COMMUNICATIONS QUARTERLY

THE JOURNAL OF
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TECHNOLOGY

Spring 1995

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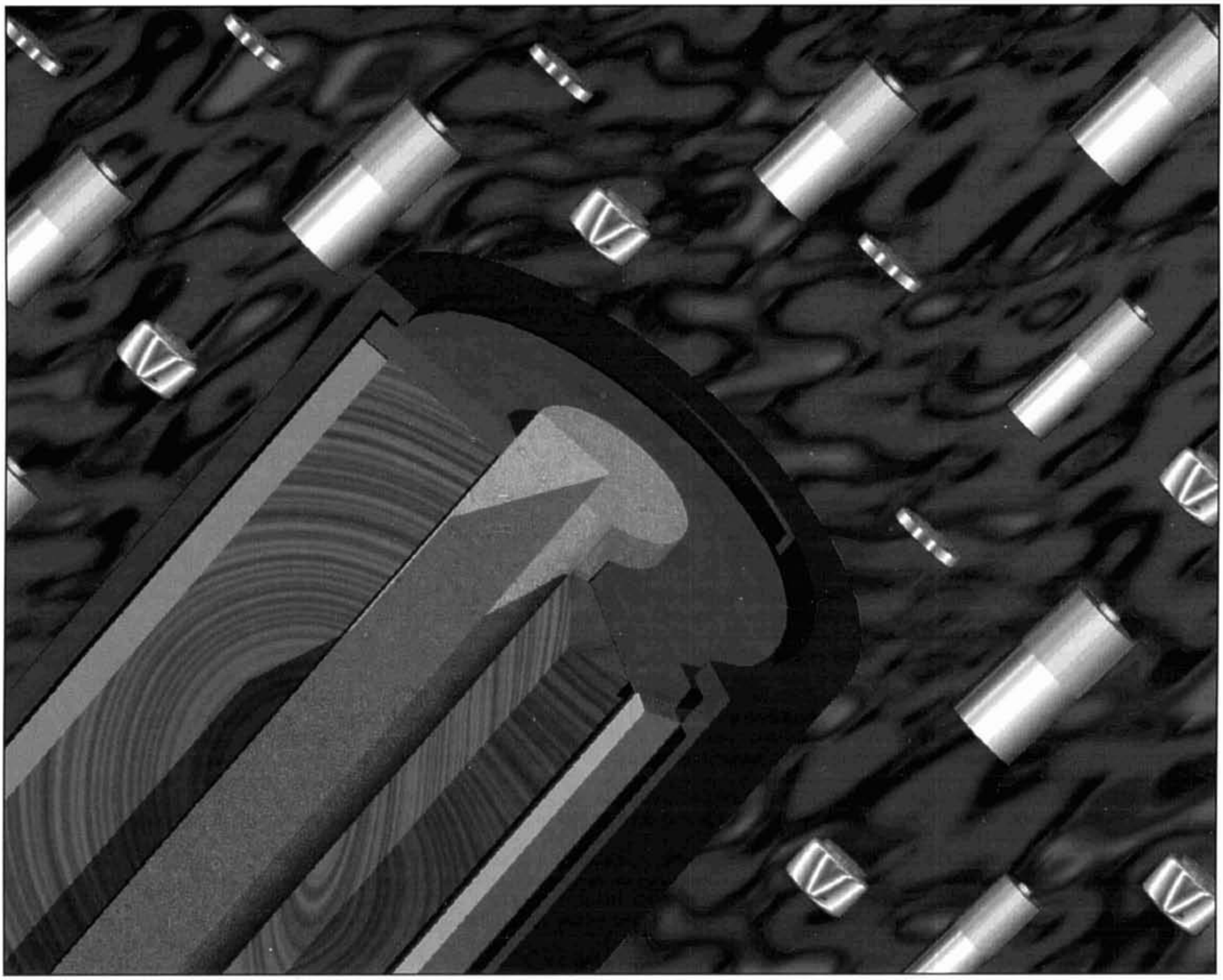

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The New Alinco DR-610T Dual Band Mobile Transceiver

Designed for convenience. The DR-610T's Channel Scope gives you visual monitoring capability to keep you engaged in local frequency activities. A built-in duplexer and a new remote mount system provide you with flexible installation options with a readily detachable front head, and the optional EDS-1 accessory junction box containing both separate microphone and external speaker jacks.

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To activate the Long Tone Zero (LITZ) emergency alert system, a repeater controller presses the touch tone "0" on his or her mic for a period longer than 3 seconds. The repeater will re-transmit this DTMF tone which will be decoded by the DR-610T's special LITZ decoder. A beep sound emits from the speaker repeatedly and the "Lit" icon will appear in the display until the station operator depresses any of the control panel keys.

Features

- Frequency Range
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- Transmit: 144.000 – 147.995 MHz (FM)
  438.000 – 449.995 MHz (FM)
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- Priority Function
- Mono Band Dual Receive(VxV) (UxU)
- 5 Channel Scope levels
- 50 CTCSS Tones, Encode standard, Decode available with the optional accessory EJ-24U Tone Squelch Unit.
- S-meter Squelch
- RF Attenuator
- APO (Automatic Power Off)
- TOT (Time Out Timer)
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- AM Aircraft RX Standard (No modification required)
- Full Duplex with odd split operation
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- Beep function
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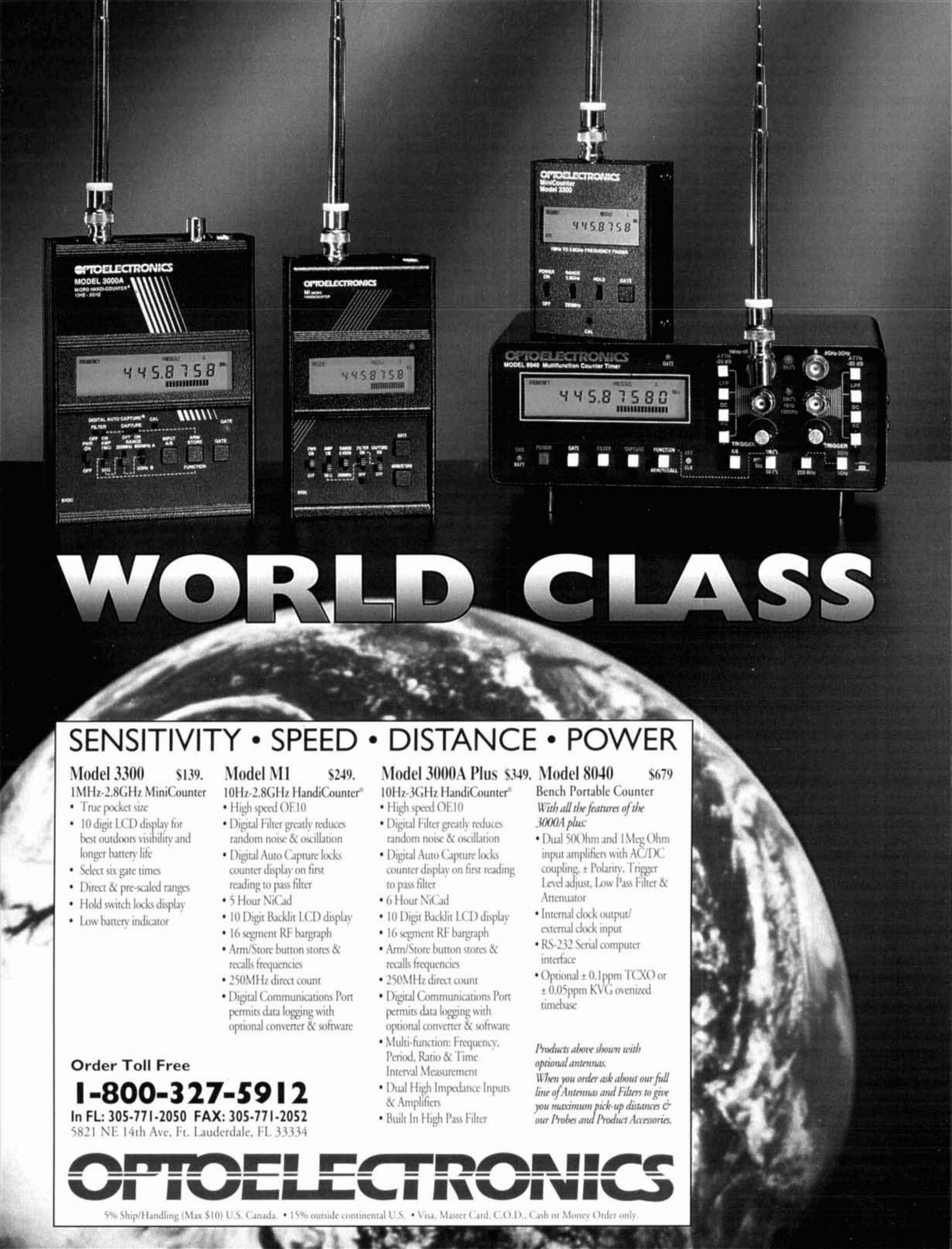
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COMMUNICATIONS QUARTERLY

