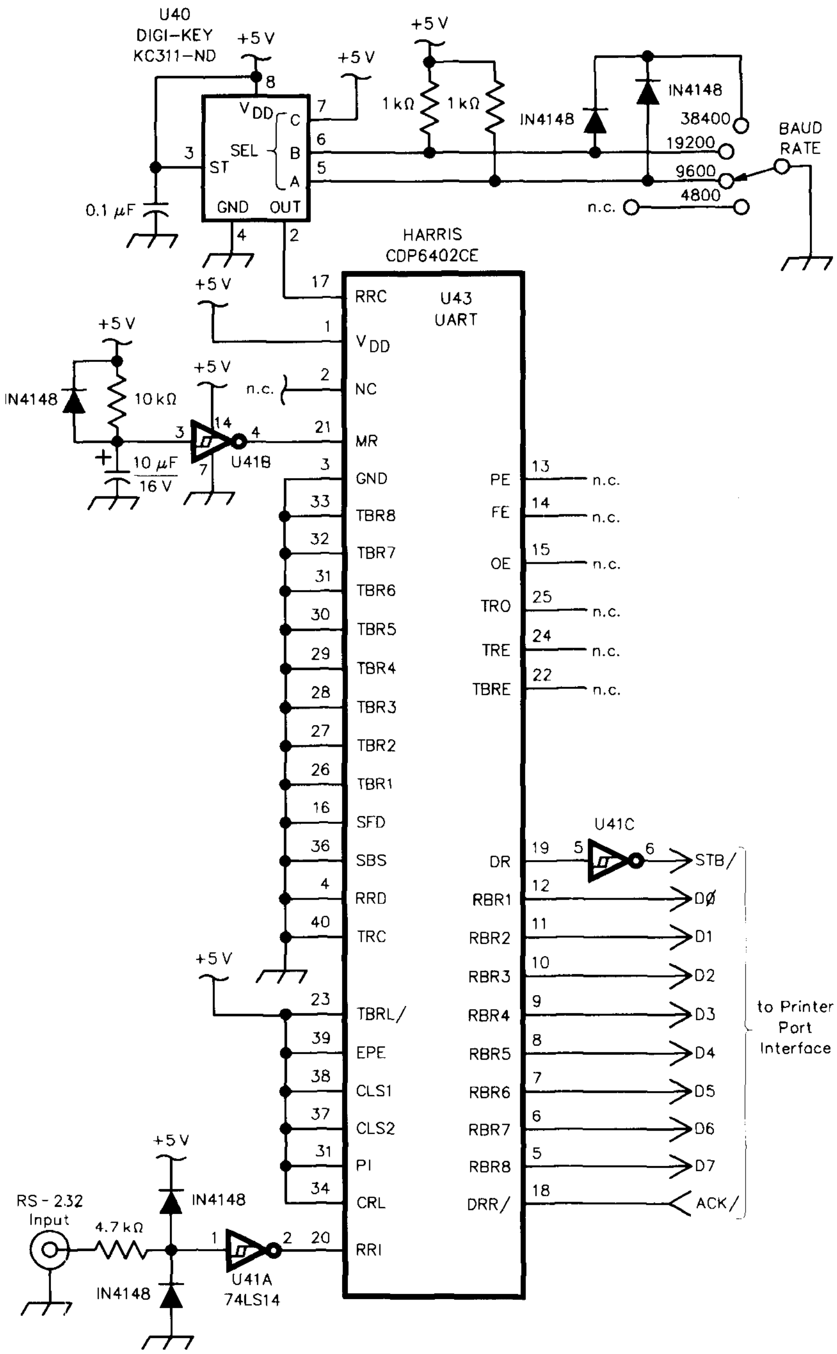

Fig 12—Serial-port interface.

A Compact Phase 3D Ground Station Antenna System

Some thought and experience fit P3D antennas for 8 bands in 5×7 feet!

By Ed Krome, K9EK (ex-KA9LNV)

Phase 3D: Operating Opportunities!

P3D, currently scheduled for a September launch, will have the ability to operate on all satellite-designated bands from 30 MHz through 24 GHz. This offers something for everyone, but also raises a few questions. With so many bands, which ones will be the most popular? Which will have the most "on" time? How in the world do I operate as many bands as possible? And where do I put the antennas? So many questions. . .

Of course, the number of bands one is able to operate depends on the individual's interests, equipment, time and money (and cleverness). Many will stay with the lower frequency bands that have been in use on the previous satellites, such as V/U (146 up/436 down; presently called Mode J), and U/V (436 up/146 down; Mode B). L/U (1269 up/436 down; Mode L) and U/S (436 up/2401 down; Mode S) also have many active stations, just waiting for the P3D launch. Since these frequency combinations have existed on previous satellites, it is likely that they will get the lion's share of time on P3D. Officially, the schedule of frequencies used and the time active will be determined by a committee made up of the primary contributors to the satellite.

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P3D has all kinds of new goodies. New bands include uplinks on 2.4 GHz (S) and 5.7 GHz (C). New downlinks will be available on 10.5 GHz (X) and 24 GHz (K) bands. All bands will be useable for all modes, including all manner of digital modes. P3D has two hardwired 9600-baud and eight agile (ground programmable) modems, as well as the 400-baud BPSK telemetry beacon. The ability to combine high-speed modems with high frequency, broad bandwidth, low-noise bands offers the possibilities of robust, high-speed digital communications.

