Chapter 23

Space Communications

An Amateur Satellite Primer

Most amateurs are familiar with repeater stations that retransmit signals to provide wider coverage. Repeaters achieve this by listening for signals on one frequency and immediately retransmitting whatever they hear on another frequency. Thanks to repeaters, small, low-power radios can communicate over thousands of square kilometers. Unfortunately, many amateurs are *not* familiar with the best repeaters that have ever existed. These are the amateur satellites that hams have been using for 40 years. (See the sidebar "Tired of the Same Old QSOs?")

This is essentially the function of an amateur satellite as well. Of course, while a repeater antenna may be up to a few hundred meters above the surrounding terrain, the satellite is hundreds or thousands of *kilometers* above the surface of the Earth. The area of the Earth that the satellite's signals can reach is therefore much larger than the coverage area of even the best Earth-bound repeaters. It is this characteristic of satellites that makes them attractive for communication. Most amateur satellites act as analog repeaters, retransmitting CW and voice signals exactly as they are received, as packet store-and-forward systems that receive whole messages from ground stations for later relay, or as specialized Earth-looking camera systems that can provide some spectacular views. See **Fig 23.2**, an image of a town in the western US.

Amateur satellites have a long history of performing worldwide communications services for amateurs. See the sidebar "Amateur Satellite History."

N1JEZ

Fig 23.1—N1JEZ's portable microwave satellite station.

LINEAR TRANSPONDERS AND THE PROBLEM OF POWER

Most analog satellites are equipped with *linear transponders*. These are devices that retransmit signals within a band of frequencies, usually 50 to 250 kHz wide, known as the *passband*. Since the linear transponder retransmits the entire band, a number of signals may be retransmitted simultaneously. For example, if three SSB signals (each separated by as little

Tired of the Same Old QSOs? Break out of Orbit and Set your Course for the "Final Frontier"

Satellite-active hams comprise a relatively small segment of our hobby, primarily because of an unfortunate fiction that has been circulating for many years—the myth that operating through amateur satellites is overly difficult and expensive.

Like any other facet of Amateur Radio, satellite hamming is as expensive as you allow it to become. If you want to equip your home with a satellite communication station that would make a NASA engineer blush, it will be expensive. If you want to simply communicate with a few low-Earth-orbiting birds using less-than-state-of-the-art gear, a satellite station is no more expensive than a typical HF or VHF setup. In many cases you can communicate with satellites using your present station equipment—no additional purchases are necessary.

Does satellite hamming impose a steep learning curve? Not really. You have to do a bit of work and invest some brain power to be successful, but the same can be said of DXing, contesting, traffic handling, digital operating or any other specialized endeavor. You are, after all, communicating with a *spacecraft!*

The rewards for your efforts are substantial, making satellite operating one of the most exciting pursuits in Amateur Radio. There is nothing like the thrill of hearing someone responding to your call from a thousand miles away and knowing that he heard you through a satellite. (The same goes for the spooky, spellbinding effect of hearing your own voice echoing through a spacecraft as it streaks through the blackness of space.) Satellite hamming will pump the life back into your radio experience and give you new goals to conquer.

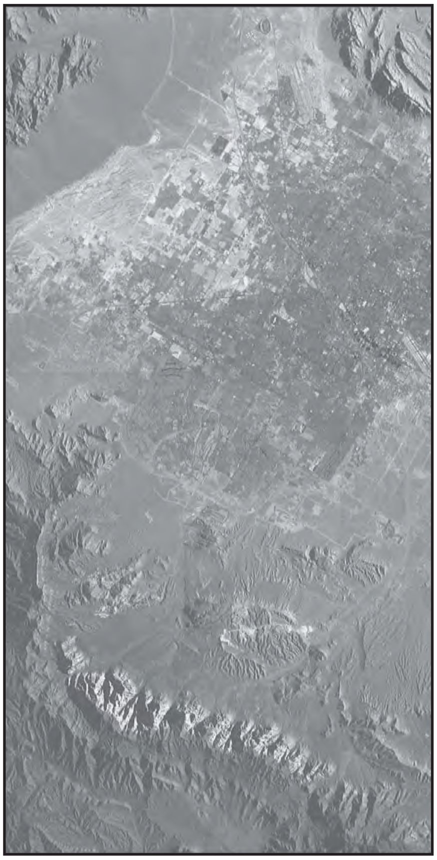


Fig 23.2—UO-36 captured this image of a well-known city in the western US. Need a hint? Think "Caesar's Palace."

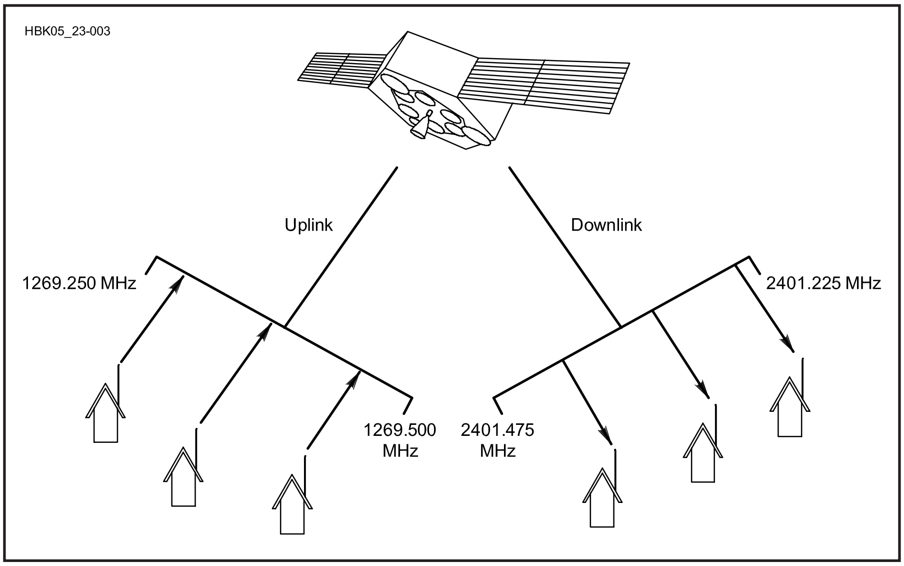


Fig 23.3—A linear transponder acts much like a repeater, except that it relays an entire group of signals, not just one signal at a time. In this example the satellite is receiving three signals on its 23-cm uplink passband and retransmitting them on its 13-cm downlink passband.

as 5 kHz) were transmitted to the satellite, the satellite would retransmit all three signals—still separated by 5 kHz each (see **Fig 23.3**). Just like a terrestrial repeater, the retransmissions take place on frequencies that are different from the ones on which the signals were originally received.

Some linear transponders invert the uplink signals. In other words, if you transmit to the satellite at the *bottom* of the uplink passband, your signal will appear at the *top* of the downlink passband. In addition, if you transmit in lower sideband (LSB), your downlink signal will be in upper sideband (USB). See **Fig 23.4**. Satellite passbands are usually operated according to the courtesy band plan, as shown. Transceivers designed for satellite use usually include features that cope with this confusing flip-flop.

Over the years, the number of amateur bands available on satellites has increased. To help in easily identifying these bands, a system of "Modes" has been created. In the early years reference to these Modes was by a single letter (Mode A, Mode B, etc), but with the launch of more satellites the opportunities greatly increased and it was necessary to show both the uplink and downlink bands. See **Table 23.1,** Satellite Operating Modes.

Linear transponders can repeat any type of signal, but those used by amateur satellites are primarily designed for SSB and CW. The reason for the SSB and CW preference has a lot to do with the hassle of generating power in space. Amateur satellites are powered by batteries, which are recharged by solar cells. "Space rated" solar arrays and batteries are very expensive. They are also heavy and tend to take up a substantial amount of space. Thanks to meager funding, hams don't have the luxury of launching satellites with large power systems such as those used by commercial birds. We have to do the best we

Table 23.1
Satellite Operating Modes

Frequency Band	*Letter Designation*	*New Designation* (Transmit, First Letter; Receive, Second Letter)	*Old Designation*
HF, 21-30 MHz	H	Mode U/V	Mode B
VHF, 144-148 MHz	V	Mode V/U	Mode J
UHF, 435-438 MHz	U	Mode U/S	Mode S
1.26-1.27 GHz	L	Mode L/U	Mode L
2.40-2.45 GHz	S	Mode V/H	Mode A
5.6 GHz	C	Mode H/S	
10.4 GHz	X	Mode L/S	
24 GHz	K	Mode L/X	
		Mode C/X	

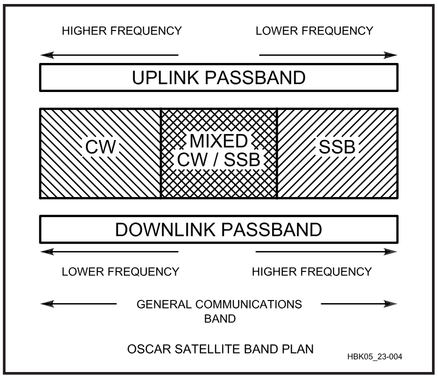


Fig 23.4—The OSCAR satellite band plan allows for CW-only, mixed CW/SSB, and SSB-only operation. Courteous operators observe this voluntary band plan at all times.

can within a much more limited "power budget."

So what does this have to do with SSB or any other mode? Think *duty cycle*—the amount of time a transmitter operates at full output. With SSB and CW the duty cycle is quite low. A linear satellite transponder can retransmit many SSB and CW signals while still operating within the power generating limitations of an amateur satellite. It hardly breaks a sweat.

Now consider FM. An FM transmitter operates at a 100% duty cycle, which means it is generating its full output with every transmission. Imagine how much power a linear transponder would need to retransmit, say, a dozen FM signals—all demanding 100% output!

Having said all that, there *are* a few, very popular FM repeater satellites. However, they do not use linear transponders. They retransmit only one signal at a time.

FINDING A SATELLITE

Before you can communicate through a satellite, you have to know what satellites are available and when they are available. (See sidebar "Current Amateur Satellites.") This isn't quite as straightforward as it seems.

Amateur satellites do not travel in geostationary orbits like many commercial and military spacecraft. Satellites in geostationary orbits cruise above the Earth's equator at an altitude of about 35,000 kilometers. From this vantage point the satellites can "see" almost half of our planet. Their speed in orbit matches the rotational speed of the Earth itself, so the satellites appear to be "parked" at fixed positions in the sky. They are available to send and receive signals 24 hours a day over an enormous area.

Of course, amateur satellites *could* be placed in geostationary orbits. The problem isn't one of physics; it's money and politics. Placing a satellite in geostationary orbit and keeping it on station costs a great deal of money—more than any one amateur satellite organization can afford. An amateur satellite group could ask similar groups in other areas of the world to contribute money to a geostationary satellite project, but why should they? Would you contribute large sums of money to a satellite that may never "see" your part of the world? Unless you are blessed with phenomenal generosity, it would seem unlikely!

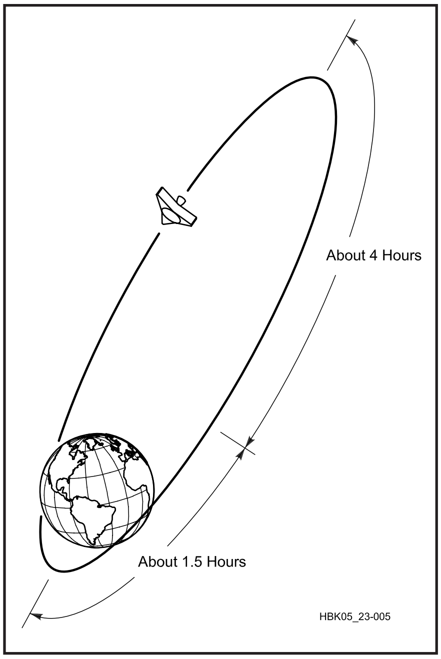
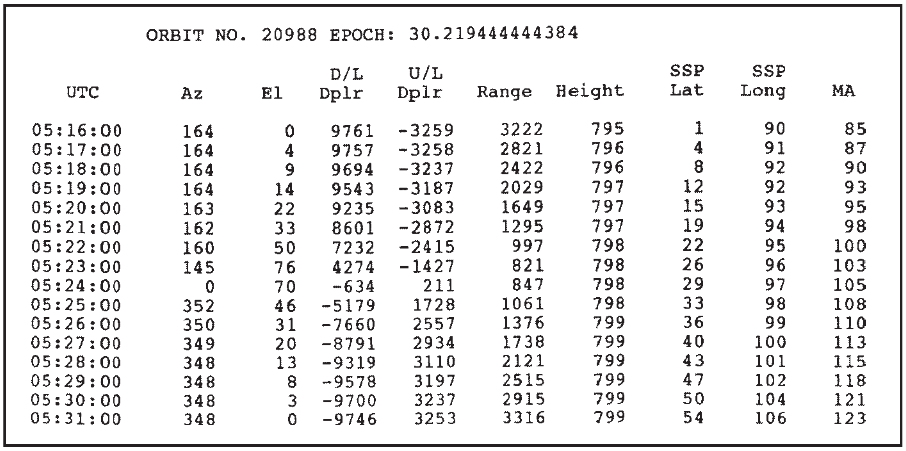


Fig 23.5—An example of a satellite in a high, elliptical orbit.

Instead, all amateur satellites are either low-Earth orbiters (LEO), or they travel in very high, elongated orbits. See **Fig 23.5**. Either way, they are not in fixed positions in the sky. Their positions relative to your station change constantly as the satellites zip around the Earth. This means that you need to predict when satellites will appear in your area, and what paths they'll take as they move across your local sky.

You'll be pleased to know that there is software available that handles this prediction task very nicely. A bare-bones program will provide a schedule for the satellite you choose. A very simple schedule might look something like **Fig 23.6**, showing the antenna pointing angles for each minute of a pass for AO-16.

The time is usually expressed in UTC.



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              ORBIT NO. 20988 EPOCH: 30.219444444384

                                D/L     U/L                       SSP     SSP
    UTC          Az      El    Dplr    Dplr    Range  Height     Lat    Long      MA

  05:16:00      164       0    9761   -3259     3222     795       1      90      85
  05:17:00      164       4    9757   -3258     2821     796       4      91      87
  05:18:00      164       9    9694   -3237     2422     796       8      92      90
  05:19:00      164      14    9543   -3187     2029     797      12      92      93
  05:20:00      163      22    9235   -3083     1649     797      15      93      95
  05:21:00      162      33    8601   -2872     1295     797      19      94      98
  05:22:00      160      50    7232   -2415      997     798      22      95     100
  05:23:00      145      76    4274   -1427      821     798      26      96     103
  05:24:00        0      70    -634     211      847     798      29      97     105
  05:25:00      352      46   -5179    1728     1061     798      33      98     108
  05:26:00      350      31   -7660    2557     1376     799      36      99     110
  05:27:00      349      20   -8791    2934     1738     799      40     100     113
  05:28:00      348      13   -9319    3110     2121     799      43     101     115
  05:29:00      348       8   -9578    3197     2515     799      47     102     118
  05:30:00      348       3   -9700    3237     2915     799      50     104     121
  05:31:00      348       0   -9746    3253     3316     799      54     106     123
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Fig 23.6—Tabular output from an orbit prediction program showing time and position information for AO-16.

Amateur Satellite History

The Amateur Radio satellite program began with the design, construction and launch of OSCAR I in 1961 under the auspices of the Project OSCAR Association in California. The acronym "OSCAR," which has been attached to almost all Amateur Radio satellite designations on a worldwide basis, stands for ***O**rbiting **S**atellite **C**arrying **A**mateur **R**adio*. Project OSCAR was instrumental in organizing the construction of the next three Amateur Radio satellites—OSCARs II, III and IV. *The Radio Amateur's Satellite Handbook*, published by ARRL has details of the early days of the amateur space program.

In 1969, the Radio Amateur Satellite Corporation (AMSAT) was formed in Washington, DC. AMSAT has participated in the vast majority of amateur satellite projects, both in the United States and internationally, beginning with the launch of OSCAR 5. Now, many countries have their own AMSAT organizations, such as AMSAT-UK in England, AMSAT-DL in Germany, BRAMSAT in Brazil and AMSAT-LU in Argentina. All of these organizations operate independently but may cooperate on large satellite projects and other items of interest to the worldwide Amateur Radio satellite community. Because of the many AMSAT organizations now in existence, the US AMSAT organization is frequently designated AMSAT-NA.

Beginning with OSCAR 6, amateurs started to enjoy the use of satellites with lifetimes measured in years as opposed to weeks or months. The operational lives of OSCARs 6, 7, 8 and 9, for example, ranged between four and eight years. All of these satellites were low Earth orbiting (LEO) with altitudes approximately 800-1200 km. LEO Amateur Radio satellites have also been launched by other groups not associated with any AMSAT organization such as the Radio Sputniks 1-8 and the ISKRA 2 and 3 satellites launched by the former Soviet Union.

The short-lifetime LEO satellites (OSCARs I through IV and 5) are sometimes designated the *Phase I* satellites, while the long-lifetime LEO satellites are sometimes called the *Phase II* satellites. There are other conventions in satellite naming that are useful to know. First, it is common practice to have one designation for a satellite before launch and another after it is successfully launched. Thus, OSCAR 40 (discussed later) was known as Phase 3D before launch. Next, the AMSAT designator may be added to the name, for example, AMSAT-OSCAR 40, or just AO-40 for short. Finally, some other designator may replace the AMSAT designator such as the case with Japanese-built Fuji-OSCAR 29 (FO-29).

In order to provide wider coverage areas for longer time periods, the high-altitude Phase 3 series was initiated. Phase 3 satellites often provide 8-12 hours of communications for a large part of the Northern Hemisphere. After losing the first satellite of the Phase 3 series to a launch vehicle failure in 1980, AO-10 was successfully launched and became operational in 1983. AO-13, the follow-up to the AO-10 mission, was launched in 1988 and re-entered the atmosphere in 1996. The successor to AO-13, AO-40 was launched on November 16, 2000 from Kourou, French Guiana.

Satellites providing store-and-forward communication services using packet radio techniques are generically called *PACSATs*. Files stored in a PACSAT message system can be anything from plain ASCII text to digitized pictures and voice.

The first satellite with a digital store-and-forward feature was UoSAT-OSCAR 11. UO-11's Digital Communications Experiment (DCE) was not open to the general Amateur Radio community although it was utilized by designated "gateway" stations. The first satellite with store-and-forward capability open to all amateurs was the Japanese Fuji-OSCAR 12 satellite, launched in 1986. FO-12 was succeeded by FO-20, launched in 1990, and FO-29, launched in 1996.

By far the most popular store-and-forward satellites are the *PACSATs* utilizing the PACSAT Broadcast Protocol. These PACSATs fall into two general categories — the *Microsats,* based on technology developed by AMSAT-NA, and the *UOSATs,* based on technology developed by the University of Surrey in the UK. While both types are physically small spacecraft, the Microsats represent a truly innovative design in terms of size and capability. A typical Microsat is a cube measuring 23 cm (9 in) on a side and weighing about 10 kg (22 lb). The satellite will contain an onboard computer, enough RAM for the message storage, two to three transmitters, a multichannel receiver, telemetry system, batteries and the battery charging/power conditioning system.

Amateur Radio satellites have evolved to provide three primary types of communication services — analog transponders for real-time CW and SSB communication, digital store-and-forward for non real-time communication, and direct "bent-pipe" single-channel FM repeaters. Which of these types interest you the most will probably depend on your current Amateur Radio operating habits. Whatever your preference, this section should provide the information to help you make a successful entry into the specialty of amateur satellite communications.

AO-16 will appear above your horizon beginning at 0516 UTC on January 30. The bird will “rise” at an azimuth of 164°, or approximately south-southeast of your station. The elevation refers to the satellite’s position above your horizon in degrees—the higher the better. A zero-degree elevation is right on the horizon; 90° is directly overhead.

By looking at this schedule you can see that the satellite will appear in your south-southeastern sky at 0516 UTC and will rise quickly to an elevation of 70° by 0524. The satellite’s path will curve further to the east and then directly to the north as it rises. Notice how the azimuth shifts from 164° at 0516 UTC to 0° at 0524. This is nearly a direct overhead pass of AO-16 and it sets in the north-northwest at 348°.

Fig 23.7—The communications range circles, or “footprints” over North America.

The more sophisticated the software, the more information it usually provides in the schedule table. The software may also display the satellite’s position graphically as a moving object superimposed on a map of the world. Some of the displays used by satellite prediction software are visually stunning! This view, **Fig 23.7,** is provided by *Nova* for *Windows*, from Northern Lights Software Associates.

Satellite prediction software is widely available on the Web. Some of the simpler programs are freeware. The AMSAT-NA Web site has the largest collection of satellite software for just about any computer you can imagine. Most AMSAT software isn’t free, but the cost is reasonable and the funds support amateur satellite programs.

Whichever software you choose, there are two key pieces of information you must provide before you can use the programs:

(1) **Your position**. The software must have your latitude and longitude before it can crank out predictions for your sta-

Current Operational Amateur Satellites

OSCAR 7, AO-7, was launched November 15, 1974 by a Delta 2310 from Vandenberg, CA. AO-7’s operating status is semi-operational in sunlight only. After being declared dead in mid 1981 due to battery failure, AO-7 has miraculously sprung back to life. It will only be on when in sunlight and off in eclipse. AO-7 will reset each orbit and may not turn on each time.

OSCAR 11, UO-11, a scientific/educational low-orbit satellite, was built at the University of Surrey in England and launched on March 1, 1984. This UoSat spacecraft has also demonstrated the feasibility of store-and-forward packet digital communications and is operational with telemetry downlinks only.

OSCAR 16, AO-16, also known as PACSAT, was launched in January 1990. A digital store-and-forward packet radio file server, it has an experimental S-band beacon at 2401.143 MHz. AO-16 is only semi-operational with the 1200-baud digipeater for APRS service.

OSCAR 26, IO-26, was launched on September 26, 1993 is semi-operational and now serves as a 1200-baud digipeater for APRS service.

RS 15, launched in December 1994, is a Mode V/H spacecraft; its uplink is on the 2m band, and its downlink is on 10m.

OSCAR 27, AO-27, was launched in September 1993 along with OSCAR 26. It features a mode V/U analog FM repeater. Because of the need to conserve power, OSCAR 27 is usually only available during daylight passes.

OSCAR 29, FO-29, launched from Japan in 1996, in a low earth orbit. It operates with a mode V/U analog transponder.

OSCAR 44, NO-44, also known as PCSAT was launched on September 30, 2001 from Kodiak, Alaska. PCSAT is a 1200-baud APRS digipeater designed for use by stations using hand-held or mobile transceivers. The operational status of PCSAT is uncertain and subject to change due to power availability.

OSCAR 50, SO-50 also known as SAUDISAT-1C, was launched December 20, 2002 aboard a converted Soviet ballistic missile from Baikonur Cosmodrome. SO-50 carries several experiments, including a mode U/V FM amateur repeater. The repeater is available to amateurs as power permits, using a 67.0 Hz uplink tone for on-demand activation.

OSCAR 51, also known as *Echo*, was launched on June 29, 2004 from the Baikonur Cosmodrome. Echo carries a FM repeater capable of 144 MHz and/or 1.2 GHz uplink with a 435 MHz and/or 2.4GHz downlink. The satellite also includes an AX.25 digital PACSAT BBS and a PSK31 uplink on 28 MHz.

VUSat-OSCAR 52 was launched on May 5, 2005. Within 24 hours its Mode U/V transponder was open for business and hams were reporting excellent signals. The first Indian Amateur Radio satellite carries two 1-W linear transponders for SSB and CW communication, although only one transponder is operational at a time. OSCAR 52 travels in a polar sun-synchronous orbit at an altitude of 632 × 621 km with an inclination of 97.8 deg with respect to the equator.

tion. The good news is that your position information doesn't need to be extremely accurate. Just find out the latitude and longitude of your city or town (the public library would have this data, as would any nearby airport) and plug it into the program.

(2) **Orbital elements**. This is the information that describes the orbits of the satellites. You can find orbital elements (often referred to as *Keplerian elements*) at the AMSAT Web site, and through many other sources on the Internet. You need to update the elements every few months. Many satellite programs will automatically read in the elements if they are provided as ASCII text files. The less sophisticated programs will require you to enter them by hand. Automatically updated software is highly recommended; it's too easy to make a mistake with manual entries.

GETTING STARTED WITH THE FM BIRDS

Do you like elevated FM repeaters with wide coverage areas? Then check out the AO-27 and AO-51 FM repeater satellites. From their low-Earth orbits these satellites can hear stations within a radius of 2000 miles in all directions.

You can operate the FM satellites with a basic dual band VHF/UHF FM transceiver and even a good FM HT, as some amateurs have managed. Assuming that the transceiver is reasonably sensitive, you can use a good "rubber duck" antenna as in **Fig 23.8**. Some amateurs have even managed to work the FM birds with HTs coupled to multi-element directional antennas such as the popular Arrow Antenna, **Fig 23.9**. Of course, this means they must aim their antennas at the satellites as they cross overhead.


Fig 23.8—W2RS shows another popular LEO FM antenna for hand-held operations.

High quality omnidirectional antennas for LEO service come in quite a number of forms and shapes. M^2 Enterprises has their EB-144 and EB-432 Eggbeater antennas, **Fig 23.10** and **Fig 23.11**, which have proven to be very useful and do not require any rotators for control. The Quadrifilar omnidirectional antenna, **Fig 23.12**, has been around for a long time, as has the turnstile-over-reflector antenna, **Fig 23.13**.

For even better performance, at the modest cost of a simple TV antenna rotator, check out the fixed elevation Texas Potato Masher antenna by K5OE, **Fig 23.14**. This antenna provides a dual band solution for medium gain directional antennas for LEO satellite operations. This is a considerable improvement over omnidirectional antennas and does not require an elevation control for good performance.