THE JOURNAL OF COMMUNICATIONS TECHNOLOGY

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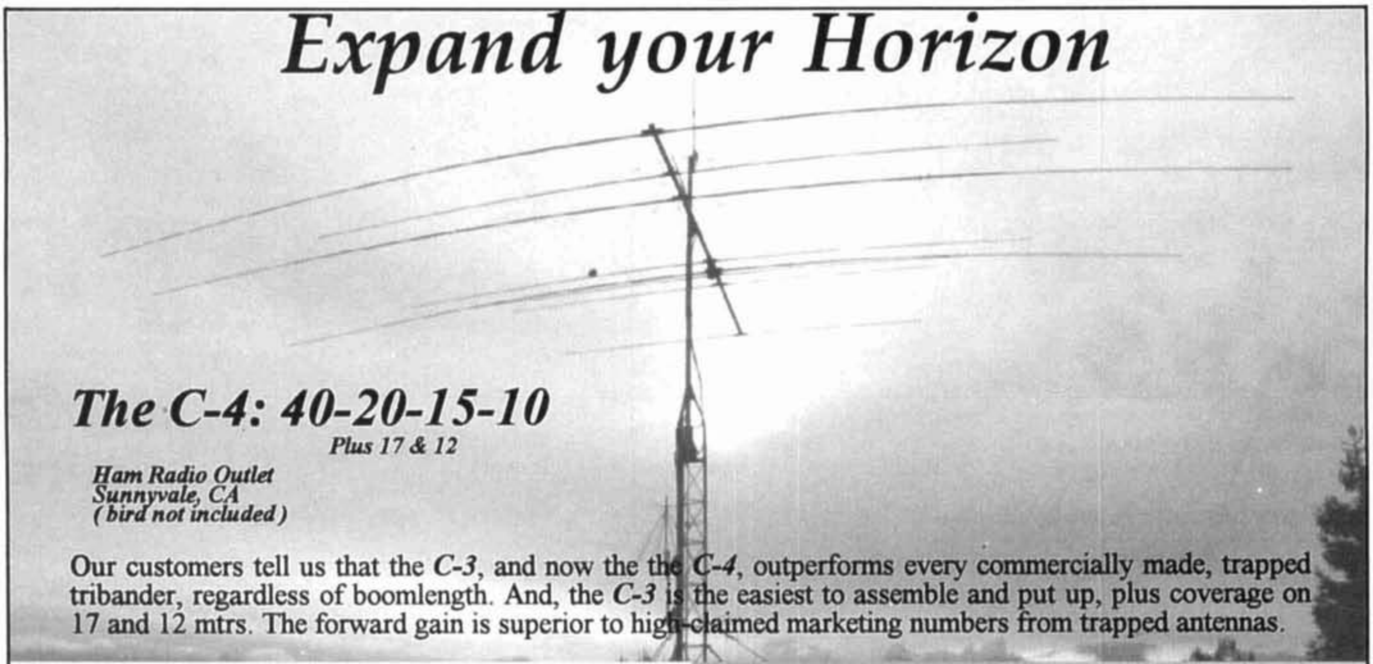
Taylor, page 81

Cover Photo: In this issue, we take an "inside" look at storage cell technology. To learn the particulars, see the article by Bryan Bergeron, NU1N, beginning on page 41. Photo by NU1N.

Expand your Horizon



The C-4: 40-20-15-10

Plus 17 & 12

Ham Radio Outlet
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(bird not included)

Our customers tell us that the *C-3*, and now the the *C-4*, outperforms every commercially made, trapped tribander, regardless of boomlength. And, the *C-3* is the easiest to assemble and put up, plus coverage on 17 and 12 mtrs. The forward gain is superior to high-claimed marketing numbers from trapped antennas.

That's why these antennas really "work."

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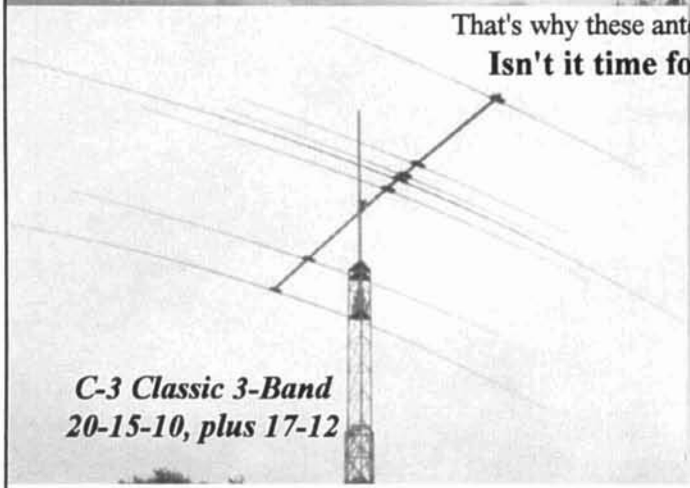

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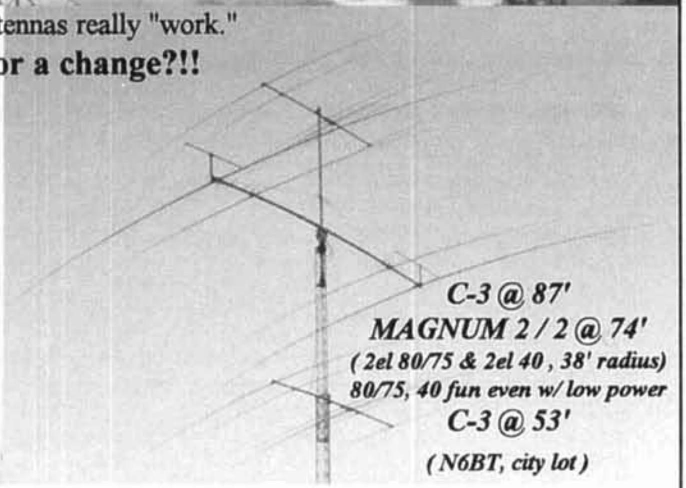
20-15-10, plus 17-12



C-3 @ 87'
MAGNUM 2 / 2 @ 74'
(2el 80/75 & 2el 40 , 38' radius)
80/75, 40 fun even w/ low power
C-3 @ 53'
(N6BT, city lot)

C-3 = No Traps = More QSO's + More 59&599's + 40 mtrs = C-4

You will be amazed at the improvement between the ***C-3*** and trapped antennas. The receiver will sparkle. Running barefoot will be fun. And now, the fantastic ***C-3*** performance has been extended to 40 meters. The ***C-4*** incorporates a re-designed EF-140S 40 mtr element on the standard ***C-3*** boom for more than 100 kHz 2:1 VSWR coverage on 40 mtrs. If you are presently enjoying the great performance of a ***C-3***, upgrade to a ***C-4!***

◆ The ***C-3*** : 7 elements: riveted and tapered for a low profile, pleasing look; 18' boom, 5.6 sqft, 32 pounds, Easy-On™ mount.