P3D's transponder system is different from any previous satellite in that all up and down links share a common IF, and are all connected to a common matrix. Therefore, any uplink can be coupled with any downlink, within technical limits. For example, you won't see any K band downlinks at perigee.

Operating Requirements

What will it take to operate these bands? P3D is noted for its high power transmitters and good ears. Frank Sperber, DL6DBN, of AMSAT-DL has published a matrix that shows up and downlink requirements along with the antennas and power levels to attain them. This is available on the AMSAT WWW site under the P3D information area. It is in German, so Table 1 is a translation of Frank's information.

These numbers give a good starting point for determining not only what will be required for operation on a particular frequency combination, but also how to operate the most bands in the most efficient manner. By "efficient" I do not mean in the electrical sense, but in the real-estate sense.

Antennas as Space Monsters

Antennas cost money and take up space. The more antennas you have, the more money winds up in the supports (towers, rotators, cable). I am fortunate in that I have a reasonable-sized backyard in a city lot and no particular zoning restrictions, except height. At least, no restrictions that I have been called on. Nonetheless, it's my wife's house, too. While she happily tolerates my 35 foot tower and basement (oh, yeah, the garage, too) full of neat stuff, she would rather that the house not sprout any more appendages. Seems reasonable—all of life is give and take, but P3D has so many opportunities! So, I have looked at how much I can cram into how little space. The proposed antenna setup is shown in Fig 1. Here's the reasoning behind this arrangement.

Let's look at both maximums and consistencies in the ground-station requirements. On some bands, we have the option of using omnidirectional antennas and still having marginal communications capability. Generally, though, short directional antennas give the best performance. The largest antennas are for 2 meters and 70 cm. A 7 element 2 meter Yagi is approximately 10 feet long. A 10 element Yagi for 70 cm is approximately 5 feet long. All other antennas are considerably shorter, so the lowest band desired dictates the overall size of the system.

Here's a radical thought: Since our goal is to cram the most antenna into the least space, why not eliminate the monster? What, no 2 meter antenna? Eliminating a 2 meter Yagi halves the length of the array and narrows it considerably, since 2 meter Yagi elements are over 3 feet long. P3D is not supposed to be a low-frequency bird; many of the builders of the satellite have little use for the 2 meter band. In Europe, 2 meters is limited to 144-146 MHz, and is absolutely stuffed with FM repeaters. Japan has 2 meter repeaters everywhere. In Spain, you hear taxicabs on 2 meters. The net result in much of the world (and in many large US cities) is that a 2 meter downlink is almost unusable due to QRM. Not a good DX band! Additionally, one can easily operate a 2 meter uplink with a little more power applied to an omnidirectional antenna, such as a groundplane or eggbeater. So I left the 2 meter Yagi in the garage. Now my maximum required array length has been reduced from ten feet to five feet and the width reduced by three feet.

Parabolic Dish Antennas

Sperber has related all higher bands to a 60 cm (that's two feet, for the SI impaired) parabolic dish. That's very convenient. Small dish antennas gained popularity on AO-13 Mode S, where they yielded superior performance at much less cost than loop Yagis. Most Mode S stations used dish antennas of one form or another, with the most popular commercial dish being a rectangular type sold by Myers Communications (Bob Myers, W1XT). Small homebrew dishes were also popular, because construction information is widely available and limited only by the builder's ingenuity. *The Satellite Experimenter's Handbook* and the *ARRL UHF/Microwave Experimenter's Handbook* contain formulas and ideas for construction.

A topic well discussed on the Internet has been the use of a single dish for both the S band (2400 MHz) downlink and the L band (1269-MHz) uplink. At first, this seems a logical combination. Unfortunately, a little analysis shows that this arrangement creates some serious problems for which there are no easy solutions.

Table 1—Translation of Frank Sperber, DL6DBN's, Uplink and Downlink Requirements

Uplink:

Band	*EIRPc**	*TX Power*	*Antenna*
146	20 dBWi(2)	10 W	7×7 el crossed Yagi
146		50 W	Crossed dipoles over plane reflector
435	21 dBWi	10 W	10×10 el crossed Yagi
435		40 W	Crossed dipoles over plane reflector
1270	23 dBWi	10 W	12 turn Helix
2400	27 dBWi	5 W	60 cm (24 inch) parabolic dish
5670	34 dBWi	10 W	60 cm dish

Downlink

Band	*Signal Strength†*	*Antenna*	*S/N*
146	–155 dBWi	7×7-el crossed Yagi	23 dB
		Crossed dipoles over reflector	16 dB
435	–157 sBWi	10×10-el crossed Yagi	24 dB
		Crossed dipoles over reflector	13 dB
2400	–167 dBWi	60 cm parabolic dish	26 dB
		14-turn Helix	18 dB
10450	–184 dBWi	60 cm dish	24 dB
24G	–197 dBWi	60 cm dish	13 dB

Note:

*EIRPc indicates effective radiated power, circularly polarized, relative to an isotropic radiator.

†dBWi means decibels relative to a 1 W reference level from an isotropic radiator. To convert these numbers into the more familiar (in the US) dBm (referenced to 1 mW), add 30 dB, because 1 dBW = +30 dBm.