Start by booting your satellite tracking software. Check for a pass with a peak elevation of 30° or higher. As with all satellites, the higher the elevation, the better. If you plan to operate outdoors or away from home, either print the schedule to a printer or jot down the times on a piece of scrap paper that you can keep with you.

When the satellite comes into range, you'll be receiving its signal about 5 kHz higher than the published downlink frequency (see **Table 23.2**, Active Amateur Satellites: Frequencies and Modes) thanks to *Doppler shifting* (see the sidebar, "Down with Doppler"). So, begin listening on the higher frequency. If you suddenly hear the noise level dropping, chances are you are picking up the satellite's signal. At about the midpoint of the pass you'll need to shift your receiver down to the published frequency, and as the satellite is heading away you may wind up stepping down another 5 kHz. Some operators program these frequency steps into memory channels so that they can compensate for Doppler shift at the push of a button.

Once again, these FM satellites behave just like terrestrial FM repeaters. Only one person at a time can talk. If two or more people transmit simultaneously, the result is garbled audio or a squealing sound on the output. The trick is to take turns and keep the conversations short. Even the best passes will only give you about 15 minutes to use the satellite. If you strike up a conversation, don't forget that there are others waiting to use the bird.

The FM repeater satellites are a good way to get started. Once you get your feet

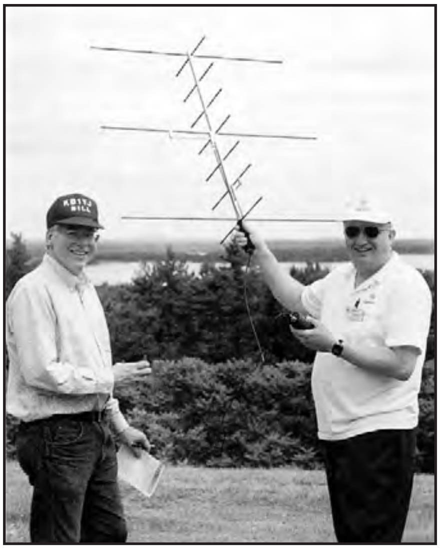


Fig 23.9—The hand-held "Arrow" gain antenna is popular for LEO FM operations. (Photo courtesy *The AMSAT Journal*, Sep/Oct 1998.)

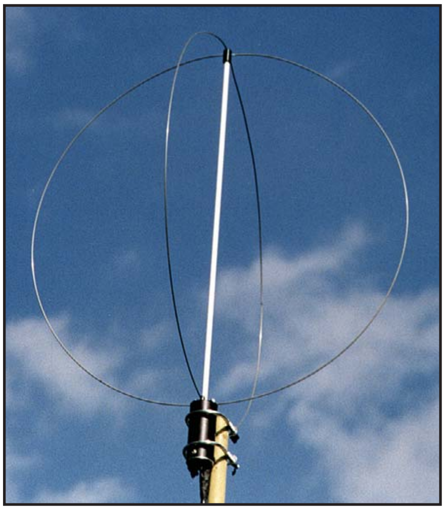


Fig 23.10—Eggbeater antennas are popular for base station LEO satellite operation. This EB144 eggbeater is for 2 m.

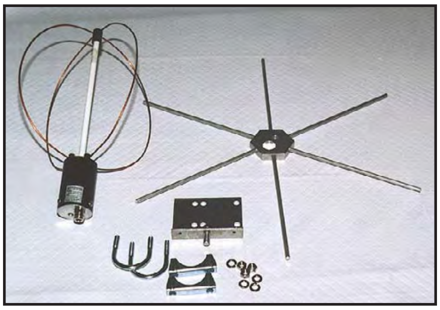


Fig 23.11—This EB-432 eggbeater antenna for 70-cm operation is small enough to put in an attic. Antenna gain pattern is helped with the radials placed below the antenna.

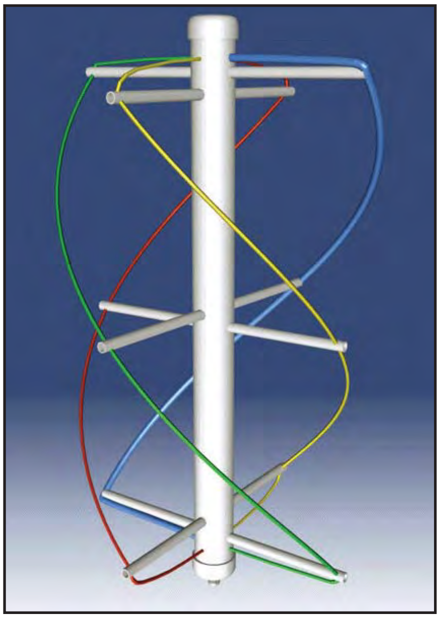


Fig 23.12—W3KH suggests that quadrifilar antennas can serve well for omnidirectional satellite station antenna service.

Table 23.2 – Active Amateur Satellites: Frequencies and Modes

Satellite (SSB/CW)	*Uplink (MHz)*	*Downlink (MHz)*
FO-29	145.900-146.000	435.800-435.900 435.795 (CW beacon)
RS-15	145.858-145.898	29.354-29.394
VO-52	435.225-435.275	145.875-145.925
Packet—1200 bit/s		
AO-16	145.90, .92, .94, .96	437.051
NO-44	145.827	144.390
Packet—9600 bit/s		
GO-32	890/145.850	435.225
FM Voice Repeaters		
AO-51	145.920	435.300
AO-27 (Daylight passes *only*)]	145.850	436.795

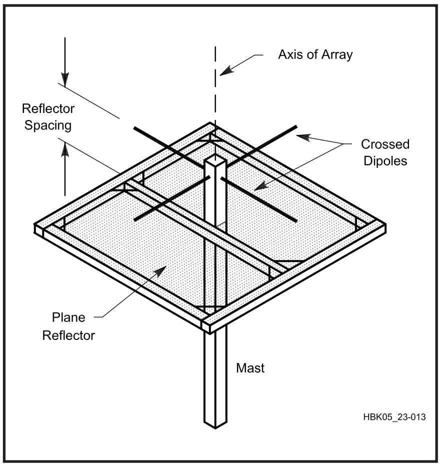


Fig 23.13—The Turnstile Over Reflector antenna has served well for LEO satellite service for a number of years.

Fig 23.14—Jerry Brown, K5OE, uses his Texas Potato Masher antennas for LEO satellite operations.

wet, you'll probably wish you could access a satellite that wasn't so crowded, where you could chat for as long as the bird was in range. You may find that a very good assist will be given to you from the book *Working the Easy Sats*, by WA4YMZ and N1JEZ. This is available from AMSAT headquarters.[3] But now it is time to move up!

MOVING UP TO OSCARS 29 AND 52

VUSat-OSCAR 52 carries a *Mode U/V* transponder, which means that it receives signals on the 70-cm band and retransmits on the 2-m band. Operating this satellite is done with the equipment and antenna setup shown in **Fig 23.15**.

Once you've determined when the satellite is due to rise above the horizon at your location, listen for the satellite's CW telemetry beacon. This signal is transmitted constantly by the satellite and carries information about the state of the satellite's systems, such as its battery voltage, solar-panel currents, temperatures and so on. You should hear it just as the satellite rises above the horizon. As soon as you can hear the beacon, start tuning across the downlink passband.

On an active day you should pick up several signals. They will sound like normal amateur SSB and CW conversations. Nothing unusual about them at all—except that the signals will be slowly drifting downward in frequency. That's the effect of Doppler shift.

Now tune your transmitter's frequency to the satellite's uplink passband. OSCAR 52 uses inverting transponders. If you transmit at the low end of the uplink passband, you can expect to hear your signal at the high end of the downlink passband. Generally speaking, CW operators occupy the lower half of the transponder passband while SSB enthusiasts use the upper half, as was shown in Fig 23.4.

Assuming that you cannot hear your own signal from the satellite on a separate receiver, the best thing to do is make your best guess as to where your signal will appear on the downlink and set your receive frequency accordingly. Send several brief CQs ("CQ OSCAR 52, CQ OSCAR 52…"), tuning "generously" around your guesstimated receive frequency after each

Fig 23.15—Simple ground plane and Yagi antennas can be used for low-Earth-orbit (LEO) satellite contacts.

one. The station that is answering your call will also be making his or her best guess about where you are listening.

The Japanese Fuji OSCAR FO-29, is also a linear transponder bird that functions much like OSCAR 52. The main difference is that it listens on 2 m and retransmits on 70 cm, Mode V/U. (FO-29 also uses inverting transponders.) Few amateurs own receivers that can listen for 70 cm CW and SSB, so this satellite is not very active. During weekend passes, however, you should be able to hear several conversations taking place.

Station Requirements for the OSCAR 29 and 52 Satellites

To work OSCAR 52 you'll need, at minimum, a multiband VHF/UHF SSB or CW transceiver. You *do not* need an amplifier; 50 W is more than enough power for the uplink. In fact, even 50 W may be too much in many instances. The rule of thumb is that your signal on the downlink should never be stronger than the satellite's own telemetry beacon.

The ability to hear yourself simultaneously on the downlink is a tremendous asset for working any satellite. It allows you to operate full duplex as you listen to the Doppler shifting of your own signal, giving you the opportunity to immediately tweak your transmit frequency to compensate (rather than fishing for contacts using the haphazard half-duplex procedure described earlier).

To work OSCAR 52 in Mode U/V, you'll need a 2-m multimode transceiver that can operate in CW or SSB. Remember that OSCAR 52 is listening for signals on 70 cm and retransmitting on 2 m. This means that also need a 70 cm transceiver. Choose your radios carefully. A number of modern HF transceivers also include 2 m and even 70 cm. The problem, however, is that some

Fig 23.17—The Yaesu FT-847's satellite mode provides the user with a full featured satellite transceiver. As a bonus, it also covers all the HF bands!

Fig 23.16—VUSat-OSCAR 52 heads for orbit!

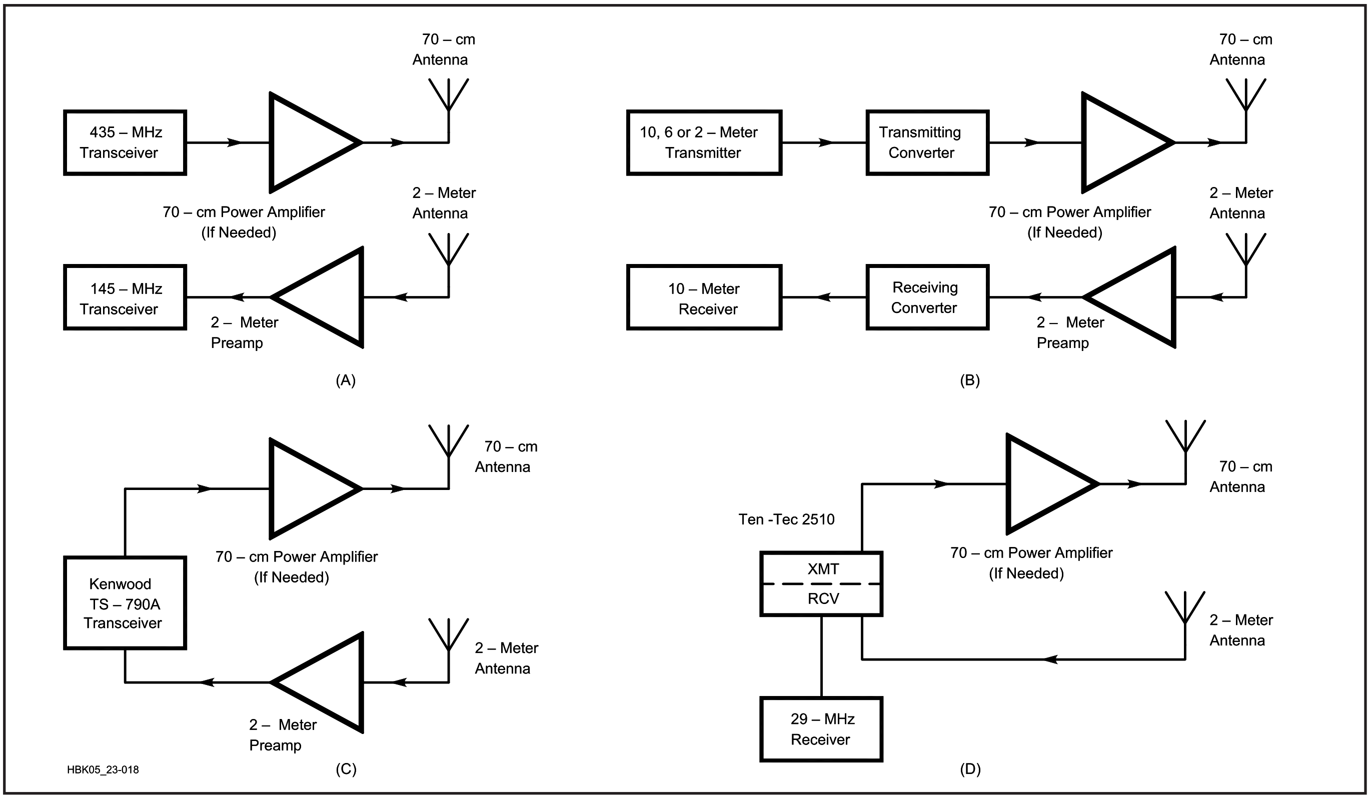


Fig 23.18—Several different Mode-U/V satellite-station configurations for OSCAR 52 are shown here. At A, separate VHF/UHF multimode transceivers are used for transmitting and receiving. The configuration shown at B uses transmitting and receiving converters or transverters with HF equipment. At C, a multimode, multiband transceiver can perform both transmitting and receiving function, full duplex, in one package. The Ten-Tec 2510 shown at D contains a 435-MHz transmitter and a 2-m to 10-m receiving converter.

of these radios do not allow *crossband splits* between VHF and HF. That is, they won't allow you to transmit on 70 cm and receive on 2 m. At the very least they won't allow you to do this simultaneously. One solution that will provide full duplex service for Mode U/V is the Yaesu FT-847 transceiver, **Fig 23.17**, all in one neat package.

Omnidirectional antennas for 2 m are sufficient for listening to OSCAR 52. A beam on 2 m would be even better, but then you incur the cost of an antenna rotator that can move the antenna up and down as well as side to side—the so-called *azimuth/elevation rotator*, or Az-El rotators.

For FO-29 the ability to transmit and receive simultaneously is a must. The Doppler effect is pronounced on the 70 cm downlink. You need to listen to your own signal continuously, making small adjustments to your 2-m uplink so your voice or CW note does not slide rapidly downward in frequency. To achieve this you will need separate 2-m and 70-cm transceivers (such as a couple of used rigs), or a dual band transceiver specifically designed for satellite use. **Fig 23.18** and **Fig 23.19** show several possible combinations of equipment for satellite operations on 2 m and 70 cm. Kenwood, ICOM and Yaesu have such radios in their product lines. These wondrous rigs make satellite operating a breeze, although their price tags may give you a bit of sticker shock (about $1600). They feature full crossband duplex, meaning that you can transmit on 2 m at the same time you are listening on 70 cm. They even have the ability to work with inverting transponders automatically. That is, as you move your receive frequency down, the transmit VFO will automatically move up (and vice versa)!

Although beam antennas and azimuth/elevation rotators are not strictly necessary to work FO-29, they vastly improve the quality of your signal. A good compromise, medium-gain antenna for 2 m and 70 cm is shown in Fig 23.14. If you decide

Down with Doppler

The relative motion between you and the satellite causes *Doppler shifting* of signals. As the satellite moves toward you, the frequency of the downlink signals will increase as the velocity of the satellite adds to the velocity of the transmitted signal. As the satellite passes overhead and starts to move away from you, the frequency will drop, much the same way as the tone of a car horn or a train whistle drops as the vehicle moves past the observer.

The Doppler effect is different for stations located at different distances from the satellite because the relative velocity of the satellite with respect to the observer is dependent on the observer's distance from the satellite. The result is that signals passing through the satellite transponder shift slowly around the published downlink frequency. Your job is to tune your uplink transmitter—*not your receiver*—to compensate for Doppler shifting and keep your frequency relatively stable on the downlink. That's why it is helpful to hear your own signal coming through the satellite. If you and the station you're talking to both compensate correctly, your conversation will stay at one frequency on the downlink throughout the pass. If you don't compensate, your signals will drift through the downlink passband as you attempt to "follow" each other. This is highly annoying to others using the satellite because your drifting signals may drift into their conversations.

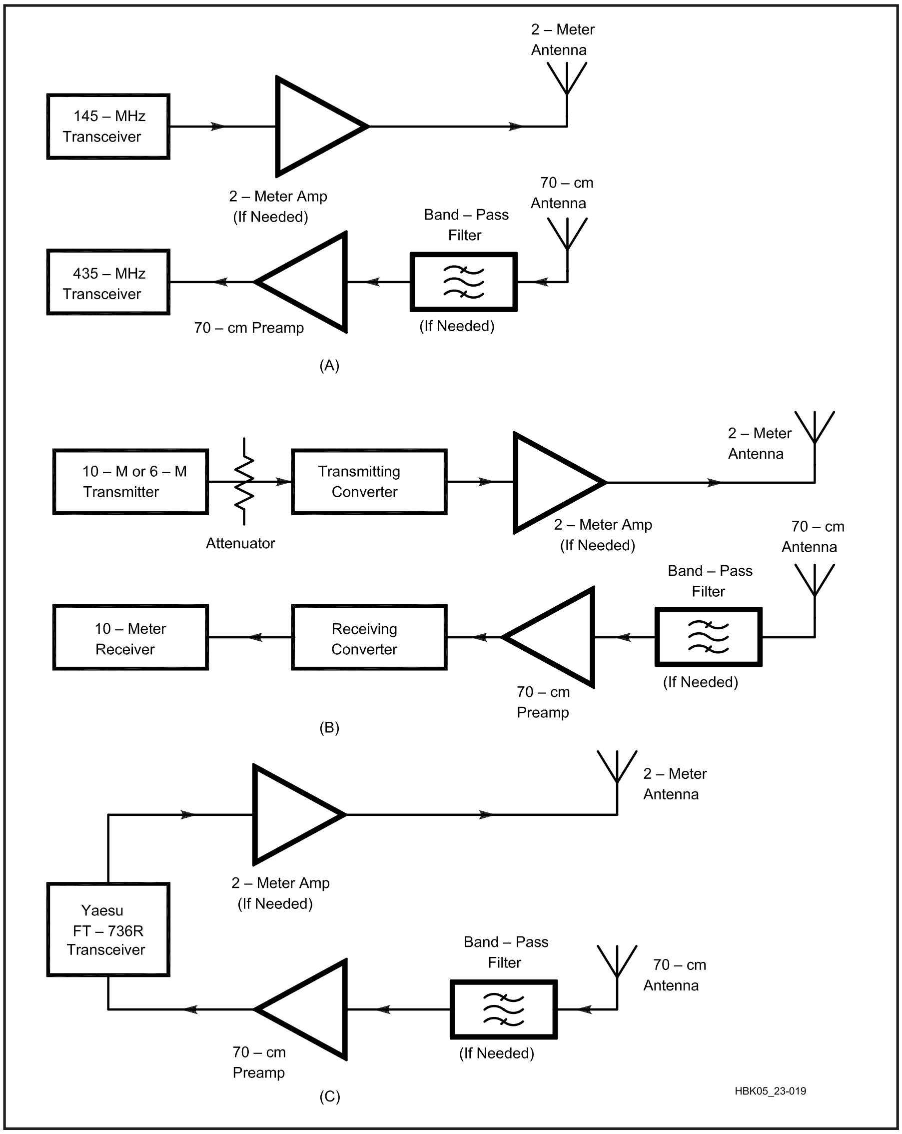


Fig 23.19—Several different Mode-V/U satellite-station configurations for OSCAR 29 are shown here. At A, separate VHF/UHF multimode transceivers are used for transmitting and receiving. The configuration shown at B uses transmitting and receiving converters or transverters with HF equipment. At C, a multimode, multiband transceiver can perform both transmitting and receiving functions, full duplex, in one package.

to go the omnidirectional route, you'll need to add a 70-cm receive preamp at the antenna to boost the downlink signal.

PHASE 3E—THE NEXT GENERATION

The next Phase 3-series satellite planned is Phase 3E or P3E. It is built on a P3C (AO-13) platform. As this *Handbook* went to press, P3E is expected to launch within the next two years. Currently, the planned transmit RF operations on P3E are R Band (47 GHz) very low power — 0.5 W PEP; K Band (24 GHz) moderate power — 5 W PEP; X Band (10.5 GHz) very low, medium and high power — up to 10 W; S Band (2.4 GHz) high power — 25 W PEP, and V Band (145 MHz) high power. Generally, *high power* here means RF output from the satellite in the 5- to 25-W PEP range using mostly linear transmitters that incorporate HELAPS technology. Very low power on X Band is to simulate the signal strength that Earth stations will see from a P5A (Mars mission) transmitter near the red planet. There are other modules on board — such as a star sensor — that are prototypes for the upcoming P5A mission. Receive frequencies on P3E will be in C Band (5.6 GHz); S Band (2.45 GHz); L Band (1.2 GHz), and U Band (435 MHz). Updates and other useful information on P3E can be found on the German AMSAT website at: **www.amsat-dl.org/p3e**.

Fig 23.20—WD4FAB's station is typical of a full-featured HF and satellite operation. On the bottom row, L-R are: IC-746 HF to 2 meter transceiver, IC-821H VHF-UHF multimode transceiver topped by a home-brew power meter, KLM 1200GU 1.2-GHz transverter, home-brew multi-antenna rotator controller on top of the station accessory control box. On the top row, L-R are: G3RUH AO-13 Telemetry Demodulator, PacComm SPIRIT2 high performance packet controller, Timewave DSP-599zx audio DSP unit for the VHF-microwave operations through the IC-821H and the TAPR EasyTrak antenna command unit for interfacing the computer tracking to the antenna controller.

SATELLITE GROUND STATIONS

The keys to your enjoyable satellite communications are in the details of your station. One such station is illustrated in **Fig 23.20** and **Fig 23.21**, showing only some of the ways that you can achieve this enjoyable ham radio operation. The following sections will describe that station and the options that are open for you to construct your own satellite station, including discussions of equipment and techniques for transmitting, receiving, antennas, and station accessories, such as audio processing and antenna pointing control.

Transmitting

The 23-cm (L) band is the highest band for which commercial amateur transceivers are readily available. Kits and converters are also available. Commercial equipment, such as the ICOM IC-910H, **Fig 23.22**, with a 23-cm module, the popular Yaesu FT-736R, **Fig 23.23**, with a 23-cm module, and the new Kenwood TS-2000, **Fig 23.24**, with a 23-cm module, all provide about 10 watts of RF output power. Of course multimode transceivers, such as the ICOM IC-821H, **Fig 23.25**, with an outboard 23-cm up-converter will also serve the satellite station very well. See **Table 23.3** for a listing of suppliers of equipment of interest to satellite operators.

Stations that do not have one of the newer transceivers, with their built-in 1.2 GHz band modules, can use a separate transverter or transmitting up-converter to achieve the L-band uplink. Commonly these up-converters employ a 2-m IF for their drive. This generally means that a separate 2-m receiver is needed along with the VHF/UHF transceiver, as often the S-band down-converter also has a 2-m IF. The station shown in Fig 23.20 is of this type, using the 2-m features of the base HF transceiver to provide the IF for the S-band down-converter. Transmitting functions use the VHF/UHF transceiver for uplinks on U band and L band through an up-converter. There are a few L-band-transmitting up-converters on the market just for satellite service. Among these are units from Down East Microwave, with its 1268-144TX; and from SSB-USA, with its MKU130TX; and from Parabolic AB. When you assemble your station, be sure to take the necessary steps to set the RF power drive level needed for your up-converter. This may mean the need for a power attenuator inserted between the transceiver and up-converter.

Operating experience with L-band uplinks has shown that the power and antenna requirements for communications at altitudes up to 40,000 km can be satisfied with 10 W of power *delivered* to a 12-turn helix antenna. This experience has also shown that L-band power levels of 40 W-PEP, or higher, *delivered to the antenna*, along with antenna gains of greater than 20 dBi (4000-5600 W-PEP EIRP) are very workable for operations at the highest altitudes, depending upon the satellite squint angle. A pretty compact L-band antenna arrangement with two 22-element antennas in a stacked array is shown in Fig 23.21. These antennas have a combined gain of about 21.5 dBi. Some other experiences with L-band dish antennas have shown that a 1.2-m offset-fed dish with a helix feed and 10-W of RF power can also provide a superb uplink. This dish antenna will have a practical gain of about 21 dBic, giving an uplink of only 1400 W-PEP EIRP but with RHCP. Circular polarization for L band makes a real uplink difference. These uplinks will provide the user a downlink that is 10-15 dB above the transponder noise floor. In more practical terms this is an S7 to S8 signal over a S3 transponder noise floor in the illustrated station, a very comfortable copy for the capable station.

Fig 23.21—Station antennas at WD4FAB. Mounted are T-B: M2 436-CP30, two stacked M^2 23CM22EZ, modified PrimeStar dish with homebrew seven-turn Helix feed antenna. The M^2 2M-CP22 antenna is off the bottom of the photo. See Fig 23.41 for details of the center section.

Fig 23.22—ICOM's IC-910H, a recent entry into the multi band VHF/UHF transceiver world, has an available 23-cm module.

Fig 23.23—The Yaesu FT-736R is a multi-mode transceiver for 2 m (144-148 MHz) and 70 cm (430-450 MHz). It can be used for full-duplex receiving and transmitting on Mode U/V and V/U. An optional 23-cm module covers 1230-1300 MHz (Mode L/U). Approximate power output: 20 W on 2 m and 70 cm, and 10 W on 23 cm.