◆ The ***C-3*** has deep side nulls and a fine pattern; F/B 14-18 dB; fed with a single 50 ohm coax; 19.8' turning radius.

◆ The element-to-boom brackets are pre-aligned on the boom, so every element is straight and will not move.

◆ The ***C-4*** maintains the same turning radius, weighs about 40 pounds, with separate feedline so that the ***C-3*** remains intact.

◆ **Force 12** has more than 60 HF antennas from 3 el 80/75 mtr yagis to 6 mtr beams. The ***MAGNUM 2 / 2*** shown above is a 2el 80/75 and 2el 40 mtr on a single boom with two feedlines. The ***MAGNUM 2 / 2*** uses EF-180B (66.5') elements on 80/75 and EF-140 (44.5') elements on 40. At about 14 sqft, the ***MAGNUM 2 / 2*** is the answer to gain on both bands. Other 80/40 available.

◆ **Force 12** now offers **magnetic transmitting / receiving loops** for 40 and 80/75, perfect for limited space and **NVIS** use: the ***MTR-66*** (6'x6') and the ***MTR-618*** (6'x18'), both made with 2" tubing. These mount vertically on the ground, deck, balcony, etc.

◆ **Force 12** has verticals for 40, 80/75 and 160 mtrs. Add to this the several 20-40 yagis, the 40-30-20 yagi and multiple band antennas like the 5BA (20-10) and the 4BA (17-10). **Force 12** offers a pair of 50 ohm 1:1 baluns; fully tested and vacuum impregnated for reliability. The B-1 is rated at 3KW and the B-1/C commercial version with N-connector, rated at 25KW.

The C-3 is available at all 12 HAM RADIO OUTLET stores. List is $489.00. The C-4 lists at $649.00. Buy now & have fun!

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EDITORIAL

A Tale of New Receivers

Before the age of transceivers, the receiver was the centerpiece of most amateur stations. Receivers were judged by their size, the number of tubes they contained, and other physical attributes. Bigger was better—a massive appearance implied quality, stability, and other desirable qualities. As younger hams, many of us saved our paper route money and allowances in quest of the ideal and ultimate receiver to meet our amateur needs. My venerable Hallicrafters S-38, although long retired, still retains a prominent position in my ham shack as a powerful reminder of those simpler times.

As digital electronics and RF semiconductors came of age during the late '60s, receivers quickly adapted to the new technology. Digital readouts replaced the bulky and expensive mechanical drive mechanisms needed for accurate and repeatable dial calibration. Phase locked loop techniques replaced expensive banks of heterodyne crystals, and electronic tuning came of age. With the development of quality and inexpensive roofing filters in the lower VHF range, up conversion designs became the rage, and bulky tracking intermediate IF stages were eliminated. Now, direct digital synthesis techniques offer superior reciprocal noise performance and frequency agility undreamed of only a few short years ago.

Of course, the transition from vacuum to solid-state electronics wasn't always a smooth road. Many earlier solid-state receivers suffered from poor dynamic range and reciprocal mixing problems—minor setbacks that didn't slow the wheels of progress for long.

Because receiver technology holds a fascination for so many of us, I like to make sure *Communications Quarterly* presents articles on recent receiver design trends and innovations. Last year, Scott Prather, KB9Y, introduced us to the Drake R8. In this issue, he looks at the Watkins-Johnson HF-1000—in Scott's words, a milestone in communications receiver development.

The HF-1000 features digital signal processing (DSP) at the final IF frequency. Today, a quality SSB, AM, or CW crystal IF filter costs at least $100 each in small quantities. Outfitting a receiver with an array of filters to meet the needs of Amtor, CW, SSB, and AM under a variety of operating conditions is an expensive undertaking. Using DSP techniques at the IF frequency, Watkins-Johnson's new receiver offers 58 selectivity positions, from 56 Hz to 8 kHz, and optimum demodulation techniques for the mode of interest. Because DSP filtering is software driven, the receivers are easily reconfigurable and can be upgraded to meet future needs without adding expensive hardware.

So where do we go from here? The HF-1000 is currently the top-of-the-line, state-of-the-art general coverage receiver. It has all the bells and whistles a high-performance receiver needs. Is this as good as it gets?

For now, I'd have to say yes. However, when I first wrote this editorial I was eagerly awaiting the opportunity to review an even more revolutionary receiver. The ComFocus Softwave remote receiver was a simple black box, connected via an umbilical cord to a plug-in card in your 386 or better shack computer. The package also included the software needed to run the system. According to the advertisements, when turned on, your computer screen would be transformed into a virtual reality receiver front panel—the personality of which could quickly be changed to meet the operator's needs. Software would serve as an AM DX receiver, communications receiver, VHF receiver, time sync receiver, and wideband spectrum display. Optional software for receiving FAX, RTTY, and SSTV was under development.

But alas, before I could get my hands on this intriguing software-receiver combination, ComFocus went out of business leaving me drooling with anticipation and empty handed.

Computers are becoming an integral part of our ham stations—whether for packet cluster, DX, or contest logging, and the Softwave receiver would have been a natural extension of that which has gone before. But even though ComFocus wasn't able to bring its innovative idea to fruition, there's sure to be someone who will take over where they left off. With any luck, those behind Softwave will be able to regroup and return. In the meantime, there are still programs like HamWindows—an interactive software program that lets you perform such operations as building and controlling your own station; accessing a computerized station log, Grey Line Map, CIA World Fact Book, and SWL window; and enjoying a

(Continued on page 104)

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Powerful! Z-181 high integration MPU with one megabyte address space.

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Perfect Beginner's TNC! Every feature you would expect in an AX.25 1200 baud TNC, plus:

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APRS (Automatic Packet Reporting System) compatible **GPS** support built-in. Works with either the standard single serial port or the optional second serial port.

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Instruction manual, schematic, Quick Command listing, and power cord included.

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Full-time GPS port (2nd serial port) allows both a GPS and computer to be attached to the PicoPacket. The GPS port also provides a real-time clock and 128k RAM.

Built-in GPS receiver. The GPS model has a built-in Trimble SVeeSix-CM3 GPS receiver. Total size only 2 x 2.5 x 3.25 inches. Active external GPS antenna provided.

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Some models are scheduled for later introduction. Call for latest availability.

- PicoPacket w/32k RAM - $129
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- PicoPacket with 2nd serial port, 128k RAM, Real Time Clock - $189
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- PicoPacket Batterypack model with 128k RAM - $199
- PicoPacket Batterypack model with second serial port, 128k, RTC - $239
- PicoPacket/GPS. Same as model directly above plus internal GPS receiver and GPS antenna - $599
- Companion GPS receiver w/active antenna, data cable - $399
- Extra battery pack - $45

The new PacComm BayMod-9600 is the lowest cost way to get on 9600 baud packet.

- The BayMod-9600 plugs into the parallel port of your PC compatible computer.
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PacComm now manufactures and markets the Gracilis line of quality wireless communication products. Watch for new additions to the product line.