Mode L/S is expected to be a very popular combination. It offers wide bandwidth and interference-free reception. Commercial equipment is readily available (Down East Microwave, SSB Electronic, Parabolic AG). Successful satellite communication requires full-duplex operation, however, which means it must be possible to transmit and receive simultaneously. If both L and S band feeds are mounted in the same dish, L band transmitter energy will be coupled into the S band receiving feed. Since an S band downlink requires a GaAsFET preamplifier or receiver front end mounted very close to (preferably at) the antenna feed, the S band front end must be able to tolerate thermal stress from the L band energy. That tiny 250 micron gate in your GaAsFET front end wasn't designed for such abuse! More than a few milliwatts will make it go "poof," instantly. Been there, done that. So the problem becomes how one isolates the S band receiver from the L band transmitter's energy, while receiving the S band downlink. Mechanically switching the S band front end between the dish feed and ground would protect the preamp, but would preclude full-duplex operation. It might be rather difficult to find your downlink, also. It would require a very high quality (expensive) relay, because losses introduced by cables, relays or anything in front of the preamp increases system noise.

Another suggested solution—counter wound, concentric helix feeds—falls short on all categories. First, all up and downlink signals are right-hand circular polarized. So using an opposite-hand feed ensures large signal attenuation. Second, there's insufficient isolation to prevent RF heating damage.

Could we use a duplexer or other filter to separate the different frequencies? The problem here is one of availability. While such filters are available in the commercial sector, I know of no reasonably priced source available to the amateur. Fabricating your own is an option only to those with the proper test equipment and expertise to use it.

The best overall solution is simply to forget using one dish for both uplink and downlink duty. Let a dish do the downlink work and use a separate antenna for the uplink. On 23 cm, a 12 turn helix (only about 18 inches long) with a 10 W amplifier may be adequate. So, mount the small helix separately, out on the opposite end of the antenna cross boom from the S band receiver, and all the problems (including desense) go away. To transmit on the higher bands where a small dish is advantageous (2400 and 5668 MHz), add a second small dish! Two dishes on one array? More on that later.

A Multiband Dish

One of the nice properties of a parabolic dish antenna is that the dish itself is not frequency sensitive. It is only a reflector. As long as the diameter of the dish is sufficiently large (maybe 10 wavelengths) that it does not act like a parasitic element, operating frequency is determined solely by the feed. So, a single dish can serve for multiband operation as shown in Fig 2. Although a dish has a particular focus, it is practical to mount several feeds next to each other and simply accept some inefficiency. If the feeds are considerably off the focus of the dish, it may be necessary to "off point" the dish slightly to concentrate the downlink signal on the feed of interest. Since we have three microwave downlink bands on P3D, we can mount feeds for all three near the center of a single dish. Since higher frequencies yield smaller beamwidths, it is advisable to mount the highest frequency feed in the center of the dish and lower frequency feeds progressively more off center. This requires no relays or isolators.

The downside of clustered feeds—besides inefficiency—is area blockage. The three feeds noted may substantially shadow the dish, reducing its effective diameter and efficiency. Since 60 cm is believed to be an adequate diameter for one band, it may be advisable to increase the dish diameter

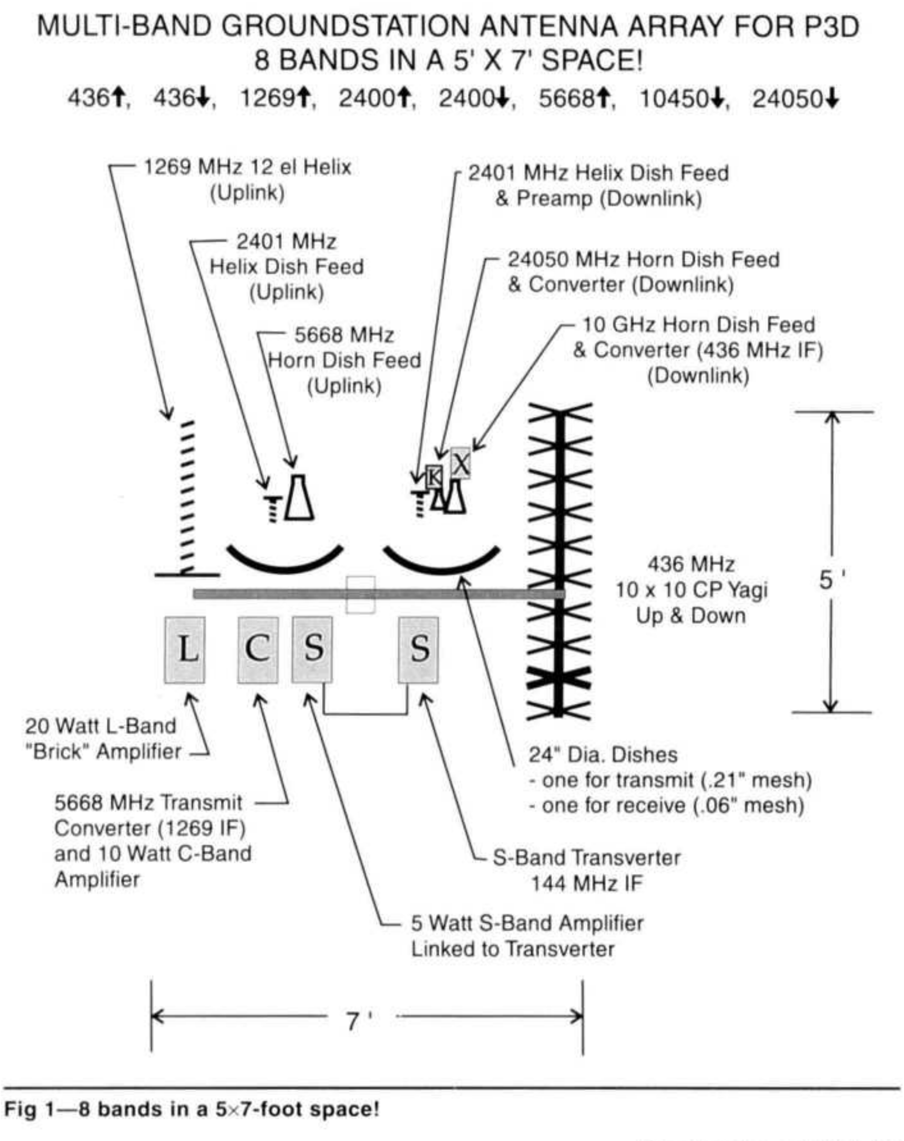

Fig 1—8 bands in a 5×7-foot space!

somewhat to compensate for the feed shading.