Fig 23.24—Kenwood's TS-2000 is an all-band, multi-mode transceiver that covers HF, 6 m, 2 m, and 70 cm. A 23-cm (1240-1300 MHz) module is optional. Typical power output is 35-45 W on 144 MHz, 30-40 W on 430 MHz and 10 W on 1240 MHz.

Fig 23.25—ICOM's IC-821H is another full-featured transceiver designed for satellite use.

For the illustrated station, the remotely mounted 23-cm amplifier (see "Double Brick Amplifier Construction") is contained in a tower-mounted-box. The regulated dc power requirements for this amplifier are of too high a current at 13.8 V-dc to bring it up from the ground, as the voltage loss of any reasonable cable would be excessive. Instead, 24 V dc unregulated power is taken from the station power supply before its regulator. This power is brought up the tower and regulated to 13.8 V where it is needed. This power regulator is borrowed from Chapter 17, "28-V, High-Current Power Supply", using only the regulator circuitry, and adjusting the output voltage down to 13.8 V dc.

Much of your station's uplink performance strongly depends upon the satellite's antenna off-pointing, or *squint* angle. L-band and U-band receiving antennas are usually high-gain arrays, with measured gains of 16 dBic and 15 dBic, respectively. This means that the antenna half-power-beamwidth (HPBW) of these arrays are relatively narrow, calculated to be HPBW = 28.5° and 32.0°, respectively. When a satellite's main axis (+Z axis) is off pointed from your ground station that off-pointing angle is known as the squint angle. If the squint angle is less than half of the HPBW, the ground station will be within the spacecraft antenna nominal beam width. It is one of the information outputs from most of the newer computer satellite tracking programs. With the weaker signals from birds at higher altitudes, the effects of the squint angle are more pronounced; making the HPBW values sometimes seem even smaller.

SOME L-BAND PROBLEMS AND SOLUTIONS

An examination of an efficient operating system must include all of the various parts of that system, and how they best fit together. The trick is in turning negatives into positives, as shown by K9EK. For L-band transmitting, the problems are more physical than electronic. **Fig 23.26** illustrates this approach.

First is the fact that transmitters and

Table 23.3 – Suppliers of Equipment of Interest to Satellite Operators

Multimode VHF and UHF Transceivers and Specialty Equipment

- ICOM America
- Kenwood Communications
- Yaesu USA

Converters, Transverters and Preamplifiers

- Advanced Receiver Research
- Angle Linear
- Down East Microwave
- Hamtronics
- Henry Radio
- The PX Shack
- Parabolic AB
- Radio Kit
- RF Concepts
- Spectrum International
- SSB Electronic

Power Amplifiers

- Alinco Electronics
- Communications Concepts
- Down East Microwave
- Encomm
- Falcon Communications
- Mirage Communications
- Parabolic AB
- RF Concepts
- SSB Electronics
- TE Systems

Antennas

- Cushcraft Corp
- Down East Microwave
- KLM Electronics
- M^2 Antenna Systems
- Parabolic AB
- Telex Communications

Rotators

- Alliance
- Daiwa
- Electronic Equipment Bank
- Kenpro
- M^2 Antenna Systems
- Telex
- Yaesu USA

Other Suppliers

- AEA
- ATV Research
- Down East Microwave
- Electronic Equipment Bank
- Grove Enterprises
- M^2 Antenna Systems
- Microwave Components of Michigan
- PacComm
- SHF Microwave Parts
- Tucson Amateur Packet Radio (TAPR)

Note: This is a partial list. The ARRL does not endorse specific products.

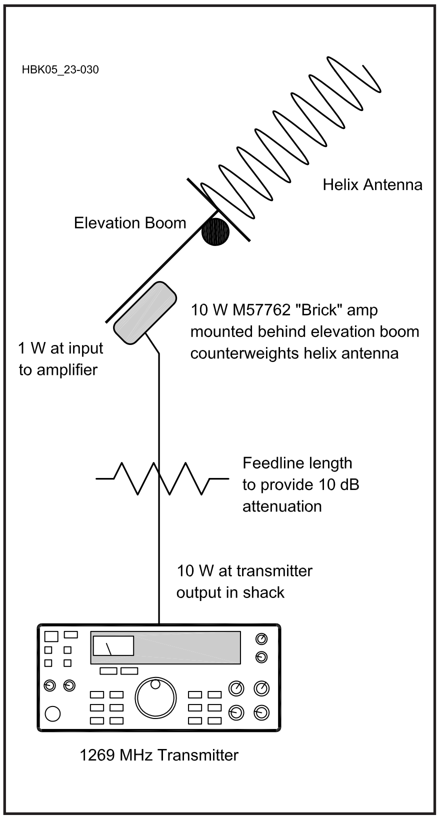


Fig 23.26—L-Band Transmitting: an integrated approach.

antennas are usually in separate places with a long length of coaxial cable connecting the transmitter to the antenna. Coaxial cable is an imperfect RF conductor and with losses increasing with frequency and length of cable. Common (and reasonably priced) coaxial cables have unwanted losses at 1270 MHz. The old standby, RG-8U, loses almost 13 dB per 100 feet at 1270 MHz. A 100-foot feedline would only have 0.5 W coming out from 10 W going in. Of course, we could increase transmitter power by 20 times to compensate, but those are quite expensive watts to be used for heating coaxial cable! Coaxial cable "hardline" is a good but an expensive solution, and even it has significant loss. Low-loss L-band waveguide is much too large and expensive to be considered.

What is needed are methods of getting all of the transmitter power to the antenna. You may not want to remotely mount your entire L-band transmitter at the antenna, although some manufacturers are offering transmitting converters for that service. A much better solution would be to split the transmit power generation into two stages, and integrate the antenna and final amplifier stage by mounting a final amplifier very near the antenna feedpoint. This will greatly reduce the transmitter to antenna feed-line loss by eliminating most of the feed line. Fortunately, an elegant solution exists for the "final amplifier stage" of this integration. This is the M57762 hybrid linear amplifier module. This 1-W input, 10-18 W output "brick" has 50-Ω input and output impedance and requires only the addition of connectors, a heat sink and simple dc power circuitry. A second design of amplifier is also offered, using two of these M57762 modules for higher output power.

There is still the problem of the feedline loss between the shack transmitter and the final amplifier stage, but there are ways to use this to an advantage. Most L-band transmitters use the M57762 brick as part of their output stage, and are rated for 10 W (+40 dBm) RF output. The remotely mounted final amplifier stage requires only 1 W (+30 dBm) RF input, so some method of reducing the transmitter output to match the amplifier input. A very satisfactory way to do this is to use the loss qualities of a length of small coaxial cable as an attenuator. For this feed, a 10-dB loss between the transmitter and amplifier is needed. Referring to cable manufacturer's data, a length of coaxial cable can be determined that will give the required 10-dB attenuation, then use it to connect the transmitter and amplifier.

SINGLE BRICK L-BAND AMPLIFIER

The amplifier of **Fig 23.27** was constructed by K9EK by mounting the M57762 module directly to a heat sink (no insulator required; but thermal compound is highly recommended), then using an etched circuit board, slipped under the leads of the module, to provide both RF and dc connections. The schematic for this amplifier is shown in **Fig 23.28**. The board is made from 0.062-inch thick, G10 board. Keep the input and output lines 0.10-inch wide to maintain the 50-Ω input and output impedance. The type N connectors should be mounted on the end of the heat sink in such a manner that the center conductors lie directly on the board traces. Ensure that the circuit board is well grounded to the heat sink by drilling and tapping several holes through the circuit board as shown.

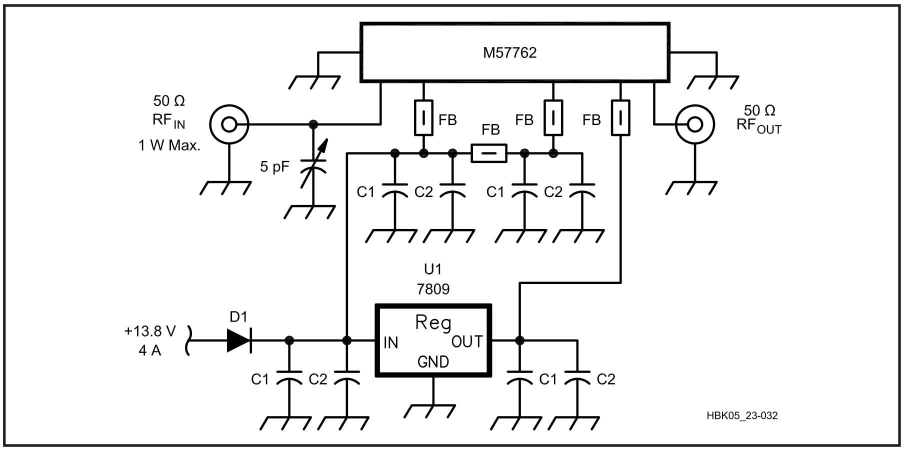


Fig 23.28—Just a handful of parts are needed to connect the brick amplifier module. All capacitor pairs are 10 µF/35 V chip or tantalum units in parallel with 1 nF chip capacitors. D1 is a 4-A (minimum) 50-V power rectifier such as Digi-Key GI820CT-ND. It prevents damage due to reverse connection of the power leads. U1 is a 7809 voltage regulator (9-V, 1-A). Check RF Parts and Down East Microwave for pricing and availability of the amplifier module.

Fig 23.27—The matching brick amplifier can be mounted on the counterbalance side of the Helix antenna boom.

This amplifier operates in class AB linear, and therefore draws some (about 400 mA) dc current when not transmitting. It was decided that the additional circuit complexity to cut the amplifier off completely was not warranted. You just turn off the dc supply during long standby periods. The full load current is approximately 4A.

A template, with additional construction details and a PC board layout, is available from the ARRL. See the *Handbook* CD-ROM **Templates** section for details.

DOUBLE BRICK L-BAND AMPLIFIER

This second L-band amplifier is more complex, offering considerably more output power (≈40 W), and was originally constructed for terrestrial 1296-MHz service by WD4FAB. This amplifier also operates in class AB linear. As the amplifier is pretty broad-banded, it can serve the satellite service as well as for the original terrestrial service plans; all is the matter of not pointing your antenna into the sky for that 1296-MHz contact! The inspirational credit for using the M57762 module and getting this unit started is given to the North Texas Microwave Society. NTMS has a lot of good ideas flowing through their newsletters.

Fig 23.29 shows this completed assembly, as it was just removed from the tower box, for the purpose of the picture taking. This assembly is composed of two flanged extruded heat sinks mounted face-to-face, with the brushless dc blower moving cooling air through the finned chamber of the heat sinks. The identical M57762 module "brick" amplifiers and their bias circuitry PCB assemblies are mounted on the troughs of each heat sink on the opposite sides of the assembly.

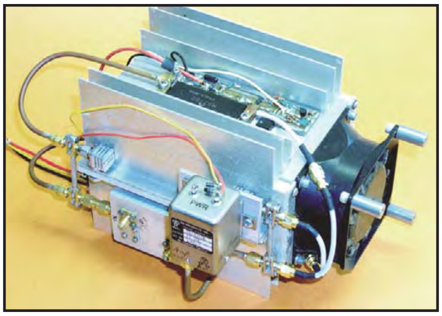


Fig 23.29—This is an alternate, more powerful, design of the L-band brick amplifier. This is a pair of heat sinks mounted face to face with a dc motor cooling fan; the electronics are mounted on each side with the combiner and relay circuitry on the near side. From left to right: output 3-dB hybrid coupler, directional coupler for power measurement, the four-port relay, and the input 3-dB hybrid coupler.

Fig 23.30 and **Fig 23.31** provide the schematic information for this amplifier assembly. The following notes will give the constructor details that may not be obvious from the photographs and schematics. Considerable care is needed in making the RF connections between these module amplifiers and their respective input and output 3-dB hybrid couplers. Slight differences in getting really equal length lines here can make a large difference in the overall performance. Notice in Fig 23.29 that the input coaxial lines, on the right, are of flexible Teflon 50-Ω cable, while the output lines, on the left, are of the semi-rigid UT141 copper jacketed co-

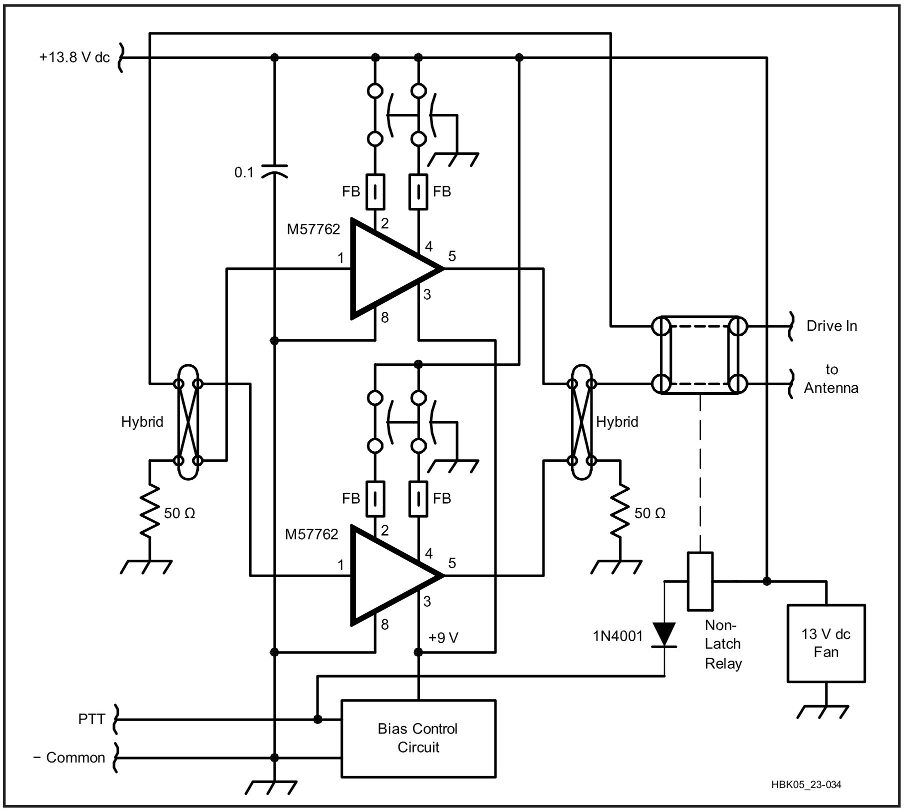


Fig 23.30—Schematic diagram of the more powerful L-band amplifier assembly.

axial cable, selected because of the higher power level at this point. Each end of the UT141 cables is terminated in an SMA connector, for ease of handling and uniformity of cable length.

Also shown along the facing side of the heat sink assembly is a collection of RF parts, which from left to right are output hybrid coupler, directional coupler for power measurement, the four-port relay and the input hybrid coupler. Having a four-port relay of this type surely makes life easier, as it handles both input and output switching. The output from the directional coupler is converted to a dc signal by a diode and capacitor right at the SMA connector (not shown) that mounts to the coupled port. That dc signal is sent back to the station to give a very useful indication of the output power. Note also the 50-Ω load terminations that are SMA-connector-mounted to the couplers. These loads absorb any unbalanced power from the amplifiers through the hybrid couplers. While the input coupler did not need such a large load, it was easier to buy two identical loads.

For the M57762 module assemblies, **Fig 23.32**, there are a number of details that are not so obvious, some mechanical and some electrical. First is to note that measures are taken to insure that the module is very thoroughly clamped to the heat sink, through the use of a pair of 6.4-mm (0.25-inch) square brass bars. Using screws alone would provide insufficient clamping forces. The module must have heat sink compound used between it and the heat sink and that interface must be smooth and flat for reasonably decent heat transfer. These bars are elongated to serve additional purposes as the bar at the output end of the module (at the right) has a two-hole SMA connector embedded in it so as to get a very close termination to the wire lead of the RF output of the module. This bar also serves as a low-resistance dc connection for the power ground lead to the module, thereby not depending upon a casual connection through mounting screws and the heat sink. For the input end, the coaxial cable is fed through a hole in the bar (at the left) to also get the close connection to the module RF input. Note the short, exposed RF leads at these points.

There are three other wire leads to the module, two for +13.8 V and one for the +9 V bias power. These leads are individually filtered with FB43101 ferrite beads, and with the leads running across the top of a 1nF trapezoidal filter capacitor soldered to the PCB. The PCB is a double-sided G10

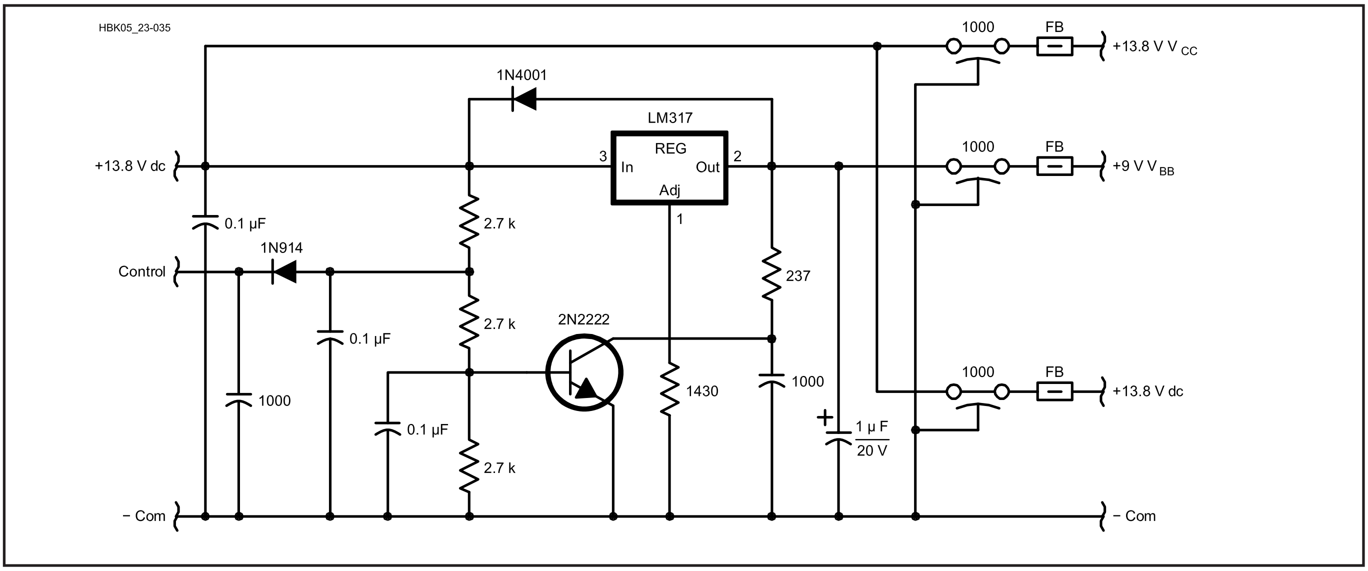


Fig 23.31—Schematic diagram of bias circuitry for the L-band amplifier assembly.

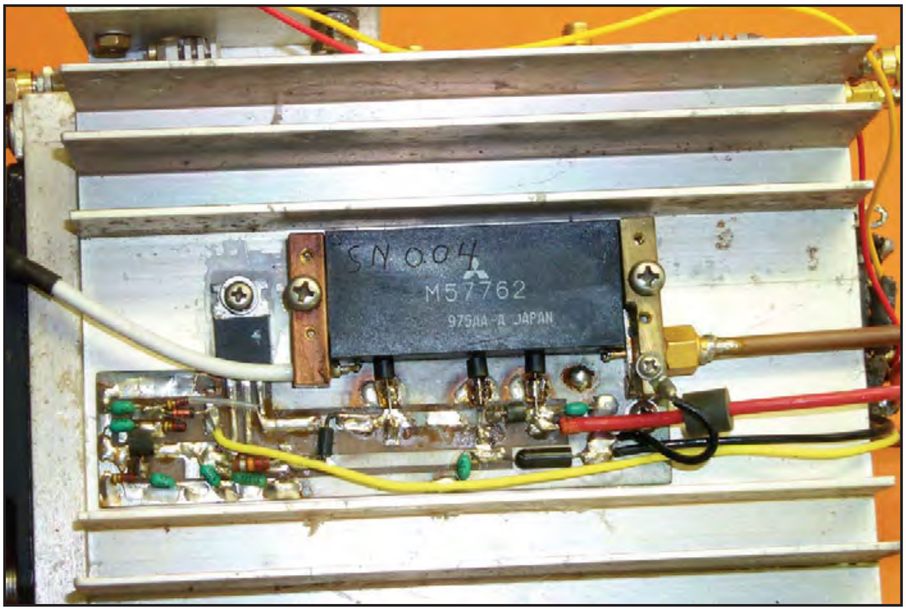


Fig 23.32—One side of the amplifier assembly, showing the brick amplifier and the one-sided PC board with bias regulator and filter circuitry. Note that the input and output coaxial cables are soldered to the brass clamp bars so that the center conductor is closely "presented" to the input and output terminations of the brick amplifier.

board, 0.062-inches thick, with only the topside formed into circuit patterns. The reverse side of the PCB is only used as the ground plane for the power circuits. The two sides of the PCB are connected with copper or brass foil wrapped around the edges at selected locations.

This bias circuitry operates to shut off the bias to the module when not transmitting, through a conventional grounding-on-PTT control line that comes up from the station. This same line, which is controlled by a sequencer in the station, also operates the four-port T/R relay. It was determined necessary to turn off the module to prohibit it from having any possible emissions while the station is in its most sensitive receiving condition, although this is unproven.

Operation of the bias circuitry is through the diode isolated control line shutting off the bias to a saturated 2N2222, which, in turn, unclamps the LM317 regulator reference lead. It is interesting what tricks can be done with these adjustable regulators. All of the additional capacitive filtering needed for the regulator is added.

One of the two identical 3-dB hybrid coupler assemblies is shown in **Fig 23.33**, with drawing details shown in **Fig 23.34**. The neat tricks of constructing these couplers using the Sage Wireline and SMA connectors was learned from KE3D, who probably "borrowed" it from S57MV. Proper wiring of the Wireline to the SMA connectors is very important here, as is having equal lengths of equal-properties coaxial lines from the amplifiers to the couplers. Careful attention to small details here pay great dividends in performance. Also note the "reversal" of the input lines from the coupler to the amplifiers, needed to compensate for 90° phase shifts of the hybrids. Without this input crossover, there would be no RF output! The first assembly of this unit had ignored that phase shift and the amplifier input lines had to be "patched" with extension cables to correct for that bit of forgetfulness.

Templates with additional construction details and PC board layouts are available for each of these two amplifiers on the CD included with this book.

RECEIVING, PREAMPLIFIERS AND RECEIVE CONVERTERS

Receiving Phase-3E downlinks will require equipment for the microwave bands. Operating experience with AO-40

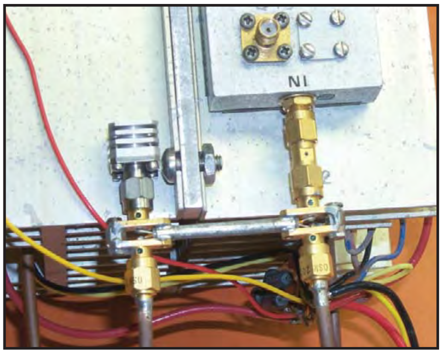


Fig 23.33—A close-up view of one of the 3-dB hybrid coupler assemblies (the two are identical) showing its construction using Sage Wireline®, four 2-hole SMA connectors, spacers and screw hardware. Note the 50-Ω terminated port.

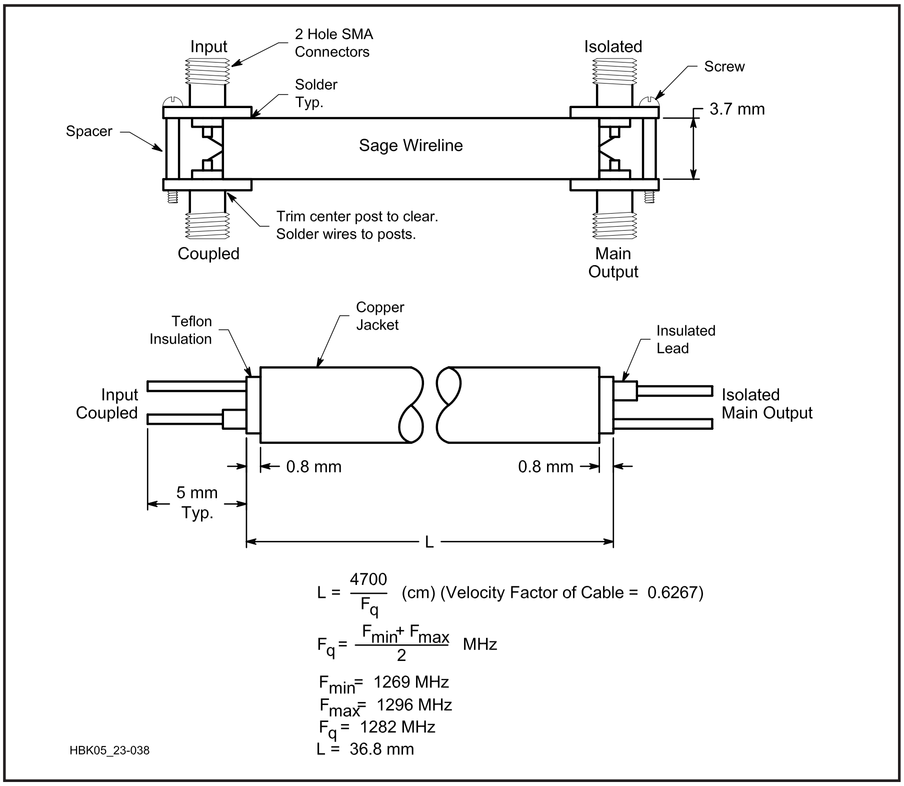


Fig 23.34—Details of the construction of the 3-dB hybrid coupler assemblies.

has shown that receiving antenna gains need to be 22 dBic, minimum. On S band this has clearly been shown to require the use of a dish antenna with at least a diameter of 600 mm. As there are no commercial base-station S band receivers, outboard S band down-converters need to be used and have become available in recent years, with a lot of interest in soaking up the surplus market units provided by Drake and others, **Fig 23.35**. Commercial Amateur S band receive converters have been coming on the market from SSB-USA, with their UEK-3000SAT; from Down East Microwave (DEM), with their 2400-144RX and 2400-432RX (see **Fig 23.36**); from Parabolic AB, with their "Mode S Down-converter"; and from other sources. Amateur microwave operation is not a "strange" activity relegated just to the specialists anymore, as satellite enthusiasts have been exploring these S band downlinks for some time and manufacturers have responded by increasing the supply of useable equipment for S band.