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TECHNICAL CONVERSATIONS

In the Fall 1994 issue of Communications Quarterly, we heard from G4LU regarding "A New Method for Measuring Cable Loss" (A.E. Popodi, AA3K/OE2APM, Spring 1994). Unfortunately, a stray minus sign crept into one of his equations; here's the fix.

Dear Editor:

A gratuitous negative sign has crept into my letter published in the Fall edition of *Communications Quarterly*. Mea Culpa! I followed a colon in my original letter with a dash, contrary to the rules of good composing, and this has caused the confusion. The first equation in the letter should read:

$$\frac{R_{max} - Z_O}{R_{max} - Z_O}$$

The equation, as published, is not equal to unity, but it is hoped that the readers will see the true reasoning.

S.F. Brown, G4LU
Shropshire, England

K6UPZ wrote regarding the formula for Q used in "A Single Coil Z-Match Antenna Coupler" (T.J. Seed, ZL3QQ, Winter 1994).

Dear Editor:

The formula for Q on page 99 of the Winter 1994 *Comm Q* would be more consistent with usual definitions of Q as:

$$Q = \frac{(R_{HI}/R_{LO} - 1)^{1/2}}{2}$$

Then the next two formulas would read:

$$X_L = R_{HI} \div 2Q$$

$$X_C = R_{LO} \times 2Q$$

The second paragraph might read: "If the generator resistance is greater than the load resistance, the source and load may be interchanged or a secondary winding may be placed on L."

Darrell D. McKibbin (Mac), K6UPZ
Ukiah, California

W7SX shared these thoughts on the Si8901 after reading about G3SBI's H-mode receiver design in our Fall 1994 issue ("Tech Notes," page 81).

Dear Editor:

I read with interest Pat Hawker's reprinted "Technical Topics" in your Fall 1994 issue of *Communications Quarterly*. It should be noted that the original Siliconix Si8901 was an SD5000 die with a simple metal mask change to configure the quad ring. The only reason that a metal mask was used was to reduce the parasitics of the circuit board cross-couplings at VHF. However, at HF the parasitic reactances become insignificant and the SD5000 should work as well as the Si8901.

I think the H-mode configuration would also work as an *active* mixer. Instead of connecting the center tap of T1 to ground, it might be biased positive (through proper RF decoupling). Thus conversion *gain* might be realized—perhaps without significant reduction in performance. I suggested this possibility in "Tomorrow's Receivers: What Will the Next 20 Years Bring," *Ham Radio*, November 1987. This was the principle of the old Siliconix U-350, which was a quad JFET active mixer designed by Ed Oxner, KB6QJ, back in the early '70s.

Another quality of these commutating DMOSFET mixers is their excellent phase integrity, particularly when driven with square waves. This property can be used to advantage when building very high performance quadrature (IQ) mixers. In fact, the dual flip-flop can be used as a very accurate dual balanced quadrature signal source. I built such a configuration using the NE602 in the Signetics lab back in 1984 and published the results in *AN1981 New Low Power Single Sideband Circuits*, now a Signetics application note. Using this technique with Si8901s should yield an outstanding IQ mixer.

If DC coupling is used on the outputs, the Si8901 also makes a very good frequency-phase detector.

The new Watkins-Johnson WJ-8711 receiver achieves its very impressive dynamic range specification by using an Si8901. Craig Corsetto, NK3S, used the '8901 in the '8711 design. Craig also helped me characterize the

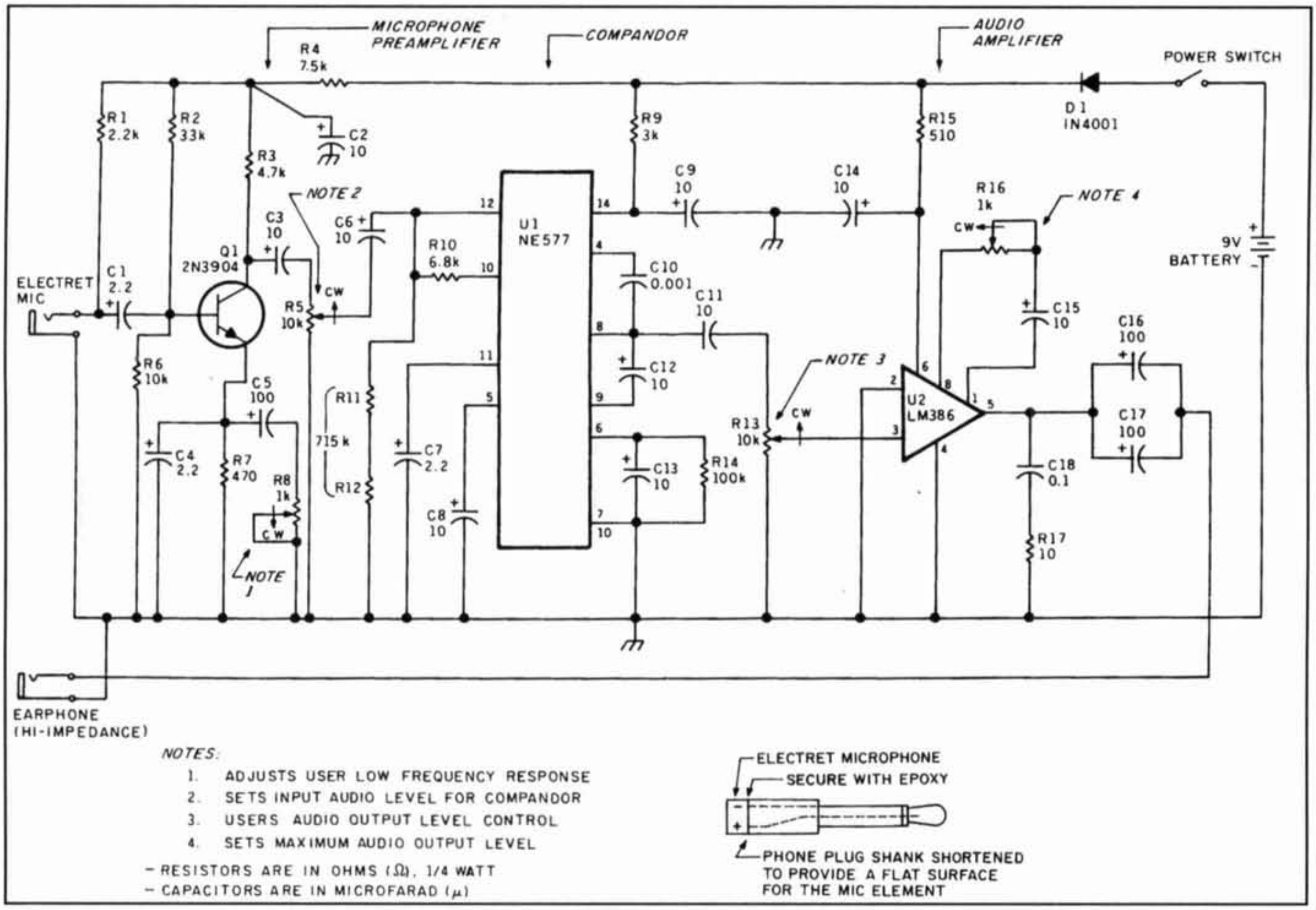


Figure 1. Schematic diagram.

very first 8901s at Hewlett Packard's Palo Alto labs in 1983. Craig was working at HP labs in those days. Ed Oxner's U-350 provided me the inspiration for the Si8901 at Siliconix in 1983. I proposed the simple design, Van Brollini, NS6N, did the metal mask layout, and Ed Oxner did the initial applications work on the device and wrote the first Siliconix application note after I left Siliconix for Signetics. At the time, Siliconix did not see any future in the RF components business! At Signetics, Don Anderson and myself did the initial applications and marketing work on the NE602 and NE604. We barely managed to keep Signetics in the RF business, although today Signetics (now Philips) enjoys very high revenue from its RF components, the `602 and `604 family being standards of the industry.