Parabolic Dish Antenna Basics

First, a parabolic dish need not be solid. It can be an open mesh, to reduce wind load. The mesh spacing should be no more than 0.1 wavelength for the dish to appear electrically solid. A wider mesh both reduces efficiency and admits more warm earth noise from the ground behind the dish to degrade the system noise figure. (Remember that when the dish points at the sky, the feed points at the ground.) The dish quality, acceptable deviation from true parabolic form, is also determined by the frequency of use. A dish formed within 0.1 wavelength of true at the frequency of use is virtually indistinguishable from perfect.

Parabolic dishes are characterized by a dimensionless factor referred to as the f/d. This is the ratio of the focal length to the diameter. It is independent of the actual dish diameter. The f/d ratios of common parabolic dishes vary from (typically) 0.25, which is referred to as a deep dish because the dish appears deeply curved, to 0.7, referred to as a shallow dish because it appears quite flat. The focal point of a deep dish is close to the dish, and that of a shallow dish is far from the dish. Each type has its advantages. A deep dish makes a compact assembly and is therefore easy to support and counterbalance compared to a shallow dish, where the feed (which, with a preamp, may become quite heavy) is much farther in front of the dish. A shallow dish, however, has a broader focus than a very deep dish, and is therefore more amenable to the use of multiple feeds.

The feed must be designed to properly illuminate the dish (typically, to have a beamwidth such that the −10 dB points are at the dish edges), so different designs are required for different f/d ratios. For example, a narrow beamwidth feed would not fully illuminate a very deep dish, leading to inefficiency. Feeds for shallow dishes are physically longer than those for deep dishes. Efficient feeds for very deep dishes (0.25 to 0.3 f/d) are quite difficult to design. A broad beamwidth feed on a shallow dish spills over; the feed sees warm earth noise around the edge of the dish. This degrades the system noise figure. Designs for dishes and feeds of all f/ds have been published in the Amateur Radio press, most commonly for dishes in the 0.4 to 0.5 f/d range. All of them work; just make sure that the feed is designed for the f/d of the dish you use.

Additional information on parabolic antennas and feeds is contained in the paper "Dish Feeds for Mode S" in *Mode S: The Book* (available from AMSAT).

Two Dishes and Physical Balance

While two parabolic dishes on a single antenna system may seem odd and cumbersome, placing them on opposite sides of the rotator helps equalize wind load and weight distribution. Since dishes have more surface area (wind load) than Yagis, place them near the rotator to minimize the moment arm (radius) between the load (the dish) and the rotator. To minimize rotator load, keep the side-to-side and front-to-back moments (weight × distance) as equal as possible, with a slight rearward bias to take up rotator gear slack. I have seen e-mail recommending severe front-to-back imbalance, apparently to prevent any elevation movement from wind. The problem is that a large imbalance accelerates rotator wear and makes boom clamps slip. Previous satellites have not required the pointing accuracy that dictates absolutely rigid antenna mounts. Pointing accuracy requirements for P3D's 5.7, 10 and 24 GHz links may require better methods of antenna support and pointing.

Some parabolic dishes have an almost built-in arrangement for counterbalancing. The dish is typically supported by a central hub. This hub can be attached to a pipe, which is clamped (through a clamp plate) to the antenna cross boom. This pipe can extend behind the cross boom and offer a convenient place to mount converters and other electronics, which will help counterbalance the dish. Use aluminum pipe to reduce the weight.

Here's a note on antenna pointing accuracy: Increasing antenna gain decreases beamwidth and requires greater pointing accuracy. So, although big dishes and long Yagis give