Fig 23.36—This SSB Electronic unit (left) is one of several solutions for mast-mounted S-band receive converters. Other manufacturers, including Down East Microwave (top), have similar offerings.

No discussion of satellite receiving systems would be complete without mentioning preamplifiers and their location. The mast mounting of sensitive electronic equipment has been a fact of life for the serious VHF/UHF operator for years, although it may seem to be a strange or difficult technology for HF operators. While a preamplifier can be added at the receiver in the station, it will do no good there. Vastly better results will be obtained if the preamp is mounted *directly* to the antenna. To get the most out of your VHF/UHF satellite station, you'll need to mount a low-noise preamplifier or receive converter on the tower or mast near the antenna, see **Fig 23.37**, so that feed-line losses do not degrade low-noise performance. Feed-line losses ahead of the preamplifier or converter add directly to receiver noise figure. Antenna mounting the preamplifier or down-converter will overcome these noise figure problems. For S band, placing either a preamp or the receiving down-converter *on* your antenna feed point is essential. Not even mast mounting the preamplifier will suffice here.

Low-noise front ends for down-converters or preamps are essential for receiving weak satellite signals, especially as the operating frequency goes higher. Multimode rigs and most down-converters will hear much better with the addition of a preamplifier employing GaAs FET or PHEMT technology ahead of the front end, albeit at the expense of the reduction in the third-order intercept point of the receiver. DEM provides a weather-resistant assembly in their 13ULNA unit. See photos of S-band dish antennas for views of this DEM product. Other very qualified preamplifier units are available from SSB-USA.

Table 23.3 lists other sources of commercially built preamplifiers and receive converters for most all VHF, UHF and microwave bands. These are available in several configurations. Many models are designed for mounting in a receive-only line for use with a receiving converter or transverter. Others, designed with multimode transceivers in mind, have built-in relays and circuitry that automatically switch the preamplifier or converter out of the antenna line during transmit. Most of these models are housed, with relays, in weatherproof enclosures that mount right at the antenna. For the equipment builder, several suitable designs appear in *The Radio Amateur's Satellite Handbook*.

Fig 23.35—S-band converter that was available from Drake, and easily modified for satellite service.

Fig 23.37—Details of WD4FAB's tower cluster of satellite antennas, including a home-brew elevation rotator. Top to bottom: M^2 436-CP30, a CP U-band antenna; two each M^2 23CM22EZA antennas shown in a CP array for L band; "FABStar" dish antenna with helix feed for S band; M^2 2M-CP22, a CP V-band antenna (only partially shown.) To left of dish antenna is a NEMA4 equipment box with an internal 40W L-band amplifier, and also hosts externally-mounted preamplifiers.

ACCESSORIES

Receiver audio output noise on these higher satellite bands is often quite disturbing to many operators, taking away from the "listenablity", or the "arm chair" quality of the QSO audio on these bands. Some of this disruption can also be from the in-band use of such equipment as microwave ovens and the modern spread-spectrum 2.4-GHz cordless telephones that are becoming common in our households. Modern receivers and accessory equipment comes to the rescue here, and is the reason for the use of the HF transceiver (an IC-746) in receiving the S-band signals of the station shown in Fig 23.20. Newer model HF transceivers provide IF DSP and other features that provide very useable "Noise Reduction" and "Noise Blanker" functions. The noise blanker, in particular, removed all the observed noise from a 2.4-GHz Spread-Spectrum cordless telephone near the illustrated station, even with the very high sensitivity of the S-band receiving equipment. In the illustrated station an outboard audio DSP unit (a Timewave DSP599zx) is very helpful to remove the audio "Random Noise" that is not removed by the IF DSP. The combination of the equipment shown does provide "arm-chair" quality comfortable listening. Some of the other most recently available Amateur transceivers may incorporate both the audio and IF DSP noted above, possibly eliminating the need for an outboard audio DSP unit.

Great caution by the operator must be exhibited when using a transceiver for receiving the S-band signals, as even the slightest inadvertent moment of transmitter operation into the "rear end" of a down-converter can make it an instant hot dog without a roll! SSBUSA offers a protection unit "The Protector" with a SSB power rating of 50 W. In the illustrated station with its IC-746 transceiver, the 2-m receive line was internally isolated from the transmitting circuits and brought out to a SMA connector at a convenient point on the rear panel. This separated receive capability on 2 m has saved the down-converter on several occasions.

One very helpful accessory for the station is the remote measurement of RF power. Such power meters are commercially available or easily constructed by the handy operator. This type of measurement is very meaningful for stations with long feed lines between the transmitter and the antennas, making the determination of EIRP more realistic. The illustrated station uses a moving-coil power meter of uncertain origin coupled with surplus or home made directional couplers for power sampling near the antennas in the equipment box on the tower.

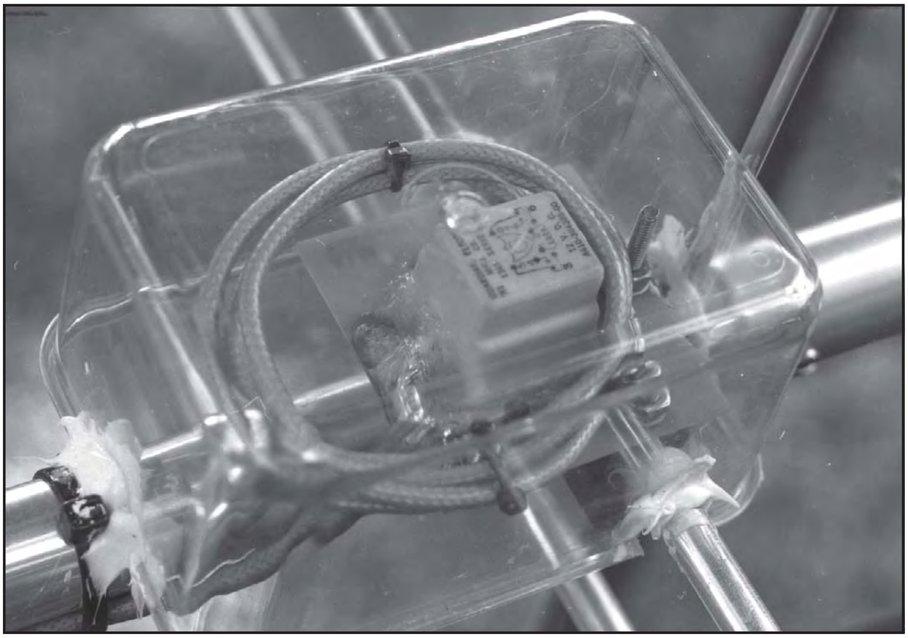


Fig 23.38—KLM 2M-22C antenna CP switching relay with relocated balun. Protective cover is needed for rain protection; see text.

Operators unfamiliar with microwave S-band operation may gain a greater confidence of their receivers with the addition of a 2101-MHz signal source. Such signal sources have been in the literature in recent years, and Down East Microwave offers a kit. An S-band signal source can also provide the user a convenient check for the station antennas and also as a calibrator for the S-band receiver S meter.

For stations using "crossed" Yagi antennas for CP operation, one feature that has been quite helpful for communicating through most of the LEO satellites, has been the ability to switch polarization from RHCP to LHCP. In some satellite operation this switchable CP ability has been essential.

The station shown has an all up capability for analog and digital satellite operations. Not shown just to the left of the photo is the station computer, which provides the satellite tracking information from the Northern Lights Software Association, NLSA, *Nova* for *Windows* tracking program. This provides output for the TAPR EasyTrak antenna controller, as well as providing the interface to the digital communications operations, using a PacComm SPIRIT-2 Packet Controller. Please note the warning sign in Fig 23.20, as it is right and proper for the unwary at that station.

EXPOSED ANTENNA RELAYS AND PREAMPLIFIERS

Experience with the exposed circularity switching relays and preamplifiers mounted on antennas have shown that they are prone to failure caused by an elusive mechanism known as "diurnal pumping." Often these relays are covered with a plastic case, and the seam between the case and PC board is sealed with a silicone sealant. Preamps may also have a gasket seal for the cover, while the connectors can easily leak air. None of these methods create a true hermetic seal and as a result the day/night temperature swings pump air and moisture in and out of the relay or preamp case. Under the right conditions of temperature and moisture content, moisture from the air will condense inside the case when the outside air cools down. Condensed water builds up inside the case, promoting extensive corrosion and unwanted electrical conduction, seriously degrading component performance in a short time.

A solution for those antennas with "sealed" plastic relays, such as the KLM CX series: you can avoid problems by making the modifications shown in **Fig 23.38**. Relocate the 4:1 balun as shown and place a clear polystyrene plastic refrigerator container over the relay. Notch the container edges for the driven element and the boom so the container will sit down over the relay, sheltering it from the elements. Bond the container in place with a few dabs of RTV adhesive sealant. Position the antenna in an "X" orientation, so neither set of elements is parallel to the ground. The switcher board should now be canted at an angle, and one side of the relay case should be lower than the other. An example for the protective cover for an S-band preamp can be seen in the discus-

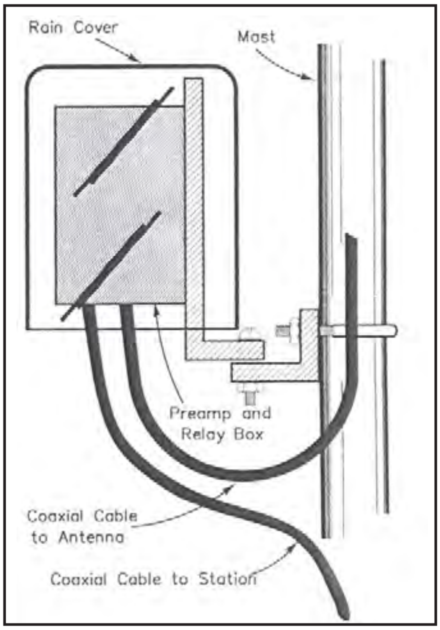


Fig 23.39—Protection for tower-mounted equipment need not be elaborate. Be sure to dress the cables as shown so that water drips off the cable jacket before it reaches the enclosure.

sion on feeds for parabolic antennas.

For both the relay and preamp cases, carefully drill a $^3/_{32}$-inch hole through the low side of the case to provide the needed vent. The added cover keeps rain water off the relay and preamp, and the holes will prevent any build-up of condensation inside the relay case. Relays and preamplifiers so treated have remained clean and operational over periods of years without problems.

Another example for the protection of remotely, tower mounted equipment is shown in Fig 23.37, illustrating the equipment box and "mast mounted" preamplifiers at the top of WD4FAB's tower. The commercial NEMA4 rated equipment box is used to protect the 23-cm power amplifier and its power supply, as well as a multitude of electrical connections. This steel box is *very* weather resistant, with an exceptionally good epoxy finish, but it is not sealed and so it will *not* trap moisture to be condensed with temperature changes. Be sure to use a box with at least a NEMA3 rating for rainwater and dust protection. The NEMA4 rating is just a little better protection than the NEMA3 rating. Using a well-rated equipment box is very well worth the expense of the box. The box also provides some pretty good flanges to mount the "mast-mounted" preamplifiers for three bands. This box is an elegant solution for the simple need of rain shelter for your equipment, as illustrated in **Fig 23.39.**

ELEVATION CONTROL

Satellite antennas need to have elevation control to point up to the sky, the "El" part of the needed Az-El control of satellite antennas. Generally, elevation booms for CP satellite antennas need to be non-conducting so that the boom does not affect the radiation pattern of the antenna. In the example shown, the elevation boom center section is a piece of extra heavy wall $1^1/_2$-inch pipe (for greater strength) coupled with a tubular fiberglass-epoxy boom extension on the 70-cm end and a home-brew long extension (not shown in the photo) on the 2-m end, using large PVC pipe reinforced with four braces of Phillystran non-metallic guy cable. (PVC pipe is notoriously flexible, but the Phillystran cables make a quite stiff and strong boom of the PVC pipe.) For smaller installations, a continuous piece of fiber-glass-epoxy boom can be placed directly through the elevation rotator.

Elevation boom motion needs to be powered, and one solution, **Fig 23.40**, uses a surplus jackscrew drive mechanism. One operator, VE5FP, found a solution for his Az-El needs by using two low-cost, light-weight TV rotators.[1] See **Fig 23.41**.

Operators through the years have employed many methods for the control of their antenna positions, ranging from true "arm-strong" manual positioning, to manual operation of the powered antenna azimuth and elevation rotators, and to fully automated computer control of the rotators. While computer control of the rotators is not essential, life is greatly assisted with the use of your computer. Fully automated control of your rotators is possible for such tasks as digital message uploading and downloading. For many years, one of the keystone control units for rotators has been the Kansas City Tracker (KCT) board installed in your computer. Most satellite tracking programs can connect to the KCT with ease. There are other options, these days, to replace the KCT unit.

A recent trend for amateur antenna control has been evolving, however, in the form of a standalone controller that translates computer antenna position information into controller commands with an understanding of antenna position limits. These boxes, represented by the new EasyTrak unit, **Fig 23.42**, from the Tucson Amateur Packet Radio (TAPR) group, have made this capability readily available for many amateurs. One of the EasyTrak units is also shown in Fig 23.20. The station computer, to the left and out of the photo, is used to upload antenna positions to EasyTrak. The computer can also control the operation of your station transceiver through the radio interface provided in EasyTrak; you will not need any other radio interface.

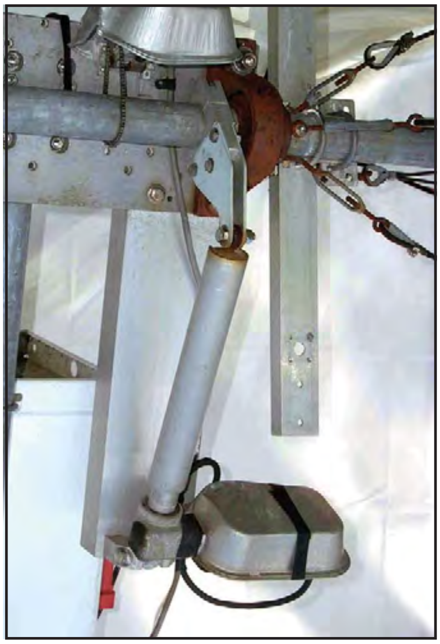


Fig 23.40—WD4FAB's home-brew elevation rotator drive using a surplus store drive screw mechanism.

Fig 23.41—VE5FP has a solution for his Az-El rotators by bolting two of them together in his "An Inexpensive Az-El Rotator System," *QST*, December 1998.

ANTENNAS

Antennas have always been favorite subjects for amateur operators. Everyone

Fig 23.42—The EasyTrak automated antenna rotator and radio controller by TAPR.

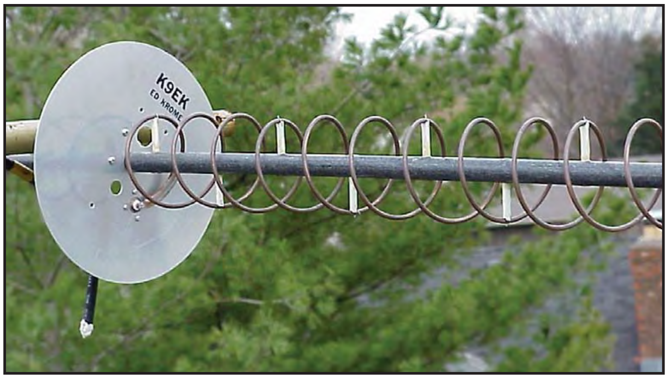


Fig 23.43—This L-band helix antenna was designed to be home-brewed without any special tools or shop equipment. It is mounted on a 4-foot-long fiberglass tube.

is an expert! Fig 23.21 shows the example of the antennas for one station. The Yagi antennas are used for the U and L-band uplinks, while the S-band dish antenna is for the downlink. These satellite antennas are tower mounted at 63 feet to avoid pointing into the many nearby trees and suffering from the "green attenuation" provided by those trees. Satellite antennas otherwise do not need to be mounted so high. If the satellite antennas are mounted lower down, the reduced feed-line length and losses are a great benefit.

Linearly polarized antennas are "horizontal" or "vertical" in terms of the antenna's position relative to the surface of the Earth, a reference that loses its meaning in space. The need to use circularly polarized (CP) antennas for space communications is well established, as in space there is no "horizontal" or "vertical," but there is right-hand and left-hand circular polarization, CP. With CP the wavefront describes a rotational path about its central axis, either clockwise (right-hand or RHCP) or counter clockwise (left-hand or LHCP). If spacecraft antennas used linear polarization, ground stations would not be able to maintain polarization alignment with the spacecraft because of changing orientation. Ground stations using CP antennas are not (generally) sensitive to the polarization motions of the spacecraft antenna, and therefore will maintain a better communications link.

UPLINK ANTENNAS

Experience with AO-40 has clearly shown the advantages of using RHCP antennas for both the uplink and downlink communications. The antennas shown in Fig 23.21 are a single-boom RHCP Yagi antenna for U band, a pair of closely spaced Yagi antennas phased for RHCP for L band, and a helix-fed dish antenna for S band. The antenna gain requirements for U band can easily be met with a 30-element "crossed Yagi," two 15 element Yagi antennas mounted on a single boom with one placed a $^1/_4$ wavelength forward of the other. This arrangement allows for an uncomplicated phasing harness to couple the two antennas together to a single feedpoint. Antennas of this size have boom lengths of 4 to 4$^1/_2$ wavelengths. The enterprising constructor can build a Yagi antenna from one of several references, such as *The ARRL Antenna Book*, or he might construct a 16 to 20 turn helix antenna for this service. Most of us might prefer, however, to purchase such a well-tested antenna from such commercial sources as M^2 or HyGain. In the past, KLM (now out of business) had offered a 40 element CP Yagi for U band satellite service, and many of these are still in satisfactory use today.

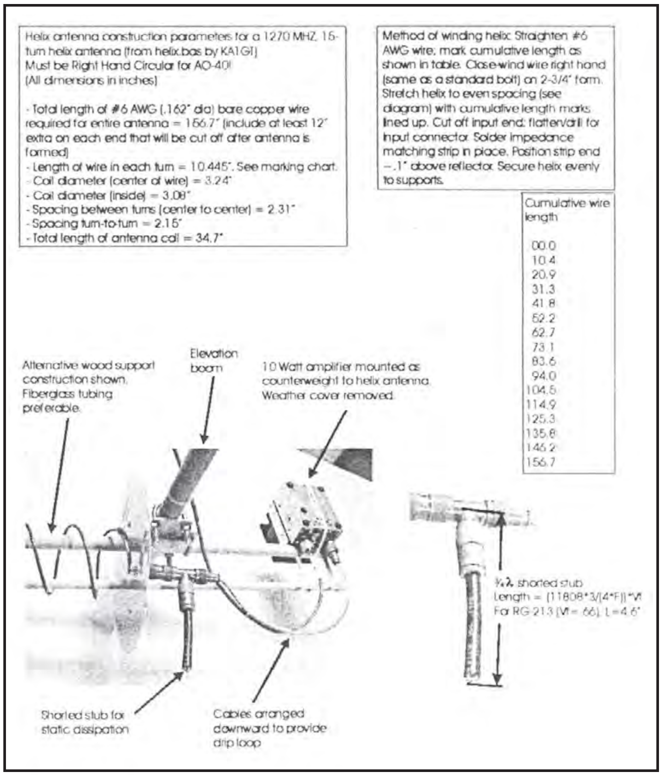
L-band uplink antennas become even more manageable, as their size for a given gain is only one-third of those for U band. Alternatively, higher gains can be obtained for the same boom lengths. With this band there is a narrower difference between using a dish antenna and a Yagi or helix, as a 21 dBic dish antenna would have a 1.2-m (4 foot) diameter. Some of us cannot afford such "real estate" on our elevation rotators and seek the lower wind-loading solutions offered by Yagi antennas. Long-boom rod-element Yagi, or loop-Yagi antennas, are commercially offered by M^2 and DEM, although this band is about the highest for practical Yagi antennas. The example shown in Fig 23.21 is a pair of rod-element Yagi antennas from M^2 in a robust arrangement. These antennas provide an overall gain of about 21.5 dBi. If greater L-band power is available than the 40 W shown in the illustrated station, the constructor may want to consider the helix antenna that follows.

L-BAND HELIX ANTENNA CONSTRUCTION

Fig 23.43 shows an easy-to-build antenna and support structure provided by K9EK. Fiberglass tubing was used for this structure as it has better outdoor longevity. Mounting of a helix of this nature requires that it be placed out "in front" of the elevation boom, so that there are no unwanted structures in the RF field of the antenna. This places a need for the counter weighting of the antenna to remove the unbalanced loading and strain on the elevation rotator. The constructor should take these provisions, and should consider the possible placement of the output amplifier as part of that counterweight, thus also making for a very short, low-loss feed line to the antenna.

Probably the easiest way to construct a helix antenna is to mark the wire, then close wind the spiral on a form, then stretch the winding out to match the required diameter and turns spacing. First, lay out the required length of #6 AWG bare copper wire (available as ground wire wherever house wiring is sold.) To straighten it, clamp one end in a vise, then squeeze the wire between two wood blocks and pull the blocks along the wire. Once the wire is straight and even, clearly mark the wire at each "cumulative wire length" dimension as shown in **Fig 23.44**. These marks show identical length per turn and they should line up along the completed helix. Allow 1-2 feet to remain on either end of the wire for handling, which will be cut off after construction. Cumulative length is used to prevent the compounding of measurement errors.

Then close wind the wire smoothly and tightly around a piece of 2$^1/_2$-inch pipe (measures ϕ2.875 inch), with the length marks outward. The wire will spring back some after winding, so using two people to help pull to keep the winding tight gener-



Helix antenna construction parameters for a 1270 MHZ, 15-turn helix antenna (from helix.bas by KA1GT)
Must be Right Hand Circular for AO-40!
(All dimensions in inches)

- Total length of #6 AWG (.162" dia) bare copper wire required for entire antenna = 156.7" (include at least 12" extra on each end that will be cut off after antenna is formed)
- Length of wire in each turn = 10.445". See marking chart.
- Coil diameter (center of wire) = 3.24"
- Coil diameter (inside) = 3.08"
- Spacing between turns (center to center) = 2.31"
- Spacing turn-to-turn = 2.15"
- Total length of antenna coil = 34.7"

Method of winding helix: Straighten #6 AWG wire; mark cumulative length as shown in table. Close-wind wire right hand (same as a standard bolt) on 2-3/4" form. Stretch helix to even spacing (see diagram) with cumulative length marks lined up. Cut off input end; flatten/drill for input connector. Solder impedance matching strip in place. Position strip end ~.1" above reflector. Secure helix evenly to supports.

Cumulative wire length
00.0
10.4
20.9
31.3
41.8
52.2
62.7
73.1
83.6
94.0
104.5
114.9
125.3
135.8
146.2
156.7

Fig 23.44—Construction details of L-band helix antenna.

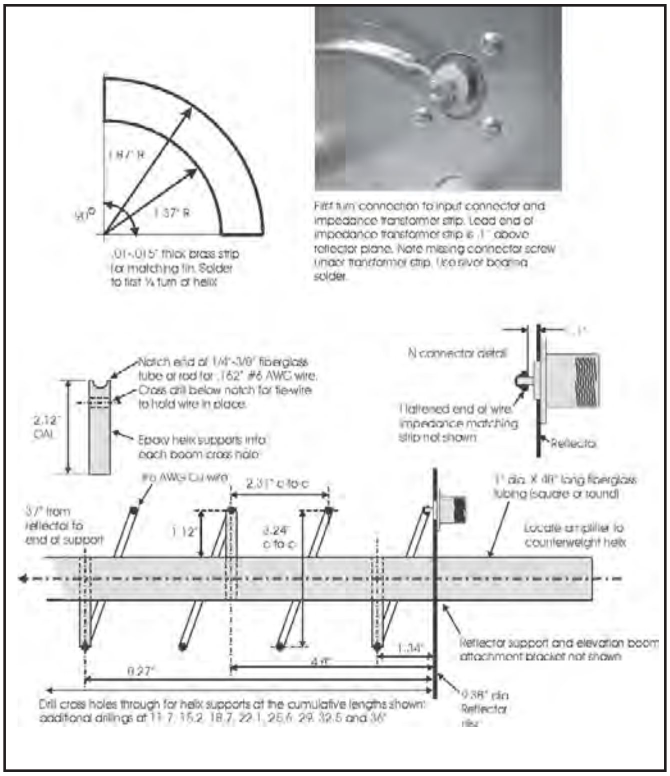


Fig 23.45—More construction details of L-band helix antenna.

ally works better. You must wind the helical element in a right-hand direction (clockwise); look at a standard machine screw or bolt and have the turns proceed in the same direction. Then hang the wire coil over a horizontal tube or form (the same PVC pipe used for winding will do well) that has been marked every 2.31 inches. Do this cumulatively to prevent errors. Holding the end turns (which will eventually be cut off) of the wire coil, gently stretch the helical element to the appropriate turn-to-turn spacing. Ensure that the turn-marks on the wire remain lined up; you may have to gently wind or unwind the helical element as you go. You can make a 2.15-inch (less your wire size) spacer to drop between turns to aid in getting the spacing correct.