There is no reason why the Si8901 should not also be such a standard. The fine work of Craig Corsetto, Jacob Makhinson, N6NWP, Colin Horrabin, G3SBI, and hopefully others will draw deserved attention to the Si8901 specifically and MOSFET mixers generally. The well-kept secret superiority of these mixers over diode rings is slowly getting out. I am very much enjoying watching it finally happen after eleven years!

Robert J. Zavrel, Jr., W7SX
Scotts Valley, California

You never know how someone may use a part or idea mentioned in one of our articles. Russell Souter, W6DJ used the compander from "Quarterly Devices," Winter 1994, to build the project below.

Dear Editor:

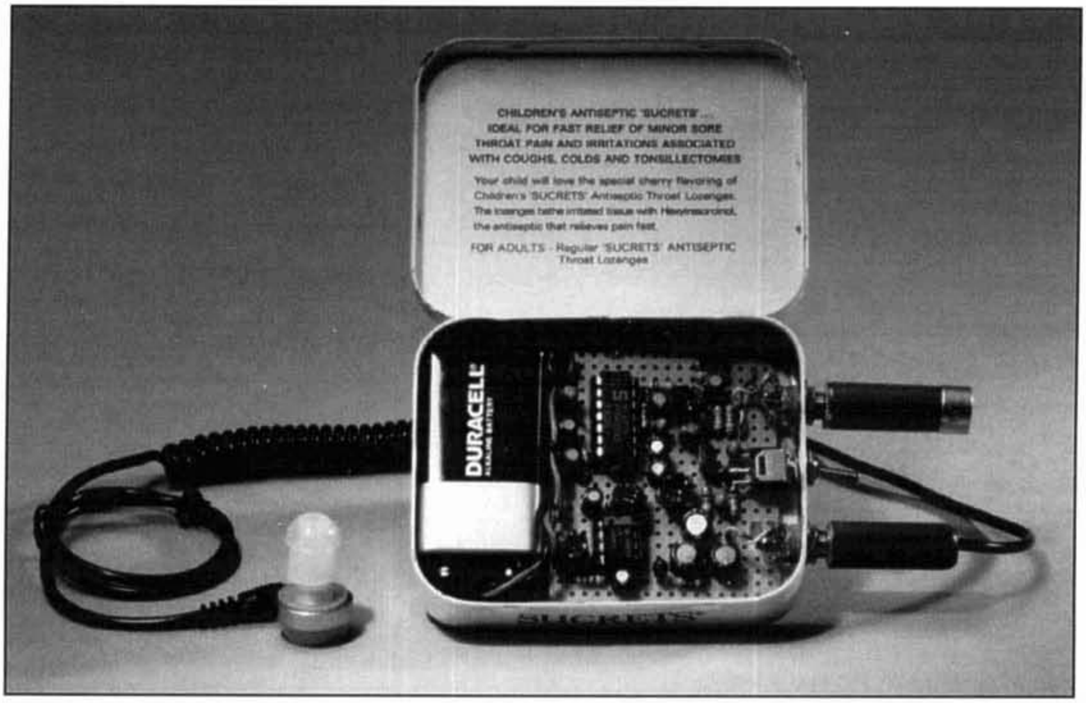
Could this hearing aid be of interest? See Rick Littlefield's article in the Winter 1994 issue of *Communications Quarterly*, pages 77 to 82.

I placed my unit in a Sucret's box. For a sophisticated appearance use Radio Shack's case 270–294 (page 95 in the latest catalog). Holes must be made on the case to reach the four adjustments, or you can disassemble the case.

Figure 1 shows the schematic diagram. Photo A shows the circuitry mounted in the box.* An extension cord can be used to place a microphone on another person—while traveling in a motor home, for instance. This is a big help for the hearing impared, as it reduces noise considerably.

Russell E. Souter, W6DJ
Grass Valley, California

* For copies of the circuit board layouts, send an SASE to: *Communications Quarterly*, P.O. Box 465, Barrington, New Hampshire 03825-0465.



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FIBER OPTICS IN AMATEUR RADIO

Waveguide of the future

Every generation of amateur radio pioneers has its frontier. In Maxim's day, it was those valueless short wavelengths below 200 meters. By mid-century, the challenge was to master the "very highs," and a generation ago a few hardy hams, armed with tin snips, hacksaws, and blowtorches, set out to populate the microwave spectrum. Tomorrow's frontier is optical communications, and this article will tell you how to go about becoming a pioneer. We'll start by reviewing the electromagnetic spectrum, and follow this with a brief discussion of guided electromagnetic waves. Next, we'll look at how optical fiber functions as a transmission line, and contemplate the propagation of light in free space. We'll then identify sources of optical communications components and equipment. Finally, we'll conclude with a look into the optical hamshack of the future.

Time, speed, and distance

Since the 1880s, when Hertz first harnessed them in the laboratory, the substance of ham radio communications has been electromagnetic waves. These orthogonal combinations of electric and magnetic fields, propagating through free space at the fastest velocity known to nature, can be modulated; that is, they can be changed from one cycle to the next, to convey incredible amounts of information. This is what communication is all about.

The behavior of electromagnetic waves is anything but arbitrary, and was contemplated extensively by Maxwell in the 1860s. He applied vector calculus to the derivation of four equations[1] that formed the basis for Hertz' experiments. Maxwell's equations allow us to quantify the concepts of frequency and wavelength, characteristic impedance and the speed of light. At a more fundamental level, Maxwell tells us that all electromagnetic waves, whether emanating from sunlight, satellite, or searchlight, behave fundamentally alike and follow the same rules of the universe.

One of those rules involves the relationship between frequency and wavelength—the two benchmarks by which we subdivide the electromagnetic spectrum. Generations of engineers have memorized a simple formula or two, but we hams want to understand the why behind what we do. So let's derive the frequency-wavelength relationship by taking a trip in the family car.

I currently reside in Williamsport, in rural Central Pennsylvania (Grid Square FN11). That's about 200 miles from Manhattan, 200 miles from Pittsburgh, 200 miles from Philadelphia, 200 miles from Baltimore, 200 miles from Washington. . . 200 miles from anywhere! If I set out to drive to any of these population centers, and average 50 miles per hour, its going to take me four hours to get there.

The math used to derive the driving time is so deceptively simple, that it's easy to miss the elegance of the underlying algebra. In physics and the family car, the relationship between distance, speed, and time is simply:

$$d = v * t \qquad (1)$$

and if we know any two of the related quantities, we know the third. Well, the same equation holds for any electromagnetic wave travel-

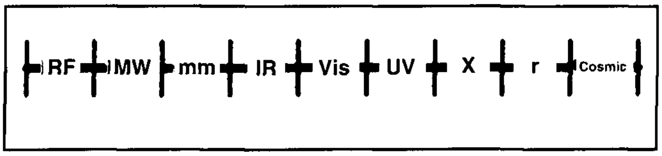

Figure 1. The electromagnetic spectrum.

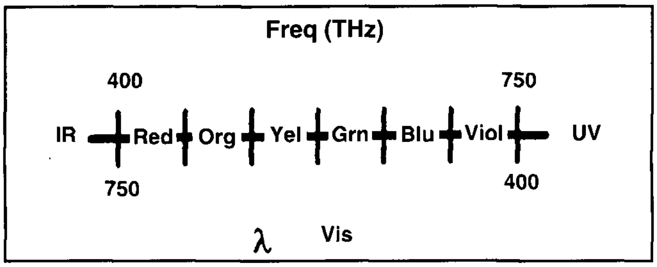

Figure 2. The visible spectrum.

ing through any medium, but if we consider one special medium (free space) the equation becomes:

$$d = c * t \tag{2}$$

where c stands for a very specific velocity, the speed of light in free space, or 300 million meters per second (a constant of nature).