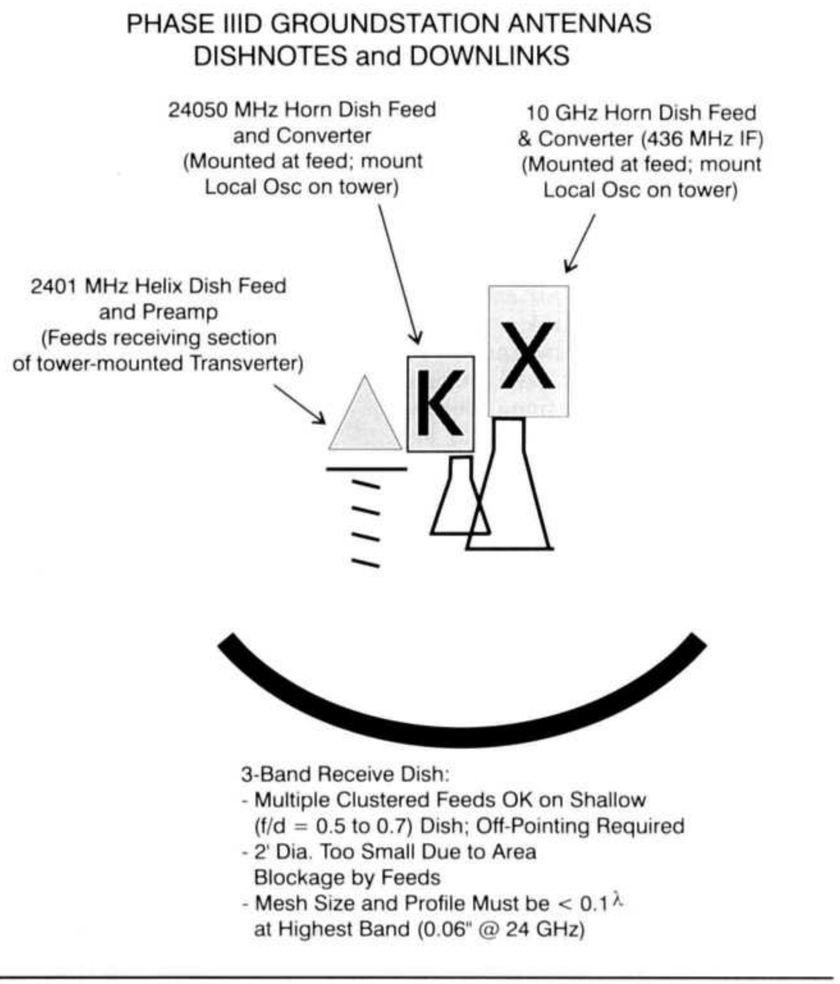

Fig 2—Dish notes and downlinks.

great signals, it may be difficult to place that gain on your target. We may find that shorter antennas with more power yield better uplinks. This will be especially true if clustered downlink feeds force us to point the array slightly off the satellite to maximize downlink strength.

Tower-Mounted Hardware

A big, bad bear of microwave communication is loss of signal between the antenna and the signal source or sink. Coaxial cable, while mechanically practical, has loss that increases with frequency. This loss translates reduced EIRP on the uplink and increased noise figure on the downlink. High-performance cables are available, but as they get better they get more expensive and more difficult to handle. The best way to reduce cable loss is to simply reduce cable length. To that end, the eight band array shows quite a lot of tower mounted RF hardware (see Fig 3). The downlink pre-amps should be mounted at the dish feeds. It is quite possible to mount an S band downconverter in the shack and connect it to the preamp with coaxial cable. I have done this for years, but I *do* use ¾ inch Hardline to reduce signal loss. Higher bands require that we mount the downconverters as close to the preamps as possible—preferably right at the dish. On X band, a foot or two of UT-141 (0.141 inch copper Hardline) with SMA connectors is satisfactory to connect a feed mounted preamp to a downconverter mounted directly behind the dish. On K band, it may not.

On the uplink, cable losses on L band (1269 MHz) are high enough that it makes sense to mount a small 10 to 20 W power amplifier at the antenna feed. Since the antenna shown is a helix, extending the helix center post behind the cross boom gives both a place to clamp the antenna to the cross boom and a place to mount the amplifier. The readily available M57762 brick amplifier module is a likely candidate for this service.

Cable losses on C band (and the difficulty of generating significant power on 5.7 GHz) mandate a tower mounted RF section. The problem is that amplifiers are heavy. My own 10 W amplifier weighs almost 15 pounds. It's probably best to mount this on the tower under the rotators, and use a minimum-length, high-quality cable to reach the feed.

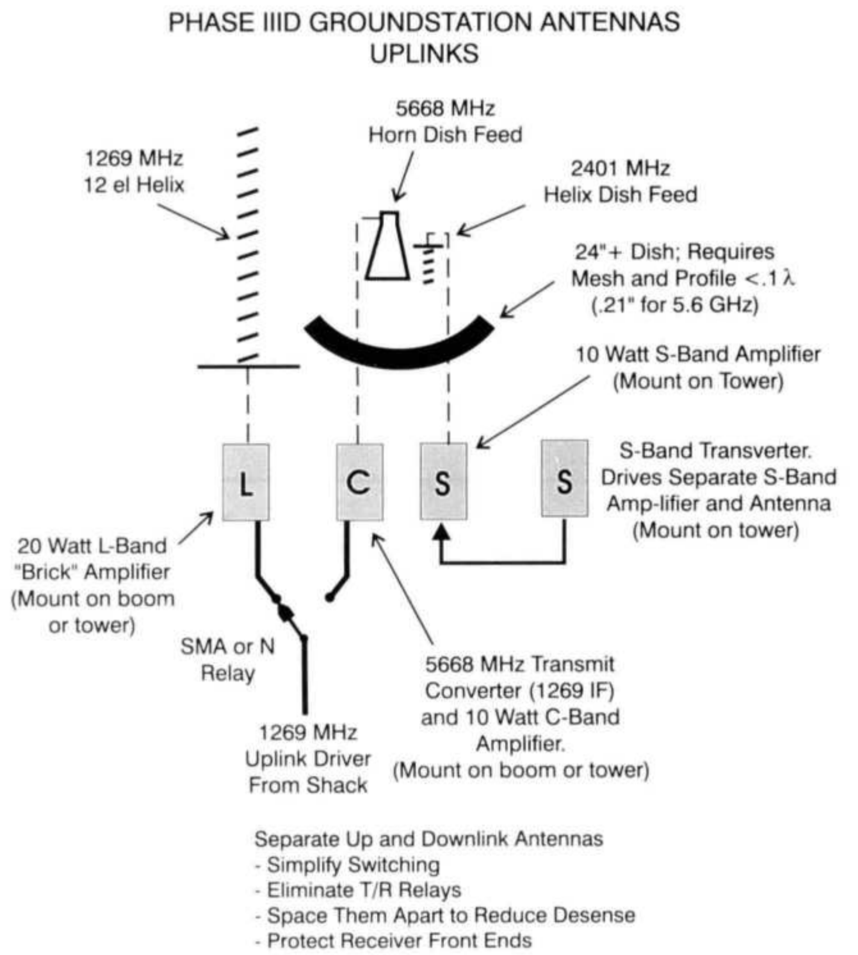

Fig 3—Uplinks.