Finally, cut off the excess wire on the input end of the helical element. Leave the opposite end uncut so if you goof on the input end, you can simply cut the error off and try again. After the antenna is completed, go back and cut off the excess from the far end. To connect the input end of the wire to the input connector, flatten the last $^1/_4$-inch of the input end of the wire with locking grip pliers or a hammer and steel block. Once it is flat and even, drill a hole in the end of the wire to slip over the center pin on an N connector.

The theoretical impedance of a helix antenna fed from the periphery is 140 Ω. A clever method of changing this to 50 Ω is by the addition of a λ/4 impedance transformer to the first quarter turn of the helical element wire itself. It has been found empirically that a 0.50-inch-wide strip of 0.010-inch-thick sheet brass makes a satisfactory impedance matching device. Cut the brass strip as shown in the figure. The strip is soldered to the first quarter turn of the helical element wire, starting 0.25 inch from the connector drilling. The underside of the strip must be flat relative to the reflector disc. Silver-bearing, lead-free plumbing solder is better than standard lead-tin solder and is highly recommended.

The method of helix antenna construction involves a single central length of 1.0 inch diameter fiberglass tubing with the helical element supported on 0.375-inch diameter fiberglass standoff rods or tubes. **Fig 23.45** shows the dimensions and construction for this helix antenna. Carefully attach the helix support rods to the central boom as shown. Mount a 7 inch to $9^1/_4$-inch diameter (0.75λ to 1λ) reflector plate to the frame with homemade angle brackets. The helical element is slipped over the boom and stretched onto the support rods and held to the rods with wire ties. A homemade clamp plate and U-bolts are used to connect central rod to the antenna elevation boom.

After attaching the helical element onto the support frame, solder the hole in the end of the first turn to the input connector, an N connector mounted from the back of the reflector plate. Position the impedance matching strip at 0.10-inch (2.5mm) spacing from the reflector plate and solder it in place. Then secure the helical element in place. On two samples of the antenna shown, the input return loss was measured in excess of –16 dB (SWR=1.38:1). If proper equipment is available, lower return loss and SWR values can be achieved with this tuning system.

A practical shortcoming of the axial mode helix antenna is not obvious. The entire helical element itself is a single, long piece of copper wire, connected to the input connector. Since this wire is physically isolated from dc ground, atmospheric static electricity may build up on the element until it damages the attached solid-state device. So, some method is needed to dc ground the helical element itself, without seriously interfering with the RF characteristics of the antenna. One method of preventing static buildup is to add a shorted λ/4 stub to the antenna feed. A shorted quarter-wave stub presents extremely high RF impedance at its non-shorted end, making it virtually invisible to RF energy at its design frequency. At the same time, it provides a dc short to ground for the helical element itself, effectively draining off static electricity before it can build up. This shorted stub can be made from a T connector and coaxial cable. The length of the stub (measured from the center of the main cable to the short itself) must be calculated and must include the VF (velocity factor) of the cable being used. Note that an actual $\lambda/4$ stub is too short to be physically realizable; and a $\lambda/2$ must be added to the cable to create a $3\lambda/4$ stub. With RG-213 cable (VF = 0.66), the total length of the $3\lambda/4$ stub is 4.60 inches. This stub has been shown to have almost no effect on antenna performance at the design frequency.

PARABOLIC REFLECTOR ANTENNAS FOR S BAND

The satellite S-band downlinks have become very popular for a variety of reasons. Among the reasons are: good performance can be realized with a physically small downlink antenna and good quality down-converters and preamps are available at reasonable prices, as previously discussed. Increased operation on S band has long been advocated by a number of people including Bill McCaa, KØRZ, who led the team that designed and built the AO-13 S-band transponder[2] and James Miller, G3RUH, who operated one of the AO-40 command stations.[3] Ed Krome, K9EK, and James Miller have published many articles detailing the construction of preamps, down-converters, and antennas for S band.[4,5,6,7,8]

WØLMD notes that like a bulb in a flashlight, the parabolic reflector, or dish antenna must have a feed source looking into the surface of the dish. Some dishes are designed so that the feed source is mounted directly in front of the dish. This is referred to as a center-fed dish. Other dishes are designed so that the feed source is off to one side, referred to as an off-center fed dish, or just offset-fed dish. The offset-fed dish may be considered a section of a center-fed dish. The center-fed dish experiences some signal degradation due to blockage of the feed system, but this is usually an insignificantly small amount. The offset-fed dish is initially more difficult to aim, as the direction of reception is not the center axis like the center-fed dishes. The attitude of the offset dish is more likely to be vertical, making it less susceptible to loss from snow accumulation. Offset-fed dishes may have difficulty pointing horizontally for terrestrial communications. One enterprising ham, W4WSR, mounted his offset-fed PrimeStar dish upside down, which matched terrestrial pointing better. Older dishes tend to be center fed; newer dishes are offset fed.

The dish's parabola can be designed so the focus point is closer to the surface of the dish, referred to a "short focal length" dish, or further away from the dish's surface, referred to as a "long focal length" dish. To get the exact focal length, measure the diameter of the dish and the depth of the dish. The diameter squared divided by 16 times the depth is the focal length. The focal length divided by the diameter of the dish gives the *focal ratio*, commonly shown as f/D. Center-fed dishes are usually short focal ratios in 0.3 to 0.35 ranges. Offset-fed dishes are usually longer focal length such as 0.45 to 0.8. If you attach a couple of small mirrors (a couple of the YF's eye shadow mirrors when she isn't looking) to the outer front surface of a dish and then point the dish at the Sun, you will easily find the focus point of the dish. Put the reflector of the patch or helix just beyond this point of focus.

An alternate method for finding a dish's focal length is suggested by W1GHZ, and he provides that calculation on his Web site at: **www.w1ghz.cx/10g/10g_home.htm**. This method literally measures a solid-surface dish by the dimensions of the bowl of water that it will form when properly positioned.

While many of us enjoy building our own antennas, some of these microwave antennas are so small that they don't require a truck to transport them. Surplus market availability of these small dish antennas makes their construction unproductive. Many hams use the practices of AO-13 operators in using a surplus MMDS linear screen parabolic reflector antenna, **Fig 23.46**. These grid-dish antennas are often called "barbeque dishes". K5OE, **Fig 23.47,** and K5GNA, **Fig 23.48**, have been showing us how to greatly improve these linearly polarized reflectors by adapting them for the CP service. See the K5OE site: **members.aol.com/k5oe/**. The work shown us by these operators illustrate that simple methods can be used to "circularize" a linear dish and to

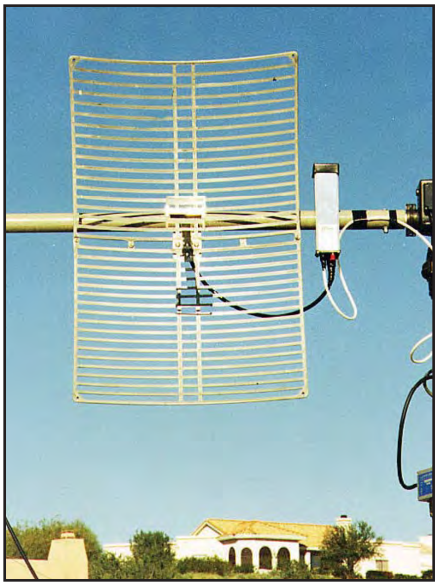


Fig 23.46—Another commercially available solution for S-band reception uses this TVRO antenna.

Fig 23.47—K5OE's mesh modification of a MMDS dish antenna with helix CP feed and DEM preamp.

Fig 23.48—K5GNA's "circularized" mesh modification of an MMDS dish antenna with helix CP feed and DEM preamp.

Fig 23.49—G3RUH's 60-cm spun aluminum dish with CP patch feed, available as a kit.

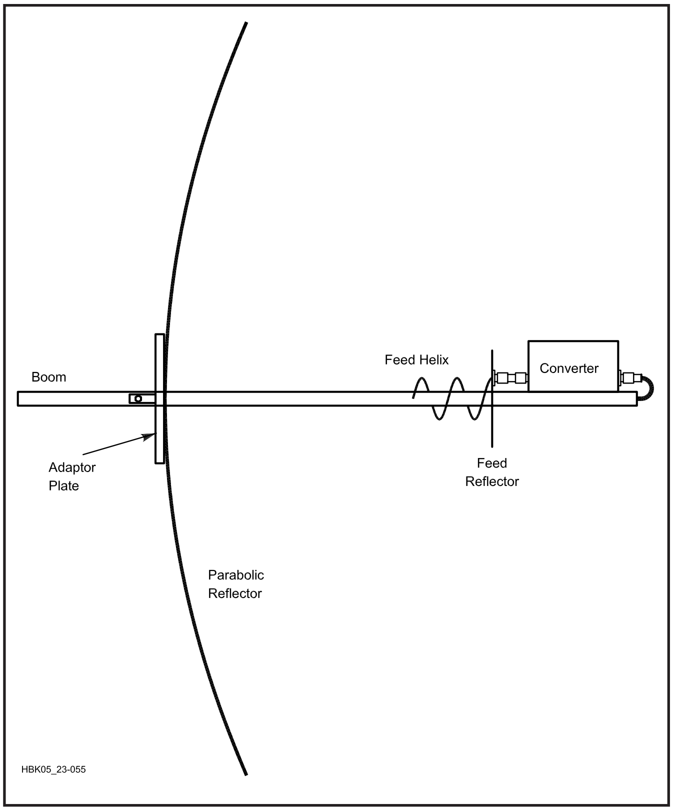


Fig 23.51—Detail of 60-cm S-band dish antenna with feed.

Fig 23.50—PrimeStar offset-fed dish with WD4FAB's helix-feed antenna. NØNSV was so pleased with the modification that he renamed the dish "FABStar," and made a new label!

further add to its gain by using simple methods to increase the dish area and feed efficiency.

Some smaller dishes are constructed from solid aluminum or steel. **Fig 23.49** shows one such 60-cm spun aluminum dish that was designed by G3RUH and ON6UG. This kit, complete with a CP patch feed is available from SSB-USA and has a gain of 21 dBic and provides a 2.5-dB Sun noise signal. Sometimes fiberglass construction is used with a conductive coating, as shown in **Fig 23.50**. Some operators are using their large, 10-foot TVRO dishes for Amateur satellite service, although these types of antennas cannot easily be mounted on a tower to clear the nearby trees. These larger dishes are generally made from perforated steel or aluminum. Dishes with perforations slightly reduce the wind loading. If the perforations are made smaller than λ/10, the dish is equivalent to solid in terms of signal reflection. At 2401 MHz (λ = 125 mm), this is about 0.50 inch, making standard 0.25-inch fence mesh a good option for a dish surface with low wind loading.

In the USA, there are large numbers of dishes that can be obtained either free or at low cost. But in some parts of the world dishes are not so plentiful, so hams make their own. G3RUH shows us his example of creating a dish antenna, see **Fig 23.51**. There are three parts to the dish antenna—the parabolic reflector, the boom, and the feed. There are as many ways to accomplish the construction, as there are constructors. It is not necessary to slavishly replicate every nuance of the design. The only critical dimensions occur in the feed system. When the construction is complete, you will have a 60-cm diameter S-band dish antenna with a gain of about 20 dBi with RHCP and a 3-dB beamwidth of 18°. Coupled with the proper down-converter, performance will be more than adequate for S-band downlink.

DISH FEEDS

On **www.ultimatecharger.com/**, WØLMD describes that the feeding of a dish has two major factors that determine the efficiency. Like a flashlight bulb, the dish feed source should evenly illuminate the entire dish, and none of the feed energy should spillover outside the dish's reflecting surface. No feed system is perfect in illuminating a dish. Losses affect the gain from either under-illuminating or over-illuminating the dish (spillover losses). Typical dish efficiency is 50 percent. That's 3 dB of lost gain. A great feed system for one dish can be a real lemon on another dish. A patch feed system is very wide angle, but a helix feed system is narrow angle. A short focal ratio center-fed dish requires a wide angle feed system to fully illuminate the dish, making the CP patch the preferred feed system. When used with an offset-fed dish, a patch-type feed system will result in a considerable spillover, or over-illumination loss, with an increased sensitivity to off-axis QRM, due to the higher f/D of this dish. Offset-fed dishes do much better when fed with a longer helix antenna.

A helix feed is simplicity personified. Mount a type N connector on a flat reflector plate and solder a couple of turns wire to the inner terminal. Designs are anywhere from two to six turns. The two-turn helices are used for very short focal length dishes in the f/D = 0.3 region, and the six-turn helices are used with longer focal length (f/D ~ 0.6) dishes, typically the offset-fed dishes. Since AO-40 is right circular and the dish reflection will reverse the polarity, the helix should be wound left circular, looking forward from the connector. Helix feeds work poorly on the short focal length dishes but really perform well on the longer focal length offset-fed dishes.

A patch feed is almost as simple. It is typically a type N connector on a flat reflector plate with a tuned flat metal plate soldered to the inner terminal. Sometimes the flat plate is square; sometimes it is rectangular, sometimes round. It could have two feed points, 90° out of phase for circular polarization, as was used in the construction of the AO-40 U-band antennas. Some patches are made rectangular with clipped corners to add circularity. On 2401 MHz, the plate is about $2^{1}/_{4}$-inches square and spaced from $^{1}/_{16}$ inch to $^{1}/_{4}$-inch away from the reflector. The point of attachment is about halfway between the center and the edge. A round patch for 2401 MHz is $\phi 2^{5}/_{8}$ inches. Patches work poorly on the longer focal length offset dishes, but do very well on the shorter focal length center-fed MMDS and TVRO dishes. A well studied CP patch feed for these short f/D dishes is shown to us by G3RUH in Fig 23.53 and **Fig 23.52**.

For additional information on constructing antennas for use at microwave frequencies, see *The ARRL UHF/Microwave Experimenter's Manual*.

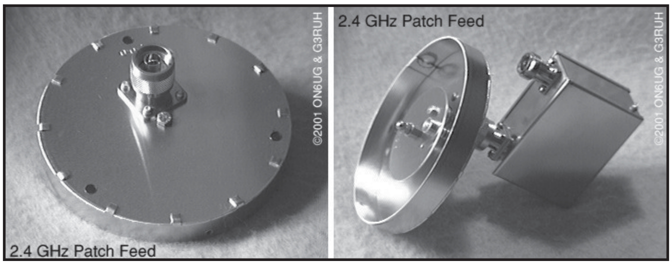


Fig 23.52—Details of CP patch feed for short f/D dish antennas by G3RUH and ON6UG.

PARABOLIC DISH ANTENNA CONSTRUCTION

The following is a condensation of several articles written by G3RUH describing a dish antenna that can be easily built and used for reception of an S-band downlink. The dish itself was previously described, and the article continues:

The parabolic reflector used for the original antenna was intended to be a lampshade. Several of these aluminum reflectors were located in department store surplus. The dish is 585 mm in diameter and 110 mm deep corresponding to an f/D ratio of 585/110/16 = 0.33 and a focal length of 0.33 × 585 = 194 mm. The f/D of 0.33 is a bit too concave for a simple feed to give optimal performance but the price was right, and the under-illumination keeps ground noise pickup to a minimum. The reflector already had a 40-mm hole in the center with three 4-mm holes around it in a 25-mm radius circle.

The boom passes through the center of the reflector and is made from 12.7-mm square aluminum tube. The boom must be long enough to provide for mounting to the rotator boom on the backside of the dish. The part of the boom extending through to the front of the dish must be long enough to mount the feed at the focus. If you choose to mount the down-converter or a preamp near the feed, some additional length will be necessary. Carefully check the requirements for your particular equipment.

A 3-mm thick piece of aluminum, 65 mm in diameter is used to support the boom at the center of the reflector. Once the center mounting plate is installed, the center boom is attached using four small angle brackets — two on each side of the reflector. See Fig 23.51 for details of reflector and boom assembly.

A small helix is used for the S-band antenna feed. The reflector for the helix is made from a 125-mm square piece of 1.6-mm thick aluminum. The center of the reflector has a 13-mm hole to accommodate the square center boom described above. The type N connector is mounted to the reflector about 21.25 mm from the middle. This distance from the middle is, of course, the radius of a helical antenna for S band. Mount the N connector with spacers so that the back of the connector is flush with the reflector surface. The helix feed assembly is shown in **Fig 23.53.**

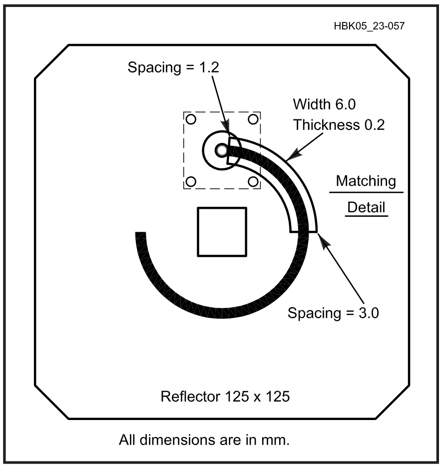


Fig 23.53—Details of helix feed for S-band dish antennas. The Type N connector is fixed with three screws and is mounted on a 1.6-mm spacer to bring the PTFE molding flush with the reflector. An easier mounting can be using a smaller TNC connector. Reflectors should be 95-100 mm, circular. Dimensions are in mm, 1 inch = 25.4 mm.

Copper wire about 3.2 mm in diameter is used to wind the helix. Wind four turns around a 40-mm diameter form. The turns are wound counterclockwise. This is because the polarization sense is reversed from RHCP when reflected from the dish surface. The wire helix will spring out slightly when winding is complete.

Once the helix is wound, carefully stretch it so that the turns are spaced 28 mm (±1 mm). Make sure the finished spacing of the turns is nice and even. Cut off the first half turn. Carefully bend the first quarter turn about 10° so it will be parallel to the reflector surface once the helix is attached to the N connector. This quarter turn will form part of the matching section.

Cut a strip of brass 0.2-mm thick and 6-mm wide matching the curvature of the first quarter turn of the helix by using a paper pattern. Be careful to get this pattern and subsequent brass cutting done exactly right. Using a large soldering iron and working on a heatproof surface, solder the brass strip to the first $^{1}/_{4}$ turn of the helix. Unless you are experienced at this type of soldering, getting the strip attached just right will require some practice. If it doesn't turn out right, just dismantle, wipe clean and try again.

After tack soldering the end of the helix to the type N connector, the first $^{1}/_{4}$ turn, with its brass strip in place, should be 1.2 mm above the reflector at its start (at the N connector) and 3.0 mm at its end. Be sure to line up the helix so its axis is perpendicular to the reflector. Cut off any extra turns to make the finished helix have $2^{1}/_{4}$ turns total. Once you are satisfied, apply a generous amount of solder at the point the helix attaches to the N connector. Remember this is all that supports the helix.

Once the feed assembly is completed, pass the boom through the middle hole and complete the mounting by any suitable method. The middle of the helix should be at the geometric focus of the dish. In the figures shown here, the feed is connected directly to the down-converter and then the down-converter is attached to the boom. You may require a slightly different configuration depending on whether you are attaching a down-converter, preamp, or just a cable with connector. Angle brackets may be used to secure the feed to the boom in a manner similar to the boom-to-reflector mounting. Be sure to use some method of waterproofing if needed for your preamp and/or down-converter.

HELIX FEED FOR AN OFFSET DISH ANTENNA

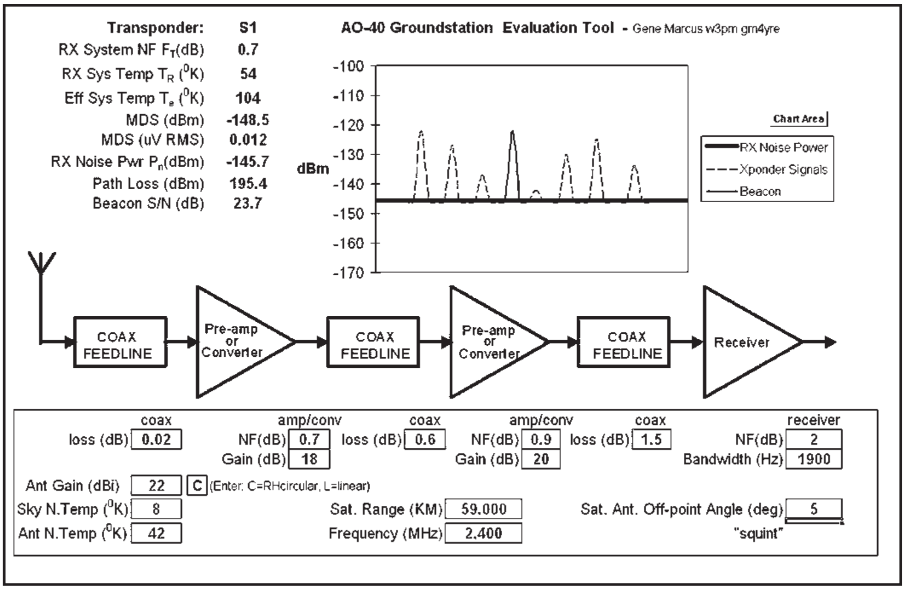
The surplus PrimeStar offset fed dish antenna with its seven-turn helix feed antenna, Fig 23.50, is described in this section. When the feed antenna is directly coupled with a preamp/down-converter system, this antenna provides superb reception of S-band signals with the satellite transponder noise floor often being the noise-limiting factor in the downlink. This performance is as had been predicted by the W3PM spreadsheet analysis, **Fig 23.54**, and actual operating experience. Operating experience also demonstrates that this antenna can receive the Sun noise 5 dB above the sky noise. Don't try to receive the Sun noise with the antenna looking near the horizon, as terrestrial noise will be greater than 5 dB, at least in a big-city environment. The operator, NØNSV, who provided this dish was rewarded for his effort with a second feed antenna, and he in turn provided new labels for the dish, titling it "FABStar".

The reflector of this dish is a bit out of the ordinary, with a horizontal ellipse shape. It is still a single paraboloid that was illuminated with an unusual feedhorn. At 2401 MHz we must be satisfied with a more conventional feed arrangement. A choice must be made to under-illuminate the sides of the dish while properly feeding the central section, or over-illuminating the center while properly feeding the sides. For the application shown here, the former choice was made. The W1GHZ water-bowl measurements showed this to be a dish with a focal point of f = 500.6 mm and requiring a feed for an f/D = 0.79. The total illumination angle of the feed is 69.8° in the vertical direction and a feedhorn with a 3-dB beamwidth of 40.3°. At 50 percent efficiency this antenna was calculated to provide a gain of 21.9 dBi. A seven-turn helix feed antenna was estimated to provide the needed characteristics for this dish and is shown in **Fig 23.55**.

The helix is basically constructed as described for the G3RUH parabolic dish, noted above. A matching section for the first λ/4 turn of the helix is spaced from the reflector at 2 mm at the start and 8 mm at the end of that fractional turn. Modifications of the design include the use of a cup reflector. For the reflector, a 2-mm thick circular plate is cut for a ϕ94 mm (0.75λ) with a thin aluminum sheet metal cup, formed with a depth of 47 mm. Employment of the cup enhances the performance of the reflector for a dish feed.

The important information for this seven-turn helix antenna is: Boom, 12.7 mm square tube or "C" channel; Element, ϕ$^1/_8$-inch copper wire or tubing; Close wind element on a ϕ1.50-inch tube or rod; Finished winding is ϕ40 mm spaced to a helical angle of 12.3°, or 28-mm spacing. These dimensions work out to have the element centerline to be of a cylindrical circumference of 1.0λ.

When WD4FAB tackled this antenna, he felt that the small amount of helical element support that James Miller used was inadequate, in view of the real life


Transponder: S1
RX System NF F_T(dB) 0.7
RX Sys Temp T_R (^{0}K) 54
Eff Sys Temp T_e (^{0}K) 104
MDS (dBm) -148.5
MDS (uV RMS) 0.012
RX Noise Pwr P_n(dBm) -145.7
Path Loss (dBm) 195.4
Beacon S/N (dB) 23.7

coax loss (dB) 0.02
amp/conv NF(dB) 0.7 Gain (dB) 18
coax loss (dB) 0.6
amp/conv NF(dB) 0.9 Gain (dB) 20
coax loss (dB) 1.5
receiver NF(dB) 2 Bandwidth (Hz) 1900
Ant Gain (dBi) 22 C (Enter: C=RHcircular, L=linear)
Sky N.Temp (^{0}K) 8
Ant N.Temp (^{0}K) 42
Sat. Range (KM) 59.000
Frequency (MHz) 2.400
Sat. Ant. Off-point Angle (deg) 5 "squint"

Fig 23.54—Screen display of W3PM's spreadsheet evaluation of ground station operation with AO-40.

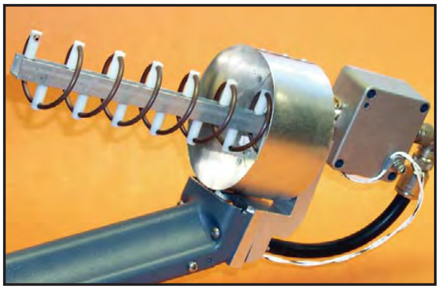


Fig 23.55—Seven-turn LHCP helix dish feed antenna with DEM preamp.