It happens that the distance occupied by one cycle of an electromagnetic wave is its wavelength, abbreviated λ. Substituting wavelength for distance, we get:

$$\lambda = c * t \tag{3}$$

where t now represents the period of the wave—the time it takes for one cycle to pass a given point. Since period is measured in seconds per cycle, and frequency in cycles per second, it's easy to see that the two must be reciprocals of each other. Consequently:

$$\lambda = c * 1/f \tag{4}$$

which can in turn be rewritten as:

$$c = \lambda * f \tag{5}$$

which is not only the textbook equation that we all know and love so well, but will lead us to a full understanding of the electromagnetic spectrum. In the time it takes me to drive to Manhattan. Or Baltimore. Or Pittsburgh. Or...

DC to daylight, and beyond

Let's take a look at an electromagnetic continuum (**Figure 1**). The spectrum is variously divided into a number of segments, including audio frequencies, radio frequencies, microwaves, millimeter-waves, infrared, visible, and ultraviolet light, X-rays, Gamma rays, and cosmic rays. It's important to remember that these are all electromagnetic waves following Maxwell's equations, obeying the same rules of nature, differing only by their frequency (and hence corresponding wavelength). In other words, each segment of the continuum is still light, albeit of a different color.

Yesterday's radio amateur concentrated on harnessing light in the RF spectrum. Today, many hams are working at microwave, and more than a few in the millimeter-waves. The province of the optical communicator is the infrared and visible spectra. What we'll choose to modulate tomorrow is anybody's guess.

Let's zoom in on the visible rainbow specifically, as seen in **Figure 2**. Here we relate color to its frequency and wavelength, remembering (in accordance with **Equation 5**) that the speed of light is a constant; that is, if one goes up, the other will go down. If we choose to measure frequency in TeraHertz* and wavelength in nanometers, an interesting coincidence asserts itself: the numeric frequencies defining the visible spectrum are equal to the numeric wavelengths of the opposite band ends. Even more startling is the discovery that the center of visible light (found by taking the square root of the product of two endpoints) has a frequency of 547.7 THz, and a wavelength of 547.7 nm! However, the best coincidence of all is that it is this central wavelength/frequency that corresponds to the peak spectral response of our sunlight-adapted eyes. Thus, it appears that both our eyes and our sun have evolved in accordance with Maxwell's equations.

Fiber optic communications take place primarily in the visible and near-infrared spectra. **Table 1** shows the center frequencies and wavelengths of the three most widely used infrared "bands." If you are to be a pioneer in this communications mode, you'll need to begin thinking in terms of frequencies in the hundreds of TeraHertz, and wavelengths on the order hundreds of nanometers. It's not so different from the transition made by microwavers a few year ago, into thinking in terms of frequency in GigaHertz,** and wavelength in centimeters. Higher frequencies, shorter wavelengths has always been the name of the game.

Optical: Why bother?

In an excellent previous article, Mike Gruchalla[2] characterized the chief advantage of fiber optic communications links in terms of their impressive information capacity. Let's define electronic communication as transferring

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*Tera, for 10^{12}, comes to us from the Greek Teras, or Monster.

**Giga, for 10^{9}, derives from the Greek Gigas, or Giant.

information from Point A to Point B via electronic means. That generally means modulating an electromagnetic wave (carrier) in some way. Whether the carrier is present or suppressed, the modulation process always generates sidebands, which define a signal bandwidth. As a rule, the greater the information content per unit time, the greater that bandwidth. This principle is the basic tenet of information theory.[3] It's also the reason why optical carriers offer an advantage over their RF or microwave counterparts.

Whatever the bandwidth of a modulated signal, the equipment at both ends of the communications link must be able to pass it. Otherwise, we begin to lose sidebands, which after all contain the information we wish to convey. Thus, we're concerned with the bandwidth of our transmit and receive circuits, antennas, and transmission media. For any frequency-selective circuit, bandwidth and carrier frequency are related by Q:

$$Q = f_c / BW \qquad (6)$$

so that, for a given circuit Q, the higher the signal carrier frequency, the wider its bandwidth (and the more information it can carry). What exactly do we mean by "for a given circuit Q?" Simply this: for any application, there is a minimum practical circuit Q that can be readily achieved in practice. Any lower Q in transmit amplifiers, and gain goes down unacceptably. Any lower Q in receiver front ends, and intermodulation distortion and image interference become a problem. Any lower Q in antennas, and their radiation pattern degrades excessively. Consequently, for any application, we are limited in bandwidth by realizable system Q.

Just what is a realizable system Q? Let's take a look at a few familiar applications (**Table 2**) to see what's readily achievable. Consider first an AM radio station transmitting in the vicinity of 1 MHz. The maximum modulating frequency is 5 kHz, and we're using double-sideband AM. This means we have an upper sideband extending out to 5 kHz above the carrier, and a lower sideband extending a like distance below it, for a total signal bandwidth of 10 kHz. Dividing carrier frequency by bandwidth, we see that AM radio uses a system Q of around 100.

Next, lets consider UHF television. Take, for example, TV channel 35, more or less in the middle of the dial (at least since Channels 70 through 83 were reallocated by the FCC to cellular telephone). The assigned channel extends from 596 to 602 MHz, which gives us a center frequency of 599 MHz, a channel bandwidth of 6 MHz, and a Q of around 100.

How about C-band satellite TV? These wideband FM downlinks are transmitted at a carrier frequency in the 3.7 to 4.2 GHz band, with 40 MHz of bandwidth per channel, for a system Q of around 100!

820	1300	1550	nm
366	231	193	THz

Table 1. Common IR fiber frequencies.

Application	fc	BW	%	Q
AM radio	1 MHz	10 kHz	1	100
UHF TV	600 MHz	6 MHz	1	100
TVRO	4 GHz	40 MHz	1	100
IR fiber	350 THz	3.5 THz	1	100

Table 2. A few familiar applications that show what's readily achievable as a realizable system Q.

Do you begin to see a pattern here? Of course, there are counterexamples abundant, but they do not negate the fact that, in a number of communications applications, system Q of around 100 (that is, modulation bandwidths on the order of one percent of carrier frequency) are common. Now if this trend holds through optical frequencies (and we have no reason to expect it shouldn't), we should also expect bandwidths on the order of one percent of carrier frequency. These are incredibly high carrier frequencies we're talking about! Which implies mind-boggling bandwidths, and correspondingly immense information capacity. Which is the primary advantage of optical communications.

Let's consider an optical communications system using the rather common infrared carrier wavelength of 850 nm. This corresponds to a frequency on the order of 350 THz. Using our "one percent rule," we would expect an information bandwidth on the order of . . . 3.5 THz! That's 3,500,000 MHz—about 100 times as much spectrum as all United States ham radio allocations, HF through millimeter waves, put together! In terms of the applications cited above, we're talking enough spectrum to support 87,000 satellite TV channels, or 583,000 standard NTSC TV channels, or about 350 million simultaneous AM voice signals (see **Table 3**)! Now, even if our bandwidth estimate is optimistic by even so much as a couple of orders of magnitude, it's still apparent that optical communications afford us with an incredible information capacity.