Most C band gear is homebrewed, so select the IF for convenience. The antenna layout shows a 1269-MHz driver in the shack (such as an FT-736R) being relay switched at the tower between an L band amplifier and an L-to-C transmit converter and amplifier.

S band is used for both up and downlinks (never simultaneously). Cable losses on 2400 MHz are high; they command short cables and tower mounted gear. It may be advantageous to tower mount (below the rotators) the entire S band transverter and S band transmit RF amplifier, with short cable runs to the antennas. The no-tune transverters (from Down East Microwave; Steve Kostro, N2CEI) lend themselves to this scheme because they have separate transmit and receive connectors. There's no need for high-frequency relays or switching. All feeding and switching is done at the 146 MHz IF. Cables to the shack are relatively small.

S band transmitting will present other problems that are beyond the scope of this article. For example, most common RF power amplifiers use tubes (planar triodes), which require high-voltage dc. This will complicate power cabling.

Onward!

This small, eight band antenna array is technically and physically workable, but it has not been constructed. The ideas are based on years of experience at homebrewing microwave antennas and gear, but there are always better ways of doing things. Challenges present opportunities. It is up to you to experiment. Have fun!

RF

By Zack Lau, W1VT

Phase 3D—Ground Station Antenna Ideas

The microwave bands on Phase 3D offer interesting possibilities for the amateur experimenter—it should be a lot easier to find other people to talk to on the microwave bands. Instead of needing other amateurs within a few hundred miles, you can talk to anyone who can access the bird at the same time. This ought to be a great boon to those living far from metropolitan areas where there are few nearby amateurs. They can now have fun on microwaves without having to convince their friends to join them.

I don't think full-duplex operation on the satellite will pose a big problem on the microwave bands. It's considered a requirement for analog-satellite operation, since monitoring your SSB/CW downlink is essential to make sure you aren't overloading the satellite. True, this requires more antennas, but microwave antennas are often less expensive than relays designed for transmit/receive switching. Relays are a particular problem on receive—even the most expensive coaxial relays often have significant losses on the higher microwave bands. Waveguide relays are an option, but even at 5.6 GHz, they are pretty large. Multiposition coaxial relays often have a dangerous problem—the multiple contacts can latch together, hooking up more than one piece of gear to a common point. This can be disastrous if one of them is a transmitter putting out a significant amount of power. PIN diode switches have too much loss to be seriously considered for low-noise receiving applications.

Unlike HF and even 2m, the sky noise can be extremely low at microwaves. This makes it possible to detect the background radiation left by the Big Bang. With satellite antennas pointing at a quiet sky, the limiting factor is the receiver noise, which can be on the order of 25 Kelvins. Under these circumstances, even coax jumpers and poor-quality adapters can have a significant effect on performance. The same noise contributions wouldn't matter on HF, and might not be worth worrying about with many 2m setups.

One of the big trade-off points is antenna gain and pointing accuracy. Using high-gain antennas allows you to use less transmit power and noisier receivers. In exchange for this gain, you need greater antenna pointing accuracy. Thus, you can trade mechanical problems for electrical ones. In practice, a system with just a single axis of rotation used for terrestrial work and rotators with 5° brake steps are barely useable with a 2-foot dish on 10 GHz. Since beamwidth scales inversely with frequency, the same dish and rotator are quite practical at 2.3 GHz. Two axes of rotation are needed to cover the sky for satellite operation at 2.4 GHz.

The trade-off is rather straightfor-

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ward on transmit; the gain and power output of your station combine to achieve a given EIRP. The trade-off between linear polarization and circular polarization is a little tricky. Ideally, it is 3 dB due to the polarization mismatch. To do a proper analysis, you really need to consider the actual antennas used in space, as well as those on the ground. It also makes a difference whether or not the satellite spins to achieve thermal equilibrium, or if it resorts to more sophisticated techniques like those used for Phase 3D.

The performance of circularly polarized antennas can vary considerably under nonideal conditions, even if they have the same gain. With some phased arrays used in space, it's possible for the polarization to flip sense if one looks off the main lobe. This makes it necessary to have switchable polarization on the ground.[1] On the other hand, helical and quadrifilar helix antennas are much better behaved. This is why linear antennas worked pretty well with AO-13's mode S downlink—the downlink was an 8-turn helix. Even helixes differ—one can modify the end of the helix slightly to improve circularity, thus reducing the modulation effects caused by a spinning satellite.

On receive, a big antenna can allow the use of a noisier receiver. Less obvious is the fact that a bigger antenna can also reduce the effect of background noise from trees and buildings. It does this in two ways. First, bigger antennas have sharper patterns so obstacles are less likely to be in the field of view. Secondly, since the noise term is already substantial due to the noisy receiver, the extra noise generated by a tree has less effect. Suppose you had a 3-dB NF receiver—the tree would have to literally fill the aperture of the antenna to double the noise output of a receiver. On the other hand, filling even half the aperture would triple the noise output of a 0.7-dB NF microwave receiver. For serious DX types intent on maximizing the range of the satellite, a big antenna would allow you to get closer to the horizon before the ground noise becomes a factor.