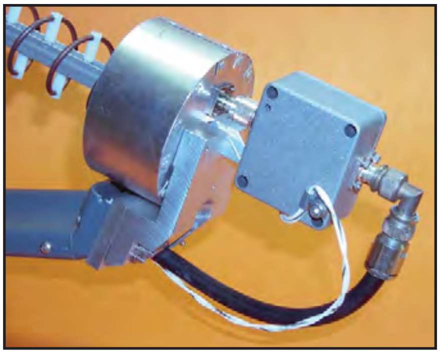


Fig 23.56—Mounting details of seven-turn helix and preamp.

bird traffic on the antennas at his QTH. He chose to use PTFE (Teflon") support posts at every ½ turn. This closer spacing of posts also permitted a careful control of the helix winding diameter and spacing making this antenna *very* robust. A fixture was set up on the drill press to uniformly predrill the holes for the element spacers and boom. Attachment of the reflector is through three very small aluminum angle brackets on the element side of the boom.

Mounting of the helix to the dish requires modification of the dish's receiver mounting boom. **Fig 23.56** shows these modifications using a machined mount. NM2A has constructed one of these antennas and shown that a machine shop is not needed for this construction. He has made a "Z" shaped mount from aluminum angle plate and then used a spacer from a block of acrylic sheet. The key here is to get the dish focal point at the 1.5-turn point of the feed antenna, which is also at about the lip of the reflector cup.

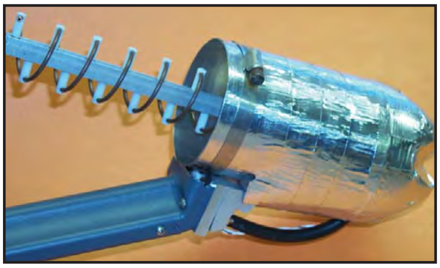


Fig 23.57—Rain cover for preamp using a two-liter soft-drink bottle with aluminum foil tape for protection from sun damage.

Fig 23.58—Welded pipe fitting mount bracket for FABStar dish antenna.

The W1GHZ data for this focal point is 500.6 mm from the bottom edge of the dish and 744.4 mm from the top edge. A two-string measurement of this point can confirm the focal point, all as shown by Wade in his writings. When mounting this feed antenna the constructor must be cautious to aim the feed at the *beam-center* of the dish, and not the geometric center, as the original microwave horn antenna were constructed. Taking the illumination angle information noted above, the helix feed antenna should be aimed 5.5° down from the geometric center of the dish.

As illustrated in Fig 23.56, a DEM preamp was directly mounted to the feed helix, using TNC connector that had been chosen for this case, as an N connector is quite large for the S-band helix. A male chassis mount connector should be mounted on either the preamp or the antenna so that the preamp can be directly connected to the antenna without any adaptors. This photo also illustrates how the reflector cup walls were riveted to the reflector plate. Exposed connectors must be protected from rainwater. Commonly, materials such as messy Vinyl Mastic Pads (3M 2200) or Hand Moldable Plastic (Coax Seal) are used. Since this is a tight location for such mastic applications, a rain cover was made instead from a two-liter soft-drink bottle as shown in **Fig 23.57**. Properly cutting off the top of the bottle allows it to be slid over the helix reflector cup and secured with a large hose clamp. Sun-damage protection of the plastic bottle must be provided and that was done with a wrapping of aluminum foil pressure-sensitive-adhesive tape.

There are many methods for mounting this dish antenna to your elevation boom. Constructors must give consideration to the placement of the dish to reduce the wind loading and off-balance to the rotator system by this mounting. In the illustrated installation, the off-balance issue was not a major factor, but the dish was placed near the center of the elevation boom, between the pillow block bearing supports. As there is already sizeable aluminum plate for these bearings, the dish was located to "cover" part of that plate, so as to not add measurably to the existing wind-loading area of the overall assembly. A mounting bracket provided with the stock dish clamps to the end of a standard 2-inch pipe (actual measure: ϕ2.38 inch) stanchion. This bracket was turned around on the dish and clamped to the leg of a welded pipe Tee assembly, see **Fig 23.58**. Pipe reducing fittings were machined and fitted in the Tee top bar, which was cut in half for clamping over the 1½-inch pipe used for the elevation boom. Bolts were installed through drilled hole and used to clamp this assembly.

AN INTEGRATED DUAL-BAND ANTENNA SYSTEM

An effective system can be built starting with off-the-shelf components—the Teksharp 1.2-meter dish and AIDC-3731AA downconverter. These systems include not only antennas, but also high quality receiving converters, both of which are covered here.

Operators are finding an increased availability of components for their stations, providing them with a broad selection of the needed equipment.[9] The products described here allow a single dish antenna to provide for the required dual-band operation, with an S-band (2.3 GHz) downlink and L-band (1.2 GHz) uplink.

A new company has surfaced on the amateur equipment horizon, Teksharp. Teksharp is providing kits for both 1.2- and 1.8-meter-diameter parabolic dish antennas. Additionally, S-band receiving converters are available from a number of different suppliers, including Teksharp. Here, Dick Jansson, WD4FAB, selected a well-proven converter, the modified AIDC-3731AA, from Bob Seydler, K5GNA. Bob takes commercial converters and modifies them for S-band amateur service, including an upgrade of the front-end band-pass filtering. This down-converter was selected for its superior and proven passband filtering, allowing an L-band transmitting uplink on the same antenna as the S-band downlink.

The antenna system described here includes the dish antenna, its dual-band feed system and the receiving converter. These three elements are critical for high quality communications. This antenna system was combined with a proven 40-W, tower mounted L-band amplifier, also described in this chapter, resulting in a fully functioning station.

THE TEKSHARP 1.2 METER DISH

The assembly methods are expected to be the same for the 1.8-meter dish. That larger antenna provides additional performance and flexibility, if desired. The gains for the 1.2-meter dish are 21.0 dBi at L-band, and 26.6 dBi at S-band.

For this project, the antenna arrived in a compact, 36×12×4 inch box of parts. **Fig 23.59** shows these parts laid out for assembly. A set of well machined and formed aluminum ribs is the key to any parabolic dish design and these are well executed. WD4FAB measured the dimensions of these ribs to understand the basic dimensional features of the dish. These figures are 1204 mm, 245 mm and 370 mm for diameter, depth and focus, respectively. Therefore, the resulting focus to diameter ratio (F/D) is 0.307.

Fig 23.59—The antenna parts as received from Teksharp.

Fig 23.60—A modified antenna base plate assembly. See the text for a description.

Separate plastic packages include the antenna assembly screws and the antenna mounting bolts. Teksharp also sent some well illustrated assembly instructions and a plastic template for the petals (or gores) for the hardware cloth covering the dish.

The included hex-head screws and nuts for the antenna assembly were high quality stainless steel. The U bolts and mast-mounting clamp hardware provided were also high quality, but the bolts and clamps were conventionally plated. It is useful to note that parts fabricated and finished in these materials can quickly corrode and become unusable in a humid climate. The machined parts for these antennas were very well made and finished, and they were a pleasure to work with.

Teksharp provides a well-suited bracket plate that supports the feed boom while also providing for the mounting of the dish to the elevation boom. In the installation shown in **Fig 23.60** at WD4FAB, a modified mounting from a previous dish described elsewhere in this chapter was used. If your arrangement is more conventional, you may be able to make use of the Teksharp mounting hardware without modification.

Before starting the assembly, a copy of a rib shape was made in order to develop some cardboard templates representing the dish surface. A 602-mm circular radius template was also fabricated to aid the author in shaping the perimeter bands to dimension rather than by guess. The dish-surface template was used to check and maintain the parabolic shape of the dish surface as the mesh cloth petals were assembled to the ribs. These petals do not always follow the rib shape in the space between the ribs and the use of the template helped correct those surface inaccuracies while still under construction. The **Antennas** chapter of this *Handbook* and the *ARRL Antenna Book*[10] provide excellent information on dish antenna construction methods.

Following the well-written Teksharp instructions, the ribs were assembled to the circular hub plate and the structure then closed with the formed perimeter bands. In the author's shop, he fashioned the ability to hold the framework in a shop vise, making the assembly task much easier. On one of the rib ends at the top of the dish, a nut was replaced with a riveted-in-place blind anchor nut to allow the coax cables to be clamped to the dish rim without having to simultaneously handle too much loose hardware while performing that step.

It is now time to create a parabolic dish

Fig 23.61—Dish antenna during assembly.

out of this strong and lightweight framework. The constructor must provide his own fabric cloth for this part of the assembly. The kit recommendations are to use ¼-inch galvanized cloth, a low cost item available at most hardware stores. The author had some eight-wires-per-inch aluminum cloth left over from a previous attempt to build a dish antenna. This was ideal, as galvanized material has a habit of eventually rusting away in a humid climate. **Fig 23.61** shows the partially assembled dish in the author's shop.

ANTENNA FEED

Early dish antennas for these ranges used helical antennas as feeds. The experiences of other operators in the testing of AO-40 antennas has shown that low F/D parabolic antennas, such as this one, are most effectively fed using patch rather than helical antennas. (See the several articles by Jerry Brown, K5OE, at **members.aol.com/k5oe/**. Also see articles by Robert Suding, WØLMD, at **www.ultimatecharger.com/dish.html**.)

WØLMD provides some useful multiband patch antennas that can be purchased for this service, as does Teksharp. The author decided to follow K5OE's guidance as recently published (see **Fig 23.62**).[11] The sharp-eyed reader may observe that WD4FAB made some modifications to the original patch design, through the addition of some nylon screws on the L-band patch. Please be advised to build this antenna exactly as in the original article unless you have some quality laboratory test equipment! Fortunately, WD4FAB had the use of a good network analyzer at the AMSAT Laboratory.

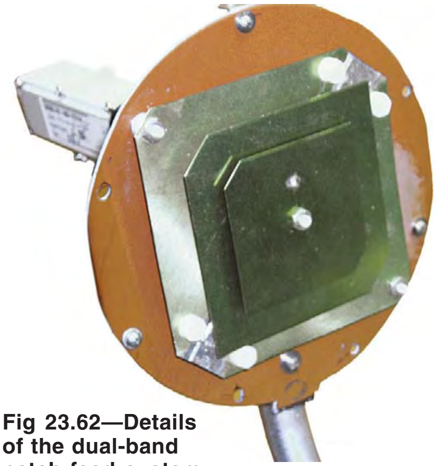


Fig 23.62—Details of the dual-band patch-feed system.

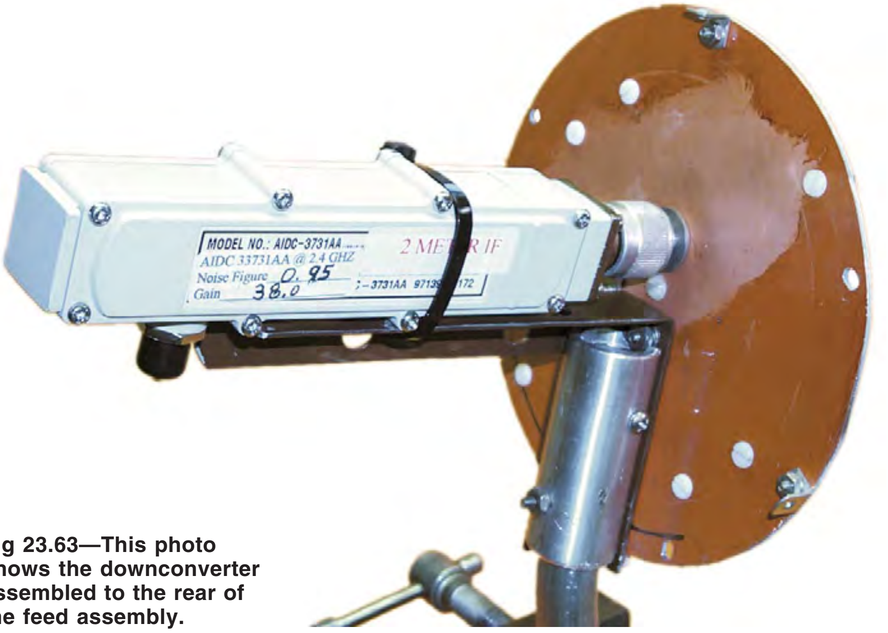


Fig 23.63—This photo shows the downconverter assembled to the rear of the feed assembly.

AIDC-3731AA S BAND DOWNCONVERTER

The next element of this system is the AIDC-3731AA downconverter from K5GNA. This converter offers one of the lower-cost approaches to receiving AO-40's 2401 MHz downlink signal. **Fig 23.63** shows the converter mounted directly to the male Type N connector on the S-band patch antenna. The output port provides a 2-meter IF output through the F connector on the side.

This converter is now available with a low overhead internal voltage regulator, allowing it to be powered by a 13.8 V dc supply source and still obtain proper regulation of the 12 V dc needed for the internal circuits. There is a considerable advantage in using this regulation scheme as it keeps the total power dissipation low, thus holding down the temperature rise from the 2.5 W of power dissipation. There is interest in keeping this power dissipation low to minimize frequency shift due to temperature rise. Converters exposed to the sun will have noticeable frequency shifts with clouds shading the sun. This 13.8 V dc power is supplied to the converter through a bias T in the shack and RG-6 coaxial cable to the IF connector of the converter.

FEED ASSEMBLY

Following the directions in K5OE's article for the dual-band patch antenna, WD4FAB provided a mounting angle on the patch assembly using a piece of steel strapping angle. The author also machined an aluminum sleeve adapter for mounting between the J-shaped feed boom and this steel angle, as can be seen in Fig 23.63.

Glossary of Satellite Terminology

AMSAT—A registered trademark of the Radio Amateur Satellite Corporation, a nonprofit scientific/educational organization located in Washington, DC. It builds and operates Amateur Radio satellites and has sponsored the OSCAR program since the launch of OSCAR 5. (AMSAT, PO Box 27, Washington, DC 20044.)

Anomalistic period—The elapsed time between two successive perigees of a satellite.

AO-#—The designator used for AMSAT OSCAR spacecraft in flight, by sequence number.

AOS—Acquisition of signal. The time at which radio signals are first heard from a satellite, usually just after it rises above the horizon.

Apogee—The point in a satellite's orbit where it is farthest from Earth.

Area coordinators—An AMSAT corps of volunteers who organize and coordinate amateur satellite user activity in their particular state, municipality, region or country. This is the AMSAT grassroots organization set up to assist all current and prospective OSCAR users.

Argument of perigee—The polar angle that locates the perigee point of a satellite in the orbital plane; drawn between the ascending node, geocenter, and perigee; and measured from the ascending node in the direction of satellite motion.

Ascending node—The point on the ground track of the satellite orbit where the sub-satellite point (SSP) crosses the equator from the Southern Hemisphere into the Northern Hemisphere.

Az-el mount—An antenna mount that allows antenna positioning in both the azimuth and elevation planes.

Azimuth—Direction (side-to-side in the horizontal plane) from a given point on Earth, usually expressed in degrees. North = 0° or 360°; East = 90°; South = 180°; West = 270°.

Circular polarization (CP) — A special case radio energy emission where the electric and magnetic field vectors rotate about the central axis of radiation. As viewed along the radiation path, the rotation directions are considered to be right-hand (RHCP) if the rotation is clockwise, and left-hand (LHCP) if the rotation is counterclockwise.

Descending node — The point on the ground track of the satellite orbit where the sub-satellite point (SSP) crosses the equator from the Northern Hemisphere into the Southern Hemisphere.

Desense — A problem characteristic of many radio receivers in which a strong RF signal overloads the receiver, reducing sensitivity.

Doppler effect — An apparent shift in frequency caused by satellite movement toward or away from your location.

Downlink — The frequency on which radio signals originate from a satellite for reception by stations on Earth.

Earth station — A radio station, on or near the surface of the Earth, designed to transmit or receive to/from a spacecraft.

Eccentricity — The orbital parameter used to describe the geometric shape of an elliptical orbit; eccentricity values vary from e = 0 to e = 1, where e = 0 describes a circle and e = 1 describes a straight line.

EIRP — Effective isotropic radiated power. Same as ERP except the antenna reference is an isotropic radiator.

Elliptical orbit — Those orbits in which the satellite path describes an ellipse with the Earth at one focus.

Elevation — Angle above the local horizontal plane, usually specified in degrees. (0° = plane of the Earth's surface at your location; 90° = straight up, perpendicular to the plane of the Earth).

Epoch — The reference time at which a particular set of parameters describing satellite motion (***Keplerian elements***) are defined.

EQX — The reference equator crossing of the ascending node of a satellite orbit, usually specified in UTC and degrees of longitude of the crossing.

ERP — Effective radiated power. System power output after transmission-line losses and antenna gain (referenced to a dipole) are considered.

ESA — European Space Agency. A consortium of European governmental groups pooling resources for space exploration and development.

FO-# — The designator used for Japanese amateur satellites, by sequence number. Fuji-OSCAR 12 and Fuji-OSCAR 20 were the first two such spacecraft.

Geocenter — The center of the Earth.

Geostationary orbit — A satellite orbit at such an altitude (approximately 22,300 miles) over the equator that the satellite appears to be fixed above a given point.

Groundtrack — The imaginary line traced on the surface of the Earth by the subsatellite point (SSP).

Inclination — The angle between the orbital plane of a satellite and the equatorial plane of the Earth.

Increment — The change in longitude of ascending node between two successive passes of a specified satellite, measured in degrees West per orbit.

Iskra — Soviet low-orbit satellites launched manually by cosmonauts aboard Salyut missions. Iskra means "spark" in Russian.

JAMSAT — Japan AMSAT organization.

Keplerian Elements — The classical set of six orbital element numbers used to define and compute satellite orbital motions. The set is comprised of inclination, Right Ascension of Ascending Node (RAAN), eccentricity, argument of perigee, mean anomaly and mean motion, all specified at a particular epoch or reference year, day and time. Additionally, a decay rate or drag factor is usually included to refine the computation.

LEO — Low Earth Orbit satellite such as the Phase 1 and Phase 2 OSCARs.

LHCP — Left-hand circular polarization.

LOS — Loss of signal — The time when a satellite passes out of range and signals from it can no longer

This angle also provided an added support for the AIDC-3731AA converter, shown strapped down with a plastic cable tie. As assembled, this is a robust feed assembly.

Mounting of the patch assembly was done with the patches aligned parallel to the plane of the dish and on the dish center line. Place the S-band reflector at the focal distance, 370 mm (14.57 inches), from the dish surface at the center. This adjustment is made by moving the feed boom along its mounting clamps until the proper measurement is achieved. That is all you have to do. You can play with mirrors, as in the instructions, to focus the sun on the patches, but doing this adjustment by measurement is easier and it is all that really needs to be done.

K5OE cautions that rain, bird droppings and bugs can mess up the tuning and operation of the patch feed antennas. He advises the use of some kind of protection for antennas. In addition, the author has an aversion to having water in hard-to-reach be heard. This usually occurs just after the satellite goes below the horizon.

Mean anomaly (MA) — An angle that increases uniformly with time, starting at perigee, used to indicate where a satellite is located along its orbit. MA is usually specified at the reference epoch time where the Keplerian elements are defined. For AO-10 the orbital time is divided into 256 parts, rather than degrees of a circle, and MA (sometimes called phase) is specified from 0 to 255. Perigee is therefore at MA = 0 with apogee at MA = 128.

Mean motion — The Keplerian element to indicate the complete number of orbits a satellite makes in a day.

Microsat — Collective name given to a series of small amateur satellites having store-and-forward capability (OSCARs 14-19, for example).

Molniya — Type of elliptical orbit, first used in the Russian Molniya series, that features a ground track that more or less repeats on a daily basis.

NASA — National Aeronautics and Space Administration, the US space agency.

Nodal period — The amount of time between two successive ascending nodes of satellite orbit.

Orbital elements — See ***Keplerian Elements***.

Orbital plane — An imaginary plane, extending throughout space, that contains the satellite orbit.

OSCAR — Orbiting Satellite Carrying Amateur Radio.

PACSAT— Packet radio satellite (see ***Microsat*** and ***UoSAT-OSCAR***).

Pass — An orbit of a satellite.

Passband — The range of frequencies handled by a satellite translator or transponder.

Perigee — The point in a satellite's orbit where it is closest to Earth.

Period — The time required for a satellite to make one complete revolution about the Earth. See ***Anomalistic period*** and ***Nodal period***.

Phase I — The term given to the earliest, short-lived, low Earth orbit (LEO) OSCAR satellites that were not equipped with solar cells. When their batteries were depleted, they ceased operating.

Phase 2 — LEO OSCAR satellites. Equipped with solar panels that powered the spacecraft systems and recharged their batteries, these satellites have been shown to be capable of lasting up to five years (OSCARs 6, 7 and 8, for example).

Phase 3 — Extended-range, high-elliptical-orbit OSCAR satellites with very long-lived solar power systems (OSCARs 10 and 40, for example).

Phase 4 — Proposed OSCAR satellites in geostationary orbits.

Polar Orbit — A low, circular orbit inclined so that it passes over the Earth's poles.

Precession — An effect that is characteristic of AO-10 and AO-40 orbits. The satellite apogee SSP will gradually change over time.

Project OSCAR — The California-based group, among the first to recognize the potential of space for Amateur Radio; responsible for OSCARs I through IV.

QRP days — Special orbits set aside for very low power uplink operating through the satellites.

RAAN — Right Ascension of Ascending Node. The Keplerian element specifying the angular distance, measured eastward along the celestial equator, between the vernal equinox and the hour circle of the ascending node of a spacecraft. This can be simplified to mean roughly the longitude of the ascending node.

Radio Sputnik — Russian Amateur Radio satellites (see ***RS #***).

Reference orbit — The orbit of Phase II satellites beginning with the first ascending node during that UTC day.

RHCP — Right-hand circular polarization.

RS # — The designator used for most Russian Amateur Radio satellites (RS-1 through RS-15, for example).

Satellite pass — Segment of orbit during which the satellite "passes" nearby and in range of a particular ground station.

Sidereal day — The amount of time required for the Earth to rotate exactly 360° about its axis with respect to the "fixed" stars. The sidereal day contains 1436.07 minutes (see ***Solar day***).

Solar day — The solar day, by definition, contains exactly 24 hours (1440 minutes). During the solar day the Earth rotates slightly more than 360° about its axis with respect to "fixed" stars (see ***Sidereal day***).

Spin modulation — Periodic amplitude fade-and-peak resulting from the rotation of a satellite's antennas about its spin axis, rotating the antenna peaks and nulls.

SSP — Subsatellite point. Point on the surface of the Earth directly between the satellite and the geocenter.

Telemetry — Radio signals, originating at a satellite, that convey information on the performance or status of onboard subsystems. Also refers to the information itself.

Transponder — A device onboard a satellite that receives radio signals in one segment of the spectrum, amplifies them, translates (shifts) their frequency to another segment of the spectrum and retransmits them. Also called linear translator.

UoSAT-OSCAR (UO #) — Amateur Radio satellites built under the coordination of radio amateurs and educators at the University of Surrey, England.

Uplink — The frequency at which signals are transmitted from ground stations to a satellite.

Visibility Circle — The range of area on the Earth that are "seen" by a satellite. This is also called the "footprint" for that satellite.

Window — Overlap region between acquisition circles of two ground stations referenced to a specific satellite. Communication between two stations is possible when the subsatellite point is within the window.

coaxial connectors. Water in these connectors does not ensure a good satellite signal! To solve both of these problems, WD4FAB went shopping for an antenna cover at his favorite "antenna parts store," K-Mart. He found help from Martha Stewart, no less, in the form of a nice, clear styrene plastic "3.3 quart airtight canister."

One of these canisters was modified to fit over the patch assembly and the feed boom. This canister was also shortened to allow it to fit into the cover lip of an unmodified canister mounted on the "rear" of the feed. The modified canister was mounted to the patch reflector with three small angle brackets, as seen in Fig 23.63. Some of the cutoff plastic cylinder should be saved. This can then be glued to the end of the cutoff container, to shim that OD to fit into the inside diameter of the cover lip of the rear canister. The author also epoxy-bonded a set of blind nuts to the inside of the canister so that the screws through the cover lip of the rear-mounted canister will

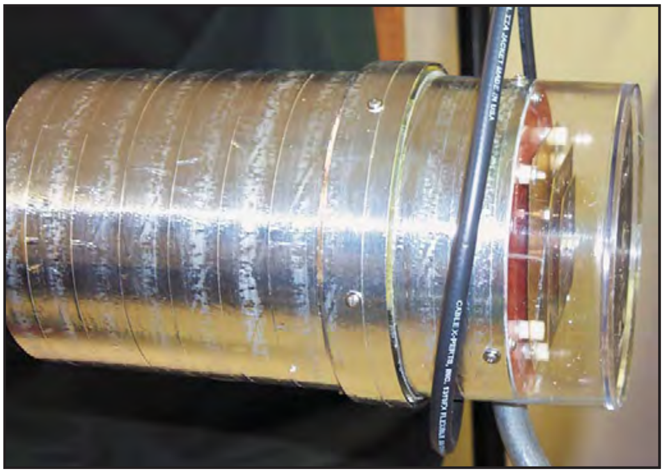


Fig 23.64—The 3.3-quart plastic canister converted for use as a radome at the feedpoint.

keep it together. That arrangement is shown in **Fig 23.64**. The slot in the front canister that passes the feed boom has space for the coaxial cables for L and S band. A further protection measure was to cover the exposed plastic with aluminum foil tape, as seen in Fig 23.64. This was not done to area in front of the patch antennas. This tape is there to protect the plastic from sun damage, although this type of clear plastic has a good record in avoiding UV harm.