Keep it in the pipe

This section is a great time saver. If you're interested in just how optical fibers function, you can either read a mathematical optics textbook, and be totally confused, or read this sec-

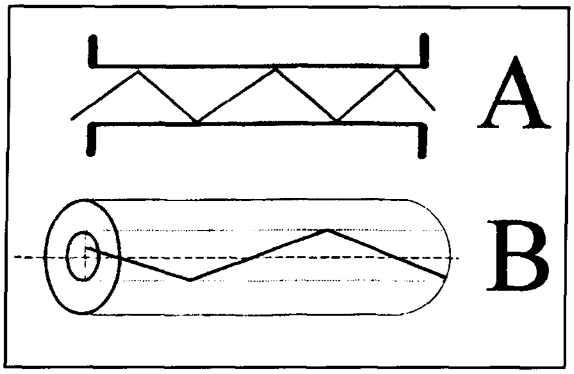

Figure 3. (A) How microwave signals propagate through rectangular waveguide. (B) Light propagation in a fiber.

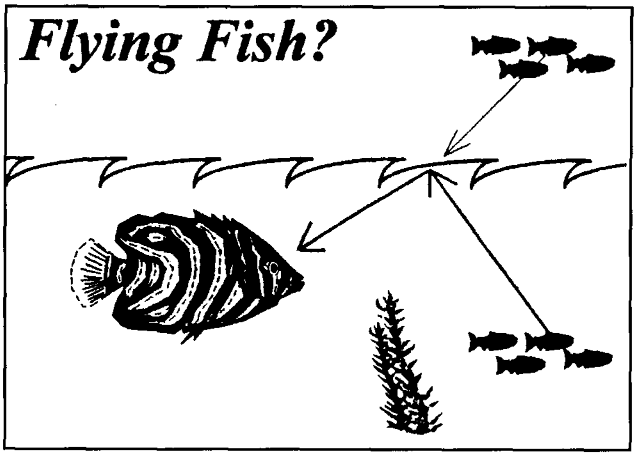

Figure 4. The phenomenon of total internal reflection.

tion. . . and be just as confused! (If you wish to avoid confusion altogether, feel free to skip this section. I don't mind.)

Optical fiber, like coax cable or rectangular waveguide, is a low-loss transmission medium for electromagnetic waves. You've probably seen how microwave signals propagate through rectangular waveguide (**Figure 3A**). Because waveguide has conductive, metallic walls, it's easy to see how the signals can bounce off the walls of the guide, to achieve forward propagation.[4] The model most often used to represent light propagation in a fiber (**Figure 3B**) shows signal reflection, too, but that's misleading. After all, how can light bounce off the edge of a transparent glass or plastic pipe?

It can't, of course. The trick for keeping light in the pipe is that the optical fiber is really a concentric sandwich of two different materials. The inner glass or plastic portion (called the *core*) is surrounded by a thin *cladding* of a slightly different type of glass or plastic, which is slightly less dense (optically) than the core. If light were propagating in the cladding, it would then be moving faster than light traveling in the core. It is the difference in propagation *speeds* that enables the light applied to a fiber to stay within the core and travel forward. . . at slightly less than what we call the *speed of light.*

To understand the operation of optical fibers, we'll invoke the *law of refraction.* When light traveling in a given medium (at a given speed) enters another medium (in which light travels at a different speed), the light ray bends. If bent enough, the light rays will re-enter the original medium, a phenomenon called *total internal reflection.* Consider, for example, Charlie Piranha (see **Figure 4**) out searching for a snack. Now who do we see cringing behind a clump of kelp but the School Lunch Program. You'd think they're safely out of sight, but guess again. As Charlie looks up, he sees the Catch of the Day reflected in the interface between water and air. Now Charlie's not one to be fooled by the Flying Fish optical illusion. He knows (and now, so do you) how sufficient refraction can result in total internal reflection.

The *angle of refraction*, the degree to which light is bent can be predicted mathematically, as a function of the relative optical density of the two materials in question. By proper design of cladding and core, we can use the law of refraction to achieve total internal reflection in the cable. That is, we can bend any light entering the cladding, forcing it to re-enter and stay within the core. Here's how that works.

Remember the **c** we introduced in **Equation 2**—the forward propagation velocity of radiant electromagnetic energy in free space? In any other material (such as glass or plastic), light will move more slowly. We can define *relative* propagation velocity, or *velocity factor*, as the speed of light in a given material relative to that in a vacuum. Mathematically:

$$V_r = V_x/C \qquad \textbf{(7)}$$

where $\mathbf{V_r}$ is velocity factor (or relative velocity), $\mathbf{V_x}$ is the propagation velocity in our material of interest, and **c** is 3×10^8 meters per second—the speed of light in a vacuum.

We can create an optical fiber by surrounding a core (of transparent material **1**) with a cladding (made of transparent material 2) as seen in **Figure 5**. To transmit light, the propagation velocity in the cladding must be greater than in the core, or:

$$V_r(2) > V_r(1) \qquad \textbf{(8)}$$

Another way to indirectly describe propagation velocity in material **x** is to refer to the material's *index of refraction*, abbreviated $\mathbf{n_x}$. Index of refraction is the reciprocal of relative velocity, or:

$$n_x = 1 / V_x \qquad \textbf{(9)}$$

Combining **Equations 9** and **8**, we see that:

$$n_1 > n_2 \qquad (10)$$

A defining characteristic of optical fibers is Numeric Aperture, **NA**, a ratio based upon these two indices of refraction:

$$NA = [n_1^2 - n_2^2]^{1/2} \qquad (11)$$

The *Law of Refraction*, also known as *Snell's Law*, quantifies the degree of bending that occurs when light travels between two media of different refractive indices. All angles are measured with respect to the normal (a line perpendicular to the plane of the interface of the two materials).

$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2 \qquad (12)$$

We can now solve Snell's Law for the special case of total internal reflection, finding the *critical angle*, Φ_c, at which light will propagate through a fiber:

$$\Phi_c = \cos^{-1} (n_2 / n_1) \qquad (13)$$

Finally, if we combine **Equations 11** and **13**, we derive the acceptance cone; that is, the angle below which light must be *launched* into the end of an optical fiber, in order for it to propagate:

$$\Theta_{accept} = 2 \sin^{-1} (NA) \qquad (14)$$

These equations allow us to calculate the critical operating parameters of optical fiber. Now let's look at what optical fiber's good for, and how to use it.

Waveguide of the future

As I mentioned previously, optical fiber can be constructed from either plastic or glass. In either case, it's necessary to surround a core of material n_1 with a cladding of *lower* refractive index n_2. I suppose it's possible to combine a glass core with plastic cladding or vice-versa, but in actual practice it's all one or the other. Glass fibers have extremely low loss (a dB or less per kilometer), and are suitable for GigaBaud data rates over great distances. Unfortunately, glass fiber will cost you anywhere from dollars to tens of dollars per foot, on a par with the best Heliax™ microwave cables. Plastic fiber, on the other hand, is cheap (pennies to dimes per foot), somewhat lossy (a good fraction of a dB per meter), and is used at kiloBaud data rates over limited distances. Think of it as the RG-58 of the optical world, in terms of both performance and cost. While glass fiber shines in long-haul trunkline applications, it's plastic fiber with which you're most likely to wire your home or hamshack.

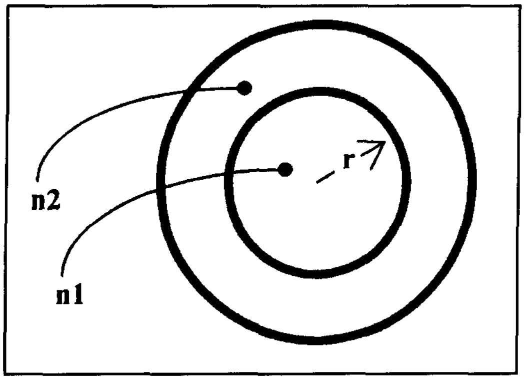

Figure 5. Creation of an optical fiber by surrounding a core with a cladding.