Unfortunately, trees perform a double whammy on microwave signals. Not only do they generate noise, they attenuate signals. My experience with terrestrial paths indicates that they

[1]Notes appear on page 22.

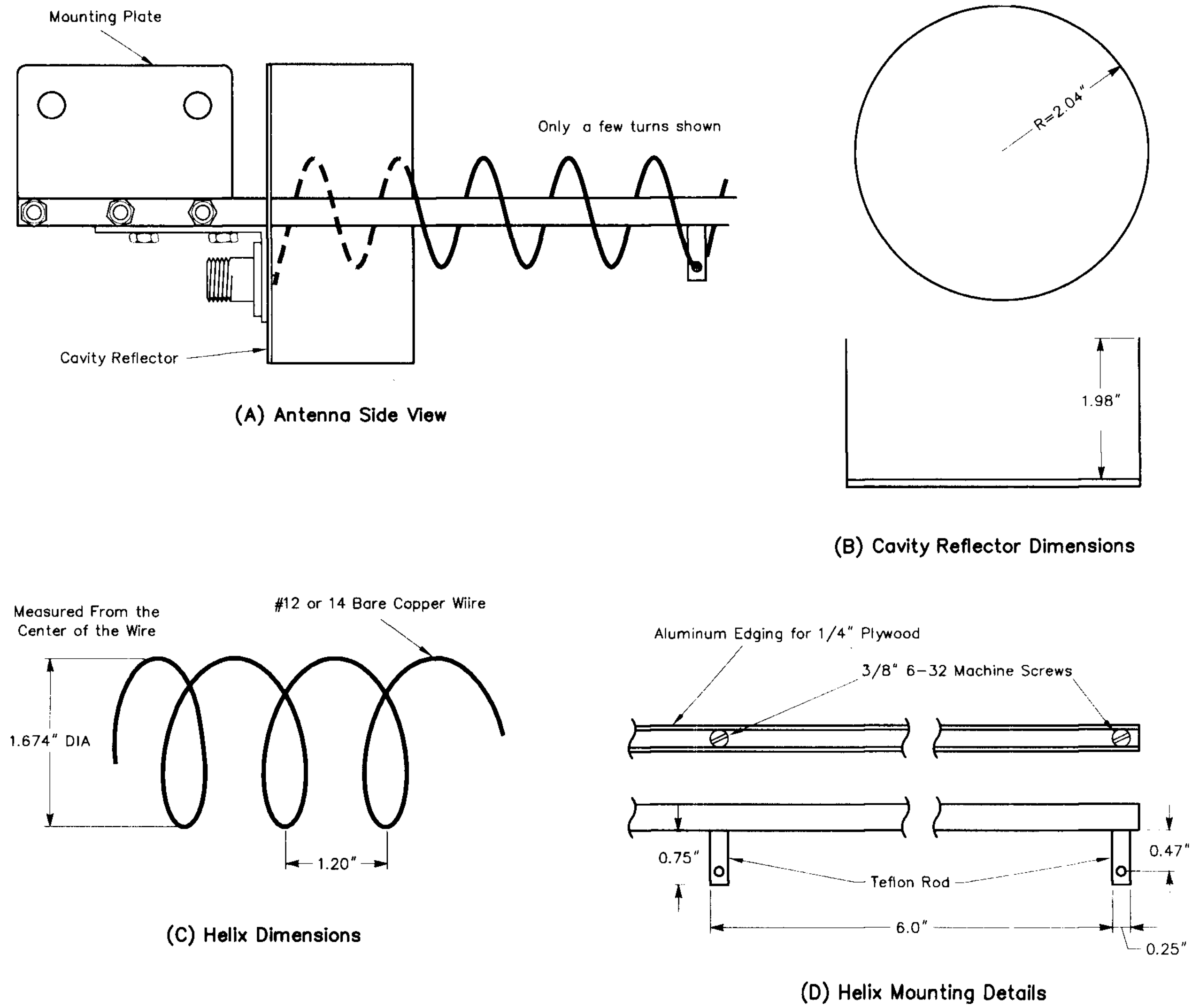

Fig 1—Sketch of a 2.4-GHz helix based on scaled King and Wong dimensions.

aren't a problem on 2m, but start to become one on 432 and 1296 MHz. At 2304 and 3456 MHz you can still brute-force paths with extra power and antennas pointed through trees. By the time you get to 5.7 and 10 GHz the situation is often hopeless, since you rarely have that much link margin. A good article on this topic is "HF and VHF Radio Wave Attenuation Through Jungle and Woods," by Seymour Krevsky, in the July 1963 *IEEE Transactions on Antennas and Propagation*. Although you may be working satellites, you should not count on the absence of warm earth noise to improve the signal-to-noise ratio. Interestingly, 2m is the crossover point where the earth noise equals the sky noise.

At 1269 MHz a good choice is a long helical antenna. It offers a good gain-to-size ratio and is relatively broadband in frequency coverage. The maximum practical gain for this antenna seems to be about 15.5 dBic for 16 turns. While formulas predict more gain for longer versions, difficulty is often encountered obtaining the expected gain. A lot of people have brought "killer" antennas to test ranges and have gone home disappointed. Darrel Emerson studied the gain for long-version helixes in "The Gain of an Axial-Mode Helix Antenna," *Antenna Compendium Volume 4*.