INSTALLATION

With all preparations made, completion of the installation of the dish antenna and converter was a breeze. **Fig 23.65** shows the dish assembly bolted to the author's old PrimeStar antenna mount. Just remember to use the built-in screw adjustment provided in the PrimeStar mount to aim the dish centerline along the centerline of your antenna pointing system. The beamwidths of L- and S-band operations in this assembly are fairly narrow, so your pointing precision will need to be pretty good. Many of the details of the WD4FAB elevation boom system are shown in Fig 23.65 as well.

Before finally closing the protective plastic containers over the feed antennas, be sure that all of the coaxial cable connections are tight and the cables are dressed properly. This final closure will need to be done at this step in the assembly. Be sure to arrange the coaxial cables so that they don't drag on the feed boom. The cable clamps at the top of the dish are there to dress the cables and support the feed boom. This is shown in **Fig 23.66**.

Fig 23.66 also shows the dish system in operating position along with the U-band (70 cm) cross-polarized (CP) Yagi antenna on the far left, and the two smaller M2 23CM22EZA antennas that were tested previously. The author has kept these two L-band antennas in service for use on 1296 MHz. He placed a ground-commanded relay to switch between the two antenna systems in the amplifier box on the top of the tower. This is also convenient to use to compare the two L-band antenna systems.

ON THE AIR

This configuration was tested with the AO-40 satellite (which is no longer operational at the time of this writing). Tests showed that AO-40 downlink signals on S band, 2401 MHz, were really solid with this system. The pointing requirements were narrow, and had to be good to within 3° to 4°, based on the specified beam width at these frequencies. The noise floor of AO-40 was clearly detectable, about 2 dB above cold sky noise.

For the uplink, WD4FAB had a usable return signal with 40 W of RF on L band when the satellite "squint" was 20° or lower, as reported in note 10. When the squint is low, good downlink signals were realized with only about 5-10 W PEP of L-band power. When the author compared the Teksharp antenna on L band to the M2 23CM22EZA stacked antennas, as shown in Fig 23.66, he saw better than an S-unit (>3-4 dB on his Kenwood TS-2000 transceiver) improvement in downlink signal. This improved performance was seen in the wider ranges of squint angles that can be used with the Teksharp antenna on the L-band uplink. When the AO-40 squint angles were greater than 20°, he still had to use his U-band uplink transmitter with the CP Yagi antenna.

Measurements of Sun noise have been attempted with this antenna system. These have been disappointing, with values of around 2 dB seen. This is compared to the solid 5 dB of Sun noise measured with the WD4FAB previous PrimeStar dish. One of the probable reasons for the lowered performance can be attributed to the front-end band-pass filtering provided in the receive converter. The operating experience with this system has been absolutely solid, however.

IN SUMMARY

It is important to consider all of the interrelated characteristics of an antenna system. It is insufficient to just whip up "any" antenna, marry "any" receive converter to that antenna and then use "any" transmitting scheme to operate with full-duplex signals from high-performance satellites. We've had the ability to employ computer analysis, as shown to us by Gene Marcus, W3PM, with his spreadsheet analysis: **www.amsat.org/amsat/ftp/software/spreadsheet/w3pm-ao40-v2.1.zip**.

Manufacturers: Antenna: Teksharp (Rick Fletcher, KG6IAL), **www.teksharp.com**, 5770 McKellar Dr, San Jose, CA 95129; **inquiries@teksharp.com**; Price: 1.2 meter dish, $165; feed boom, $40; dual-band (S/L) patch feed, $200. Downconverter Bob Seydler, K5GNA, **members.aol.com/k5gna/myhomepage/**, 8522 Rebawood, Humble, TX 77346-1789; 281-852-0252, **bob@k5gna.com**. Price: $100, setup for 12 V operation add $20.

JUST THE BEGINNING

This section barely nicks the surface of satellite operating. There is much more to learn and enjoy. It is suggested that you spend some time at the AMSAT Web site. You'll pick up a wealth of information there. Speaking of "picking up," grab a copy of the *ARRL Radio Amateur's Satellite Handbook* and the *ARRL Antenna Book* (see your favorite dealer, or buy it on *ARRLWeb*). Between these two resources you'll be able to tap just about all the amateur satellite knowledge you're likely to need.

In the meantime, see you in orbit!

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Fig 23.65—Mounting details of the antenna system.

Fig 23.66—The completed and tower-mounted antenna system ready to go! The 40-W, 23-cm amplifier is enclosed in the box below the dish antenna.

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Earth-Moon-Earth (EME)

EME communication, also known as "moonbounce," has become a popular form of space communication. The concept is simple: The moon is used as a passive reflector for VHF and UHF signals. With a total path length of nearly 500,000 miles, EME is the ultimate DX. EME is a natural and passive propagation phenomenon, and EME QSOs count toward the WAS, DXCC and VUCC awards. EME opens up the VHF and UHF bands to a new universe of worldwide DX.

The first demonstration of EME capability was done by the US Army Signal Corps just after WW II. In the 1950s, using 400 MW of effective radiated power, the US Navy established a moon relay link between Washington, DC, and Hawaii that could handle four multiplexed Teletype (RTTY) channels. The first successful amateur reception of EME signals occurred in 1953 by W4AO and W3GKP.

It took until 1960 for two-way amateur communications to take place. Using surplus parabolic dish antennas and high-power klystron amplifiers, the Eimac Radio Club, W6HB, and the Rhododendron Swamp VHF Society, W1BU, accomplished this milestone in July 1960 on 1296 MHz. In the 1960s, the first wave of amateur EME enthusiasts established amateur-to-amateur contacts on 144 MHz and 432 MHz. In April 1964, W6DNG and OH1NL made the first 144-MHz EME QSO. 432-MHz EME experimentation was delayed by the 50-W power limit (removed January 2, 1963). Only one month after the first 144-MHz QSO was made, the 1000-ft-diameter dish at Arecibo, Puerto Rico, was used to demonstrate the viability of 432-MHz EME, when a contact was made between KP4BPZ and W1BU. The first amateur-to-amateur 432-MHz EME QSO occurred in July 1964 between W1BU and KH6UK.

The widespread availability of reliable low-noise semiconductor devices along with significant improvements in Yagi arrays ushered in the second wave of amateur activity in the 1970s. Contacts between stations entirely built by amateurs became the norm instead of the exception. In 1970, the first 220- and 2304-MHz EME QSOs were made, followed by the first 50-MHz EME QSO in 1972.

Fig 23.67—Tommy Henderson, WD5AGO, pursues 144-MHz EME from his Tulsa, Oklahoma, QTH with this array. Local electronics students helped with construction.

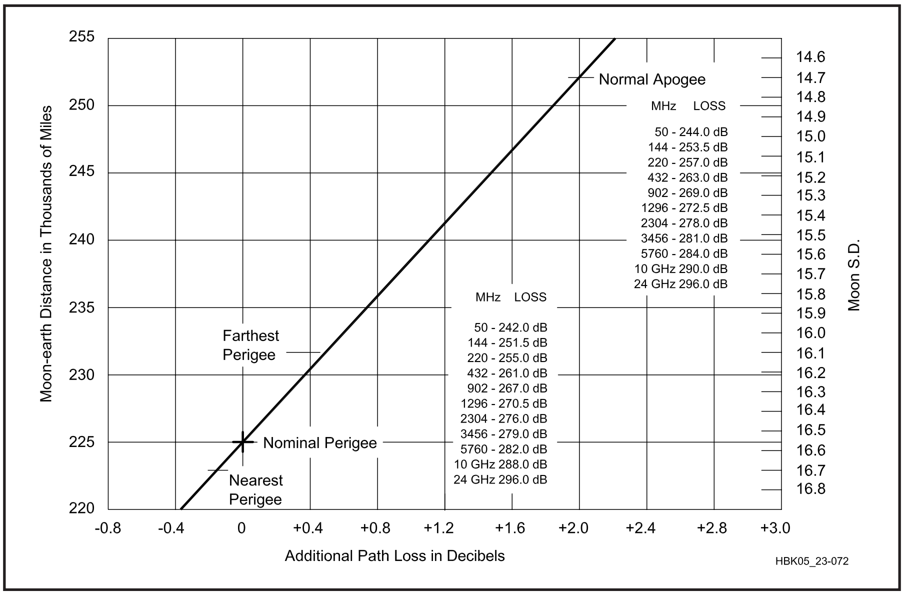

Fig 23.68—Variations in EME path loss can be determined from this graph. SD refers to semi-diameter of the moon, which is indicated for each day of the year in *The Nautical Almanac*.

1970s activity was still concentrated on 144 and 432 MHz, although 1296-MHz activity grew.

As the 1980s approached, another quantum leap in receive performance occurred with the use of GaAsFET preamplifiers. This, and improvements in Yagi performance (led by DL6WU's log-taper design work), and the new US amateur power output limit of 1500 W have put EME in the grasp of most serious VHF and UHF operators. The 1980s saw 144- and 432-MHz WAS and WAC become a reality for a great number of operators. The 1980s also witnessed the first EME QSOs on 3456 MHz and 5760 MHz (1987), followed by EME QSOs on 902 MHz and 10 GHz (1988).

EME is still primarily a CW mode. As stations have improved, SSB is now more popular. Regardless of the transmission mode, successful EME operating requires:

1) As close to the legal power output as possible.

2) A fairly large array (compared to OSCAR antennas).

3) Accurate azimuth and elevation rotation.

4) Minimal transmission-line losses.

5) A low system noise figure, preferably with the preamplifier mounted at the array.

CHOOSING AN EME BAND

Making EME QSOs is a natural progression for many weak-signal terrestrial operators. Looking at EME path loss vs frequency (**Fig 23.68**), it may seem as if the lowest frequency is best, because of reduced path loss. This is not entirely true. The path-loss graph does not account for the effects of cosmic and man-made noise, nor does it relate the effects of ionospheric scattering and absorption. Both short- and long-term fading effects also must be overcome.

50-MHz EME is quite a challenge, as the required arrays are very large. In addition, sky noise limits receiver sensitivity at this frequency. Because of power and licensing restrictions, it is not likely that many foreign countries will be able to get on 50-MHz EME.

144 MHz is probably the easiest EME band to start on. It supports the largest number of EME operators. Commercial equipment is widely available; a 144-MHz EME station can almost be completely assembled from off-the-shelf equipment. 222 MHz is a good frequency for EME, but there are only a handful of active stations, and 222 MHz is available only in ITU Region 2.

432 MHz is the most active EME band after 144 MHz. Libration fading is more of a problem than at 144 MHz, but sky noise is more than an order of magnitude less than on 144 MHz. The improved receive signal-to-noise ratio may more than make up for the more rapid fading. However, 432-MHz activity is most concentrated into the one or two weekends a month when conditions are expected to be best.

902 MHz and above should be considered if you primarily enjoy experimenting and building equipment. If you plan to operate at these frequencies, an unobstructed moon window is a must. The antenna used is almost certain to be a dish. 902 MHz has the same problem that 222 MHz has — it's not an international band. Equipment and activity are expected to be limited for many years.

1296 MHz currently has a good amount of activity from all over the world. Recent equipment improvements indicate 1296 MHz should experience a significant growth in activity over the next few years. 2300 MHz has received renewed interest. It suffers from nonaligned international band assignments and restrictions in different parts of the world.

ANTENNA REQUIREMENTS

The tremendous path loss incurred over the EME circuit requires a high-power transmitter, a low-noise receiver and a high-performance antenna array. Although single-Yagi QSOs are possible, most new EME operators will rapidly become frustrated unless they are able to work many different stations on a regular basis. Because of libration fading and the nature of weak signals, a 1- or 2-dB increase in array gain will often be perceived as being much greater. An important antenna parameter in EME communications is the antenna noise temperature. This refers to the amount of noise received by the array. The noise comes from cosmic noise (noise generated by stars other than the sun), Earth noise (thermal noise radiated by the Earth), and noise generated by man-made sources such as power-line leaks and other broadband RF sources.

Yagi antennas are almost universally used on 144 MHz. Although dish antennas as small as 24 ft in diameter have been successfully used, they offer poor gain-to size trade-offs at 144 MHz. The minimum array gain for reliable operation is about 18 dBd (20.1 dBi). The minimum array gain should also allow a station to hear its own echoes on a regular basis. This is possible by using four 2.2-λ Yagis. The 12-element 2.5-λ Yagi described in the **Antennas** chapter is an excellent choice. When considering a Yagi design, you should avoid old-technology Yagis, that is, designs that use either constant-width spacings, constant-length directors or a combination of both. These old-design Yagis will have significantly poorer side lobes, a narrower gain bandwidth and a sharper SWR bandwidth than modern log-taper designs. Modern wideband designs will behave much more predictably when stacked in arrays, and, unlike many of the older designs, will deliver close to 3 dB of stacking gain.

222-MHz requirements are similar to those of 144 MHz. Although dish antennas are somewhat more practical, Yagis still predominate. The 16-element 3.8-λ Yagi described in the **Antennas** chapter is a good building block for 222-MHz EME. Four of these Yagis are adequate for a minimal 222-MHz EME station, but six or eight will provide a much more substantial signal.

At 432 MHz, parabolic-dish antennas become viable. The minimum gain for reliable 432-MHz EME operation is 24 dBi.

Yagis are also used on 432 MHz. The 22-element Yagi described in the **Antennas** chapter is an ideal 432-MHz design. Four of the 22-element Yagis meet the 24-dBi-gain criteria, and have been used successfully on EME. If you are going to use a fixed polarization Yagi array, you should plan on building an array with substantially more than 24-dBi gain if you desire reliable contacts with small stations. This extra gain is needed to overcome polarization misalignment.

At 902 MHz and above, the only antenna worthy of consideration is a parabolic dish. While it has been proven that Yagi antennas are capable of making EME QSOs at 1296 MHz, Yagi antennas, whether they use rod or loop elements, are simply not practical.

EME QSOs have been made at 1296 MHz with dishes as small as 6 ft in diameter. For reliable EME operation with similarly equipped stations, a 12-ft diameter dish (31 dBi gain at 1296 MHz) is a practical minimum. TVRO dishes, which are designed to operate at 3 GHz make excellent antennas, provided they have an accurate surface area. The one drawback of TVRO dishes is that they usually have an undesirable F/d ratio. More information on dish construction and feeds can be found in *The ARRL Antenna Book* and *The ARRL UHF/Microwave Experimenter's Manual*.

POLARIZATION EFFECTS

All of the close attention paid to operating at the best time, such as nighttime perigee, with high moon declination and low sky temperatures is of little use if signals are not aligned in polarization between the two stations attempting to make contact. There are two basic polarization effects. The first is called spatial polarization. Simply stated, two stations (using az-el mounts and fixed linear polarization) that are located far apart, will usually not have their arrays aligned in polarization as seen by the moon. Spatial polarization can easily be predicted, given the location of both stations and the position of the moon.

The second effect is Faraday rotation. This is an actual rotation of the radio waves in space, and is caused by the charge level of the Earth's ionosphere. At 1296 MHz and above, Faraday rotation is virtually nonexistent. At 432 MHz, it is believed that up to a 360° rotation is common. At 144 MHz, it is believed that the wavefront can actually rotate seven or more complete 360° revolutions. When Faraday rotation is combined with spatial polarization, there are four possible results:

1) Both stations hear each other and can QSO.

2) Station A hears station B, station B does not hear station A.

3) Station B hears station A, station A does not hear station B.

4) Neither station A nor station B hear each other.

At 144 MHz, there are so many revolutions of the signal, and the amount of Faraday rotation changes so fast that, generally, hour-long schedules are arranged. At 432 MHz, Faraday rotation can take hours to change. Because of this, half-hour schedules are used. During the daytime, you can count on 90 to 180° of rotation. If both stations are operating during hours of darkness, there will be little Faraday rotation, and the amount of spatial polarization determines if a schedule should be attempted.

At 1296 MHz and above, circular polarization is standard. The predominant array is a parabolic reflector, which makes circular polarization easy to obtain. Although the use of circular polarization would make one expect signals to be constant, except for the effect of the moon's distance, long-term fading of 6 to 9 dB is frequently observed.

With improved long-Yagi designs, for years the solution to overcoming polarization misalignment has been to make the array larger. Making your station's system gain 5 or 6 dB greater than required for minimal EME QSOs will allow you to work more stations, simply by moving you farther down the polarization loss curve. After about 60° of misalignment, however, making your station large enough to overcome the added losses quickly becomes a lifetime project! See **Fig 23.69**.

At 432 MHz and lower, Yagis are widely used, making the linear polarization standard. Although circular polarization may seem like a simple solution to polarization problems, when signals are reflected off the moon, the polarization sense of circularly polarized radio wave is reversed, requiring two arrays of opposite polarization sense be used. Initially, crossed Yagis with switchable polarization may also look attractive. Unfortunately, 432-MHz Yagis are physically small enough that the extra feed lines and switching devices become complicated, and usually adversely affect array performance. Keep in mind that even at 144 MHz, Yagis cannot tolerate metal mounting masts and frames in line with the Yagi elements.

When starting out on EME, keep in mind that it is best to use a simple system. You will still be able to work many of the larger fixed-polarization stations and those who have polarization adjustment (only one station needs to have polarization control). Once you gain understanding and confidence in your simple array, a more complex array such as one with polarization rotation can be attempted.

RECEIVER REQUIREMENTS

A low-noise receiving setup is essential for successful EME work. Many EME signals are barely, but not always, out of the noise. To determine actual receiver performance, any phasing line and feed line losses, along with the noise generated in the receiver, must be added to the array noise reception. When all losses are considered, a system noise figure of 0.5 dB (35 K) will deliver about all the performance that can be used at 144 MHz, even when low-loss phasing lines and a quiet array are used.

The sky noise at 432 MHz and above is low enough (cold sky is <15 K (kelvins) at 432 MHz, and 5 K at 1296 MHz) so the lowest possible noise figure is desired. Current high-performance arrays will have array temperatures near 30 K when unwanted noise pickup is added in. Phasing line losses must also be included, along with any relay losses. Even at 432 MHz, it is impossible to make receiver noise insignificant without the use of a liquid-cooled preamplifier. Current technology gives a minimum obtainable GaAsFET preamplifier noise figure, at room temperature, of about 0.35 dB (24 K).

GaAsFET preamps have also been standard on 1296 MHz and above for several years. Noise figures range from about 0.4 dB at 1296 MHz (30 K) to about 2 dB (170 K at 10 GHz). HEMT devices are now available to amateurs, but are of little use below 902 MHz because of 1/f noise. At higher frequencies, HEMT devices have already shown impressively low noise figures. Current HEMT devices are capable of noise figures close to 1.2 dB at 10 GHz (93 K) without liquid cooling.

At 1296 MHz, a new noise-limiting factor appears. The physical temperature of the moon is 210 K. This means that just like the Earth, it is a black-body radiator. The additional noise source is the reflection of sun noise off the moon. Just as a full moon reflects sunlight to Earth, the rest of the electromagnetic spectrum is also reflected. On 144 and 432 MHz, the beamwidth of a typical array is wide enough (15° is typical for 144 MHz, 7° for 432 MHz) that the moon, which subtends a 0.5° area is small enough to be insignificant in the array's pattern. At 1296 MHz, beamwidths approach 2°, and moon-noise figures of up to 5 dB are typical at full moon. Stations operating at 2300 MHz and above have such narrow array patterns that many operators actually use moon noise to assure that their arrays are pointed at the moon!

A new weak-signal operator is encouraged to experiment with receivers and filters. A radio with passband tuning or IF-shift capability is desired. These features are used to center the passband and the pitch of the CW signal to the frequency at which the operator's ears perform best. Some operators also use audio filtering. Audio filtering is effective in eliminating high-frequency noise generated in the radio's audio or IF stages. This noise can be very fatiguing during extended weak signal operation. The switched-capacitor audio filter has become popular with many operators.

TRANSMITTER REQUIREMENTS

Although the maximum legal power (1500 W out) is desirable, the actual power required can be considerably less, depending on the frequency of operation and size of the array. Given the minimum array gain requirements previously discussed, the power levels recommended for reasonable success are shown in **Table 23.4**

The amplifier and power supply should be constructed with adequate cooling and safety margins to allow extended slow-speed CW operation without failure. The transmitter must also be free from drift and chirp. The CW note must be pure and properly shaped. Signals that drift and chirp are harder to copy. They are especially annoying to operators who use narrow CW filters. A stable, clean signal will improve your EME success rate.

Table 23.4

Transmitter Power Required for EME Success

Power at the array	
50 MHz	1500 W
144 MHz	1000 W
222 MHz	750 W
432 MHz	500 W
902 MHz	200 W
1296 MHz	200 W
2300 MHz and above	100 W

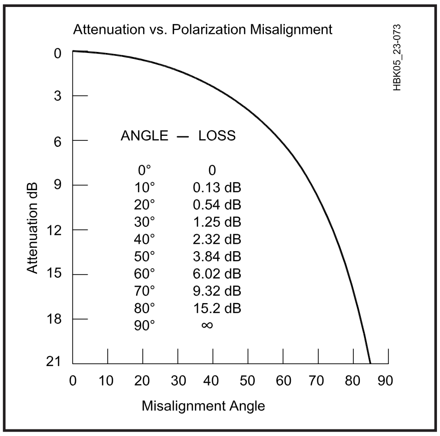

Fig 23.69—The graph shows how quickly loss because of polarization misalignment increases after 45°. The curve repeats through 360°, showing no loss at 0° and maximum loss at 90° and 270°.

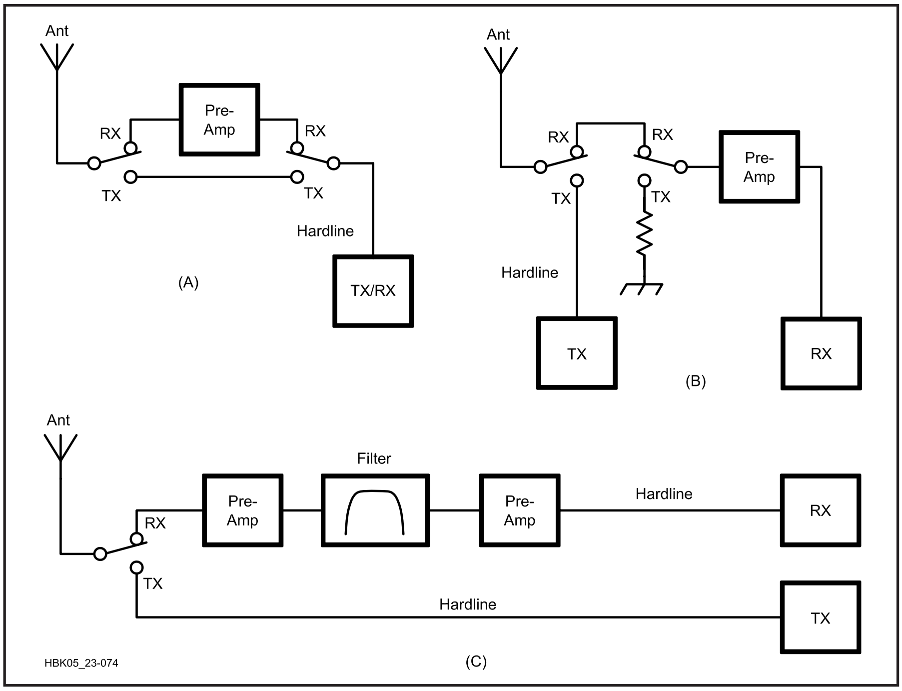

Fig 23.70—Two systems for switching a preamplifier in and out of the receive line. At A, a single length of cable is used for both the transmit and receive line. At B is a slightly more sophisticated system that uses two separate transmission lines. At C, a high-isolation relay is used for TR switching. The energized position is normally used on receive.

CALCULATING EME CAPABILITIES

Once all station parameters are known, the expected strength of the moon echoes can be calculated given the path loss for the band in use (see Fig 23.72). The formula for the received signal-to-noise ratio is:

$$S / N = P_o - L_t + G_t - P_l + G_r - P_n \qquad (1)$$

where

P_o = transmitter output power (dBW)
L_t = transmitter feed-line loss (dB)
G_t = transmitting antenna gain (dBi)
P_l = total path loss (dB)
G_r = receiving antenna gain (dBi)
P_n = receiver noise power (dBW).

Receiver noise power, P_n, is determined by the following:

$$P_n = 10 \log_{10} KBT_s \qquad (2)$$

where

$K = 1.38\times10^{-23}$ (Boltzmann's constant)
B = bandwidth (Hz)
T_s = receiving system noise temperature (K).

Receiving system noise temperature, T_s, can be found from:

$$T_s = T_a + (L_r - 1)\,T_1 + L_r\,T_r \qquad (3)$$

where

T_a = antenna temperature (K)
L_r = receiving feed-line loss (ratio)
T_1 = physical temperature of feed line (normally 290 K)
T_r = receiver noise temperature (K).

An example calculation for a typical 432-MHz EME link is:

P_o = +30 dBW (1000 W)
L_t = 1.0 dB
G_t = 26.4 dBi (8 × 6.1-λ 22-el Yagis)
P_l = 262 dB
G_r = 23.5 dBi (15 ft parabolic)
T_a = 60 K
L_r = 1.02 (0.1-dB preamp at antenna)
T_1 = 290 K
T_r = 35.4 K (NT = 0.5 dB)
T_s = 101.9 K
P_n = –188.5 dB
S/N = + 5.4 dB

It is obvious that EME is no place for a compromise station. Even relatively sophisticated equipment provides less-than-optimum results.

Fig 23.71 gives parabolic dish gain for a perfect dish. The best Yagi antennas will not exceed the gain curve shown in the **Antennas** chapter. If you are using modern, log-taper Yagis, properly spaced, figure about 2.8 to 2.9 dB of stacking gain. For old-technology Yagis, 2.5 dB may be closer to reality. Any phasing line and power divider losses must also be subtracted from the array gain.