The King and Wong study did come up with a 35-turn helix with a measured gain of 17.8 dB (I assume to be dBi.)[2] They had an interesting construction technique—they wound $^{3}/_{16}$-inch copper tubing around Styrofoam supported by a $1^{1}/_{8}$-inch diameter aluminum boom. The diameter of the helix was 4.23 inches measured from the center to center of the tubing. The pitch was 12.8°. Unlike most helix antennas, they used a 5-inch high, 10.3-inch diameter cavity in place of the usual ground plane. The gain peaked at 950 MHz. A set of scaled dimensions for 2.4 GHz is shown in Fig 1. It may be possible to improve the antenna further by optimizing the cavity (the cavity was optimized for the 10-turn version).

Fig 1 doesn't describe the coax connector to helix transition because I have not actually tested these dimensions. You might start off with the helix transition design developed by James Miller, G3RUH, on page 23.40 of the *1997 ARRL Handbook*. James also describes a 16-turn, 15.5-dBi helix for 2.4 GHz, in case you just want to copy a design. If you need an instrument for antenna matching at 2.4 GHz, a good choice is Paul Wade's return loss bridge using chip resistors, presented in February 1995 *QEX*.

The technique King and Wong used is particularly interesting because many amateurs have expressed concern about supporting a helix around a metal boom. Many designs use wood as a nonconductive support, even though wood has a poor strength-to-weight ratio as compared to aluminum. Those attempting to copy the King and Wong parameters may actually do better by using a metal boom to more closely resemble the original design. Of course, the actual helix supports have to be nonconductive. I've made supports out of Teflon rod—drilled to tightly hold the copper wire and tapped to allow it to be screwed to a boom made out of aluminum extrusion. The aluminum extrusion is commonly used to cover the edge of $^{1}/_{4}$-inch plywood.

I think that a long helical antenna is also a good choice for 2.4-GHz transmitting, if you have at least 10 W of transmit power. Since they are inexpensive to make, two or four of them might be a good way to combine lower power amplifiers. Four 1-W amplifiers each connected to a 16-dBic helix ought to yield the +27 dBWic, which is recommended for Phase 3D. 1-W devices may be considerably cheaper than high-power devices, since people are marketing them for unlicensed applications.

For 2.4 GHz and above receive, the choice is quite obvious—use a small dish. You could get as much gain by stacking Yagis or helixes, however, the losses involved in combining them generate enough noise to kill much of the benefit. One way to avoid this extra loss is to use multiple preamplifiers. The real decision is whether to use an offset dish or a conventional one with the focus at the center. The offset dish has significant advantages for satellite use, which is why they are used for direct broadcast TV. Most significant is the high G/T (gain-to-noise temperature) ratio obtainable for a given size dish. Not only is the aperture blockage minimized by moving the feed out of the way, but the sidelobes are intentionally designed to point skyward with typical dish positions. This further improves the G/T ratio. Thus, an offset dish may allow a smaller dish to be used—perhaps an 18-inch instead of a 24-inch dish, for the same signal-to-noise ratio with favorable conditions.

When considering the position of the feed with an offset dish, a clever idea emerges—why not mount several feeds on a turret? Unlike conventional dishes, the unused feeds aren't blocking the aperture of the dish. Finally, offset dishes are often cheaper, a real plus to economy-minded amateurs. The big advantage to this scheme is that each feed can be optimized. Someone intending to transmit and receive with the same reflecting surface might use different feeds. The transmit feed could be optimized for maximum gain, while the receiving feed could be optimized for best gain-to-noise ratio. The inability to use both feeds at once isn't a problem—Phase 3D won't be capable of using the same band for uplink and downlink at the same time.

I think conventional dishes are still preferred for terrestrial use, if cost isn't a factor. The G/T ratio isn't a big deal, since the antennas are pointed at the horizon, and always look at a lot of warm earth. The big advantage is the ease of pointing—the symmetry of the dish makes it easy to point at the horizon. This doesn't matter much for satellite work where such a convenient reference doesn't exist. In addition, designing a suitable feed for a conventional dish is a bit easier. Paul Wade has tackled this problem for offset dishes.[3] The job of positioning the feed is also a bit easier, due to the symmetry of the dish.

Amateurs looking for a real challenge might try designing a multiband circularly polarized dish feed. Multiband feeds are hard to design, even for the simpler case of linear polarization. The challenge is keeping the phase center of the feed close to where it has to be for good gain. This is a problem with many log periodic designs—the phase center moves with frequency. As Paul Wade has pointed out in his series of microwave antennas, the most critical aspect of dish feeding is correctly placing the feed—you can lose many dB with an out of focus dish.[4]

Notes

[1]Davidoff, M., K2UBC, "Off-Axis Circular Polarization of Two Orthogonal Linearly Polarized Antennas," *Orbit*, September/October 1983, pp 14-15.

[2]King, H. E., and Wong, J. L., "Characteristics of 1 to 8 Wavelength Uniform Helical Antennas," *IEEE Transactions on Antennas and Propagation*, vol AP-28, March 1980, pp 291-296.

[3]Wade, P. C., N1BWT, "More on Parabolic Dish Antennas," December 1995 *QEX*, pp 14-22.

[4]Wade, P. C., N1BWT, "Practical Microwave Antennas," October 1994 *QEX*, pp 13-22.