LOCATING THE MOON

The moon orbits the Earth once in approximately 28 days, a lunar month. Because the plane of the moon's orbit is tilted from the Earth's equatorial plane by approximately 23.5°, the moon swings in a sine-wave pattern both north and south of the equator. The angle of departure of the moon's position at a given time from the equatorial plane is termed declination (abbreviated decl). Declination angles of the moon, which are continually changing (a few degrees a day), indicate the latitude on the Earth's surface where the moon will be at zenith. For this presentation, positive declination angles are used when the moon is north of the equator, and negative angles when south.

The longitude on the Earth's surface where the moon will be at zenith is related to the moon's Greenwich Hour Angle, abbreviated G.H.A. or GHA. "Hour angle" is defined as the angle in degrees to the west of the meridian. If the GHA of the moon were 0°, it would be directly over the Greenwich meridian. If the moon's GHA were 15°, the moon would be directly over the meridian designated as 15° W longitude on a globe. As one can readily understand, the GHA of the moon is continually changing, too, because of both the orbital velocity of the moon and the Earth's rotation inside the moon's orbit. The moon's GHA changes at the rate of approximately 347° per day.

GHA and declination are terms that may be applied to any celestial body. *The Astronomical Almanac* (available from the Superintendent of Documents, US Government Printing Office) and other publications list the GHA and decl of the sun and moon (as well as for other celestial bodies that may be used for navigation) for every hour of the year. This information may be used to point an antenna when the moon is not visible. *Almanac* tables for the sun may be useful for calibrating remote-readout systems.

Using the Almanac

The Astronomical Almanac and other almanacs show the GHA and declination of the sun or moon at hourly intervals for every day of the period covered by the book. Instructions are included in such books for interpolating the positions of the sun or moon for any time on a given date. The orbital velocity of the moon is not constant, and therefore precise interpolations are not linear.

Fortunately, linear interpolations from one hour to the next, or even from one day to the next, will result in data that is entirely adequate for Amateur Radio purposes. If linear interpolations are made from 0000 UTC on one day to 0000 UTC on the next, worse-case conditions exist when apogee or perigee occurs near midday on the next date in question. Under such conditions, the total angular error in the position of the moon may be as much as a sixth of a degree. Because it takes a full year for the Earth to orbit the sun, the similar error for determining the position of the sun will be no more than a few hundredths of a degree.

If a polar mount (a system having one axis parallel to the Earth's axis) is used, information from the *Almanac* may be used directly to point the antenna array. The local hour angle (LHA) is simply the GHA plus or minus the observer's longitude (plus if east longitude, minus if west). The LHA is the angle west of the observer's meridian at which the celestial body is located. LHA and declination information may be translated to an EME window by taking local obstructions and any other constraints into account.

Azimuth and Elevation

An antenna system that is positioned in azimuth (compass direction) and elevation (angle above the horizon) is called an *az-el* system. For such a system, some additional work will be necessary to convert the almanac data into useful information. The GHA and decl information may be converted into azimuth and elevation angles with the mathematical equations that follow. A calculator or computer that treats trigonometric functions may be used. *CAUTION:* Most almanacs list data in degrees, minutes, and either decimal minutes or seconds. Generally, computer programs have typically required this information in degrees and decimal fractions, so a conversion may be necessary before the almanac data is entered.

Determining az-el data from equations follows a procedure similar to calculating great-circle bearings and distances for two points on the Earth's surface. There is one additional factor, however. Visualize two observers on opposite sides of the Earth who are pointing their antennas at the moon. Imaginary lines representing the boresights of the two antennas will converge at the moon at an angle of approximately 2°. Now assume both observers aim their antennas at some distant star. The boresight lines now may be consid-

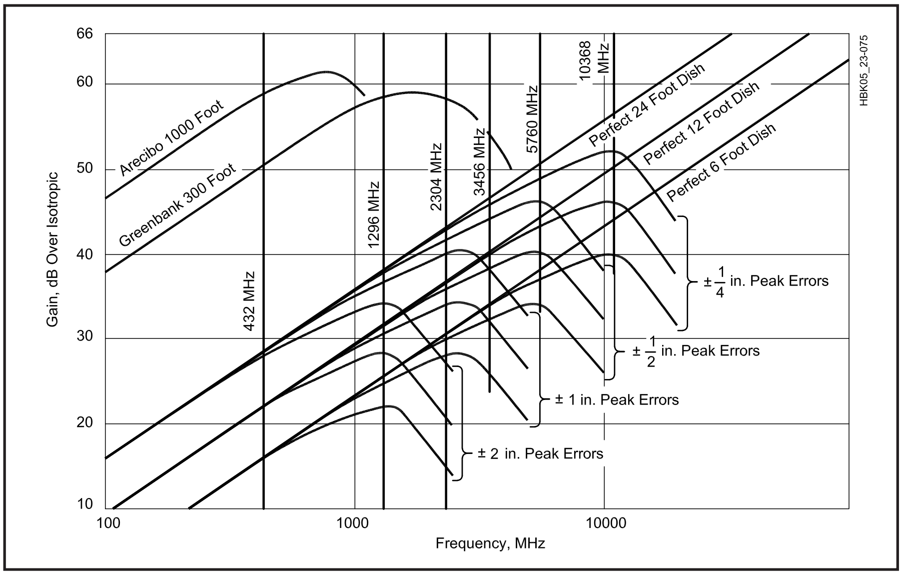

Fig 23.71—Parabolic-antenna gain vs size, frequency and surface errors. All curves assumed 60% aperture efficiency and 10-dB power taper. Reference: J. Ruze, British IEEE.

ered to be parallel, each observer having raised his antenna in elevation by approximately 1°. The reason for the necessary change in elevation is that the Earth's diameter in comparison to its distance from the moon is significant. The same is not true for distant stars, or for the sun.

Equations for az-el calculations are:

$$\sin E = \sin L \sin D + \cos L \cos D \cos LHA \tag{4}$$

$$\tan F = \frac{\sin E - K}{\cos E} \tag{5}$$

$$\cos C = \frac{\sin D - \sin E \sin L}{\cos E \cos L} \tag{6}$$

where

E = elevation angle for the sun
L = your latitude (negative if south)
D = declination of the celestial body
LHA = local hour angle = GHA plus or minus your longitude (plus if east longitude, minus if west longitude)
F = elevation angle for the moon
K = 0.01657, a constant (see text that follows)
C = true azimuth from north if sin LHA is negative; if sin LHA is positive, then the azimuth = 360 – C.

Assume our location is 50° N latitude, 100° W longitude. Further assume that the GHA of the moon is 140° and its declination is 10°. To determine the az-el information we first find the LHA, which is 140 minus 100 or 40°. Then we solve equation 4:

$$\sin E = \sin 50 \sin 10 + \cos 50 \cos 10 \cos 40$$
$$\sin E = 0.61795 \text{ and } E = 38.2^\circ$$

Solving equation 5 for F, we proceed. (The value for sin E has already been determined in equation 4.)

$$\tan F = \frac{0.61795 - 0.06175}{\cos 38.2}$$
$$= 0.76489$$

From this, F, the moon's elevation angle, is 37.4°.

We continue by solving equation 6 for C. (The value of sin E has already been determined.)

$$\cos C = \frac{\sin 10 - 0.61795 \sin 50}{\cos 38.2 \cos 50}$$

C therefore equals 126.4°. To determine if C is the actual azimuth, we find the polarity for sin LHA, which is sin 40° and has a positive value. The actual azimuth then is 360 – C = 233.6°.

If az-el data is being determined for the sun, omit equation 5; equation 5 takes into account the nearness of the moon. The solar elevation angle may be determined from equation 4 alone. In the above example, this angle is 38.2°.

The mathematical procedure is the same for any location on the Earth's surface. Remember to use negative values for southerly latitudes. If solving equation 4 or 5 yields a negative value for E or F, this indicates the celestial body below the horizon.

These equations may also be used to determine az-el data for man-made satellites, but a different value for the constant, K, must be used. K is defined as the ratio of the Earth's radius to the distance from the Earth's center to the satellite.

The value for K as given above, 0.01657 is based on an average Earth-moon distance of 239,000 miles. The actual Earth-moon distance varies from approximately 225,000 to 253,000 mi. When this change in distance is taken into account, it yields a change in elevation angle of approximately 0.1° when the moon is near the horizon. For greater precision in determining the correct elevation angle for the moon, the moon's distance from the Earth may be taken as:

$$D = -15{,}074.5 \times SD + 474{,}332$$

where

D = moon's distance in miles
SD = moon's semi-diameter, from the almanac.

Computer Programs

Digital modes are also used for EME communications. The *WSJT* software for *Windows* includes a mode known as JT44. This software enables moonbounce contacts using sound-card-equipped PCs, single Yagi antennas and under 200 watts of RF—an accomplishment that seemed virtually impossible in previous years. It now appears possible that this mode, and other digital modes that may appear in the future, will place EME communication within reach of hams with both modest antenna space and budgets. Complete details and operating instructions can be viewed by downloading the *WSJT User Guide* at **pulsar.princeton.edu/~joe/K1JT/WSJT300.PDF**.

As has been mentioned, a computer may be used in solving the equations for azimuth and elevation. For EME work, it is convenient to calculate az-el data at 30-minute intervals or so, and to keep the results of all calculations handy during the EME window. Necessary antenna-position corrections can then be made periodically.

RealTrak prints out antenna azimuth and elevation headings for nearly any celestial object. It can be used with the Kansas City Tracker program described in the satellite section to track celestial objects automatically. *VHF PAK* provides real-time moon and celestial object position information. Two other real-time tracking programs are *EME Tracker* and the *VK3UM EME Planner*.

Libration Fading of EME Signals

One of the most troublesome aspects of

receiving a moonbounce signal, besides the enormous path loss and Faraday rotation fading, is libration fading. This section will deal with libration (pronounced *lie-brayshun*) fading, its cause and effects, and possible measures to minimize it.

Libration fading of an EME signal is characterized in general as fluttery, rapid, irregular fading not unlike that observed in tropospheric scatter propagation. Fading can be very deep, 20 dB or more, and the maximum fading will depend on the operating frequency. At 1296 MHz the maximum fading rate is about 10 Hz, and scales directly with frequency.

On a weak CW EME signal, libration fading gives the impression of a randomly keyed signal. In fact on very slow CW telegraphy the effect is as though the keying is being done at a much faster speed. On very weak signals only the peaks of libration fading are heard in the form of occasional short bursts or "pings."

Fig 23.72 shows samples of a typical EME echo signal at 1296 MHz. These recordings, made at W2NFA, show the wild fading characteristics with sufficient S/N ratio to record the deep fades. Circular polarization was used to eliminate Faraday fading; thus these recordings are of libration fading only. The recording bandwidth was limited to about 40 Hz to minimize the higher sideband-frequency components of libration fading that exist but are much smaller in amplitude. For those who would like a better statistical description, libration fading is Raleigh distributed. In the recordings shown in Fig 23.72, the average signal-return level computed from path loss and mean reflection coefficient of the moon is at about the +15 dB S/N level.

It is clear that enhancement of echoes far in excess of this average level is observed. This point should be kept clearly in mind when attempting to obtain echoes or receive EME signals with marginal equipment. The probability of hearing an occasional peak is quite good since random enhancement as much as 10 dB is possible. Under these conditions, however, the amount of useful information that can be copied will be near zero. Enthusiastic newcomers to EME communications will be stymied by this effect since they know they can hear the signal strong enough on peaks to copy but can't make any sense out of what they try to copy.

What causes libration fading? Very simply, multipath scattering of the radio waves from the very large (2000-mile diameter) and rough moon surface combined with the relative motion between Earth and moon called librations. To understand these effects, assume first that the Earth and moon are stationary (no libration) and that a plane wave front arrives at the moon from your Earthbound station as shown in **Fig 23.73A**.

The reflected wave shown n Fig 23.73B consists of many scattered contributions from the rough moon surface. It is perhaps easier to visualize the process as if the scattering were from many small individual flat mirrors on the moon that reflect small portions (amplitudes) of the incident wave energy in different directions (paths) and with different path lengths (phase). Those paths directed toward the moon arrive at your antenna as a collection of small wave fronts (field vectors) of various amplitudes and phases. The vector summation of all these coherent (same frequency) returned waves (and there is a near-infinite array of them) takes place at the feed point of your antenna (the collecting point in your antenna system). The level of the final summation as measured by a receiver can, of course, have any value from zero to some maximum. Remember that we assumed the Earth and moon were stationary, which means that the final summation of these multipath signal returns from the moon will be one fixed value. The condition of zero relative motion between Earth and moon is a rare event that will be discussed later in this section.

Consider now that the Earth and moon are moving relative to each other (as they are in nature), so the incident radio wave "sees" a slightly different surface of the moon from moment to moment. Since the lunar surface is very irregular, the reflected wave will be equally irregular, changing in amplitude and phase from moment to moment. The resultant continuous summation of the varying multipath signals at your antenna feed-point produces the effect called libration fading of the moon-reflected signal.

The term *libration* is used to describe small perturbations in the movement of celestial bodies. Each libration consists mainly of its diurnal rotation; moon libration consists mainly of its 28-day rotation which appears as a very slight rocking motion with respect to an observer on Earth. This rocking motion can be visualized as follows: Place a marker on the surface of the moon at the center of the moon disc, which is the point closest to the observer, as shown in **Fig 23.74**. Over time, we will observe that this marker wanders around within a small area. This means the surface of the moon as seen from the Earth is not quite fixed but changes slightly as different areas of the periphery are exposed because of this rocking motion. Moon libration is very slow (on the order of 10^{-7} radians per second) and can be determined with some difficulty from pub-

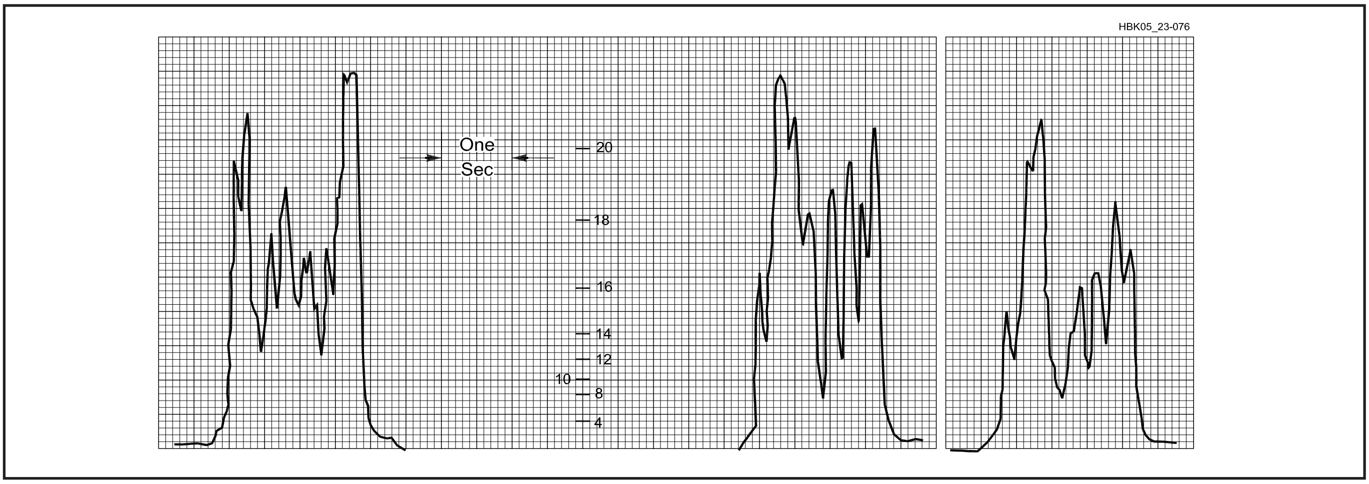

Fig 23.72—Chart recording of moon echoes received at W2NFA on July 26, 1973, at 1630 UTC. Antenna gain 44 dBi, transmitting power 400 W and system temperature 400 K.

lished moon ephemeris tables.

Although the libration motions are very small and slow, the larger surface area of the moon has nearly an infinite number of scattering points (small area). This means that even slight geometric movements can alter the total summation of the returned multipath echo by a significant amount. Since the librations of the Earth and moon are calculable, it is only logical to ask if there ever occurs a time when the total libration is zero or near zero. The answer is yes, and it has been observed and verified experimentally on radar echoes that minimum fading rate (not depth of fade) is coincident with minimum total libration. Calculation of minimum total libration is at best tedious and can only be done successfully by means of a computer. It is a problem in extrapolation of rates of change in coordinate motion and in small differences of large numbers.

EME OPERATING TECHNIQUES

Many EME signals are near the threshold of readability, a condition caused by a combination of path loss, Faraday rotation and libration fading. This weakness and unpredictability of the signals has led to the development of techniques for the exchange of EME information that differ from those used for normal terrestrial work. The fading of EME signals chops dashes into pieces and renders strings of dots incomplete. This led to the use of the "T M O R" reporting system. Different, but similar, systems are used on the low bands (50 and 144 MHz) and the high bands (432 MHz and above). **Tables 23.5** and **23.6** summarize the differences between the two systems.

As equipment and techniques have improved, the use of normal RST signal reports has become more common. It is now quite common for two stations working for the first time to go straight to RST reports if signals are strong enough. These normal reports let stations compare signals from one night to the next. EME QSOs are often made during the ARRL VHF contests. These contacts require the exchange of 4-digit grid locators. On 432 MHz and above, the sending of GGGG has come to mean "Please send me your grid square," or conversely, "I am now going to send my grid square."

The length of transmit and receive periods is also different between the bands. On 50 and 144 MHz, 2-minute sequences are used. That is, stations transmit for two full minutes, and then receive for two full minutes. One-hour schedules are used, with the eastern-most station (referenced to the international date line) transmitting first. **Table 23.7** gives the 2-minute sequence procedure. On 222 MHz, both the 144 and 432-MHz systems are used.

Table 23.5

Signal Reports Used on 144-MHz EME

T — Signal just detectable
M — Portions of call copied
O — Complete call set has been received
R — Both "O" report and call sets have been received
SK — End of contact

Table 23.6

Signal Reports Used on 432-MHz EME

T — Portions of call copied
M — Complete calls copied
O — Good signal—solid copy (possibly enough for SSB work)
R — Calls and reports copied
SK — End of contact

On 432 MHz and above, 2½-minute sequences are standard.

The longer period is used to let stations with variable polarization have adequate time to peak the signal. The last 30 seconds is reserved for signal reports only. **Table 23.8** provides more information on the 432-MHz EME QSO sequence. The western-most station usually transmits first. However, if one of the stations has variable polarization, it may elect to transmit second, to take the opportunity to use the first sequence to peak the signal. If both stations have variable polarization, the station that transmits first should leave its polarization fixed on transmit, to avoid "polarization chasing."

CW sending speed is usually in the 10 to 13-wpm range. It is often best to use greater-than-normal spacing between individual dits and dahs, as well as between complete letters. This helps to overcome libration fading effects. The libration fading rate will be different from one band to another. This makes the optimum CW speed for one band different from another. Keep in mind that characters sent too slowly will be chopped up by typical EME fading. Morse code sent too fast will simply be jumbled. Pay attention to the sending practices of the more successful stations, and try to emulate them.

Doppler shift must also be understood. As the moon rises or sets it is moving toward or away from objects on Earth. This leads to a frequency shift in the moon echoes. The amount of Doppler shift is directly proportional to frequency. At 144 MHz, about 500 Hz is the maximum shift. On 432 MHz, the maximum shift is 1.5 kHz. The shift is upward on moonrise and downward on moonset. When the moon is due south, your own echoes will have no Doppler shift, but stations located far away will still be affected. For scheduling, the accepted practice is to transmit zero beat on the schedule frequency, and tune to compensate for the Doppler shift. Be careful—most transmitters and transceivers have a built-in CW offset. Some radios read this offset when transmitting, and others don't. Find out how your transmitter operates and compensate as required.

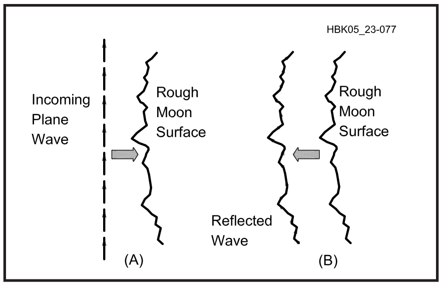

Fig 23.73— How the rough surface of the moon reflects a plane wave as one having many field vectors.

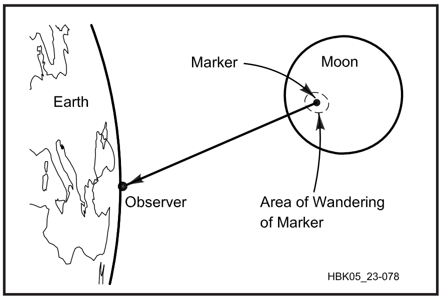

Fig 23.74— The moon appears to "wander" in its orbit about the Earth. Thus a fixed marker on the moon's surface will appear to move about in a circular area.

Random operation has become popular in recent years. In the ARRL EME contest, many of the big guns will not even accept schedules during the contest periods, because they can slow down the pace of their contest contacts.

EME Operating Times

Obviously, the first requirement for EME operation is to have the moon visible by both EME stations. This requirement not only consists of times when the moon is above the horizon, but when it is actually clear of obstructions such as trees and buildings. It helps to know your exact EME operating window, specified in the form of beginning and ending GHAs (Greenwich

Table 23.7

144-MHz Procedure — 2-Minute Sequence

Period	$1\frac{1}{2}$ minutes	30 seconds
1	Calls (W6XXX DE W1XXX)	
2	W1XXX DE WE6XXX	TTTT
3	W6XXX DE W1XXX	OOOO
4	RO RO RO RO	DE W1XXX K
5	R R R R R R	DE W6XXX K
6	QRZ? EME	DE W1XXX K

Table 23.8

432-MHz Procedure — 2½-Minute Sequence

Period	2 minutes	30 seconds
1	VE7BBG DE K2UYH	
2	K2UYH DE VE7BBG	
3	VE7BBG DE K2UYH	TTT
4	K2UYH DE VE7BBG	MMM
5	RM RM RM RM	DE K2UYH K
6	R R R R R	DE VE7BBG $\overline{\text{SK}}$

Hour Angle) for different moon declinations. This information allows two different stations to quickly determine if they can simultaneously see the moon.

Once your moon window is determined, the next step is to decide on the best times during that window to schedule or operate. Operating at perigee is preferable because of the reduced path loss. Fig 23.68 shows that not all perigees are equal. There is about a 0.6-dB difference between the closest and farthest perigee points. The next concern is operating when the moon is in a quiet spot of the sky. Usually, northern declinations are preferred, as the sky is quietest at high declinations. If the moon is too close to the sun, your array will pick up sun noise and reduce the sensitivity of your receiver. Finally, choosing days with minimal libration fading is also desirable.

Perigee and apogee days can be determined from the *Astronomical Almanac* by inspecting the tables headed "S.D." (semidiameter of the moon in minutes of arc). These semi-diameter numbers can be compared to Fig 23.68 to obtain the approximate moon distance. Many computer programs for locating the moon now give the moon's distance. The expected best weekends to operate on 432 MHz and the higher bands are normally printed well in advance in various EME newsletters.

When the moon passes through the galactic plane, sky temperature is at its maximum. Even on the higher bands this is one of the least desirable times to operate. The areas of the sky to avoid are the constellations of Orion and Gemini (during northern declinations), and Sagittarius and Scorpios (during southern declinations). The position of the moon relative to these constellations can be checked with information supplied in the *Astronomical Almanac* or *Sky and Telescope* magazine.

Frequencies and Scheduling

According to the ARRL-sponsored band plan, the lower edge of most bands is reserved for EME operation. On 144 MHz, EME frequencies are primarily between 144.000 and 144.080 MHz for CW, and 144.100 and 144.120 MHz for SSB. Random CW activity is usually between 144.000 and 144.020 MHz. In the US, 144.000 to 144.100 MHz is a CW subband, so SSB QSOs often take place by QSYing up 100 kHz after a CW contact has been established. Because of the large number of active 144-MHz stations, coordinating schedules in the small EME window is not simple. The more active stations usually have assigned frequencies for their schedules.

On 432 MHz, the international EME CW calling frequency is 432.010 MHz. Random SSB calling is done on 432.015 MHz. Random activity primarily takes place between 432.000 and 432.020 MHz. The greater Doppler shift on 432 MHz requires greater separation between schedule frequencies than on 144 MHz. Normally 432.000 MHz, 432.020 MHz and each 5-kHz increment up to 432.070 MHz are used for schedules.

Activity on 1296 MHz is centered between 1296.000 and 1296.040 MHz. The random calling frequency is 1296.010 MHz. Operation on the other bands requires more specific coordination. Activity on 33 cm is split between 902 and 903 MHz. Activity on 2300 MHz has to accommodate split-band procedures because of the different band assignments around the world.

EME Net Information

An EME net meets on 14.345 MHz on weekends for the purpose of arranging schedules and exchanging EME information. The net meets at 1600 UTC. OSCAR satellites are becoming more popular for EME information exchange. When Mode B is available, a downlink frequency of 145.950 MHz is where the EME group gathers. On Mode L and Mode JL, the downlink frequency is 435.975 MHz.

Other Modes

Most EME contacts are still made on CW, although SSB has gained in popularity and it is now common to hear SSB QSOs on any activity weekend. The ability to work SSB can easily be calculated from Eq 1. The proper receiver bandwidth (2.3 kHz) is substituted. SSB usually requires a +3-dB signal-to-noise ratio, whereas slow-speed CW contacts can be made with a 0-dB signal-to-noise ratio. Slow-scan television and packet communication has been attempted between some of the larger stations. Success has been limited because of the greater signal-to-noise ratios required for these modes, and severe signal distortion from libration fading.