87 k	TVRO channels
583 k	NTSC TV channels
350 M	Voice channels

Table 3. Channels supported by 3.5 THz bandwidth.

At microwave frequencies, we normally operate rectangular waveguide in a single dominant *mode*, as seen in **Figure 3A**. This means only a single ray propagates through the guide, and it always reaches the walls of the guide at a fixed angle. Thus, in the absence of reflective losses, all signals exiting the waveguide will do so *in phase*, and there will be no cancellation of propagated energy. Because single-mode propagation in waveguide only occurs when the physical aperture of the guide is on the order of a half wavelength, a given guide will exhibit only a limited operating bandwidth. For example, WR-90 X-band waveguide operates in its primary mode over a frequency range of only 8 to 12 GHz.

It's possible to achieve single-mode propagation in optical fiber as well; in fact, this would lead to the lowest possible signal attenuation. However, if that half-wavelength guideline holds here as well, we would need a core radius (**r** in **Figure 5**) on the order of a fraction of a micron.* Multi-mode fibers are more practical in that the physical dimensions are more realizable, although with light rays entering and exiting the fiber at various angles, you can see that some of the waves are going to emerge *out of phase*, and cancel. It is this phase cancellation that accounts for much of the loss in multimode fibers.

Certainly the simplest way for hams to apply fiber-optic techniques would be to obtain plastic multi-mode fiber with a fairly wide acceptance cone, and a fairly large core radius, and epoxy the polished ends of such fiber directly to LEDs (used as modulated optical transmitters) and phototransistors (used as optical demodulators). This is, in fact, the approach used in the optical projects proposed at the end of this article, although many of the plastic fiber kits referenced do use connectors between the fiber and the optoelectronic active devices.

Free-space lightwave communications

Hams have been doing a lot of work with free-space laser communications in recent years, and this DX mode has a great deal in common with fiber optic communication. In both cases, it's necessary to modulate a light source, either visible or infrared, with either analog or digital information. Because both free-space and guided light communications use LEDs or lasers as signal sources, the electronic portion of the transmit equipment will likely be identical. Also, the receive circuitry for free-space optical communications will have a great deal in common with guided optical applications. Thus we have an opportunity for some interesting synergy.

Consider, for example, the current** laser DX record shot of 157.7 miles reported in **Reference 5**. KY7B and WA7LYI used 15 mW HeCd lasers as sources, and photo-multiplier tubes in their receivers. A number of experimental long-haul fiber optic links have used similar equipment. At a more modest level, the HeNe laser communications systems used by NU1N[6,7] use transmit and receive electronics identical to those commonly encountered in the fiber optic industry. And WA2NDM's laser diode driving circuit[8] is ideally suited to either free-space or fiber applications.

In the following section, we'll be looking at some parts kits for fiber optic projects. Be aware that, at least for short-haul paths, they may prove suitable for free-space experiments as well. Working your own grid square with visible light may well be a goal to set your sights on!

Piecepart potpourri

When I first started microwaving some 25 or so years ago, my biggest challenge was locating sources of components. Short of stripping out surplus military equipment (which was, thankfully, abundant), there was little to be found in the way of affordable microwave parts. Today's optical experimenter is more fortunate. Because the much touted Information Superhighway is to be paved with glass, educational institutions are anxious to incorporate fiber into their curricula. Numerous commercial vendors are eager to supply them with parts and kits which, it just so happens, will meet the ham experimenter's needs perfectly. The **Appendix** lists a few such vendors and their wares.

For amateur applications, the best optical transmission line is probably Super-ESKA SH4001. This inexpensive multi-mode plastic fiber, 900 microns in diameter, is optimized for use with red visible light (such as that which emanates from inexpensive LEDs). Its numerical aperture is 0.5, for an acceptance cone of 60 degrees. Expect insertion loss to be on the order of 0.3 dB per meter. The protective buffer covering ESKA can be stripped off with ordinary AWG 20 wire strippers (although no-nick strippers are better to avoid damaging the cladding). This fiber can be cut with diagonal cutters (although a hot-knife cut generally requires no polishing), and its ends polished, when necessary, with 400 to 600 grit wet-or-dry emery cloth. In short, ESKA users can expect low cost ($1 per meter in small quantities, *much* less in bulk), moderate performance, and ease of use.

For interconnect, I favor the AMP Optimate DNP (stands for dry, non-polish) line of optical connectors. Plugs, bulkhead receptacles, and active device mounts all cost about $1 each in singles, less in quantity. These plastic connectors require no specialized tools, and are a perfect for ESKA fiber. Most of the kits listed in the **Appendix** use DNP connectors; the rest use equally inexpensive Motorola plastic SMAs, which are dimensionally similar to the familiar SMA microwave connector.

For light sources, red T 1-3/4 size LEDs work great. They fit the AMP DNP device mounts if you file off the curved lens and polish the end with fine grit emery cloth. For sensitive detectors, look for some inexpensive phototransistors. For faster frequency response (high Baud rates), you might prefer a photodiode. Here's a tip: when forward biased, LEDs emit photons. When reverse biased, they make dandy photo diodes. It's hard to beat Radio Shack variety for a low-cost "matched pair."

A look at the optical hamshack

Amateur radio has traditionally been as much an analog discipline as pre-CD musical recording (if you'll pardon the analogy). However, much like the digitization of music, I suppose it was inevitable that the computer

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*Actually, by making Numeric Aperture very small, it's possible to raise the required radius for single-mode operation to several microns. But that's still inconveniently (and expensively) small. Single-mode optical fibers are the most costly, and least lossy, available.

**As of this writing (August 1994). Since records are made to be broken, a new one may be in place by the time you read this.

would in time invade our hamshacks. Today, microprocessors have insinuated themselves into our transceivers, teletypes, antenna rotators, signal processors, satellite trackers, Morse code keys, and even our logbooks! It is the increasing digitization of amateur radio which will likely provide our window into the realm of optical communications.

If you've ever tried to copy weak signals with a computer on in the shack, you've probably already noticed what I call the *aviary effect*: more birdies than Palmer ever hit. Computers, for all their utility, are horrendous sources of RFI. Shield them though we might, the interference persists. And even if you remote the computer, the cables which interconnect it to your rig, no matter how well shielded, will still spew out garbage.

Let's exile the hamshack computer to the basement, and access it remotely with *optical fiber*. After all, fiber is more secure than the best shielded coax. An inexpensive fiber optic duplex digital link will do the trick (they're available in kit form). While we're at it, let's digitize our rotor signals, and send them up the tower on plastic, rather than copper. As for driving our radios, the TNC, DSP box, etc., interface whatever is possible optically for the greatest possible interference immunity.

Ever run a phone patch through a local repeater? You'll remember that it was relatively easy to interface, because the frequency response of your telephone line is only about 3 kHz. How about a VideoPhone patch through an ATV repeater? A bit more of a challenge to pipe around 6 MHz wide video isn't it? This sounds like a job for...SuperFiber! And if we digitize the video first (standards are now emerging for digital HDTV), we can employ digital compression techniques to either increase our resolution at a given Baud rate, or reduce the Baud rate for our original resolution. There's every reason to expect fiber optic hams to emerge at the forefront of video teleconferencing technology.

We've only scratched the surface in this article. Optical fiber is ideally suited to piping high data rate digital signals around the shack, without the problems of RFI which wire systems suffer. Anything that can be thought can be digitized, and anything that can be digitized can be transmitted optically. The possibilities are without limit.

Conclusion

In years past, amateur radio innovation opened up new vistas for the electronic communications industry. We hams have pioneered the use of every major segment of the spectrum, and have paved the way for worldwide digital, microwave, and satellite distribution of information. For once, we seem to be taking a back seat to the laboratories of industry and the halls of academia; the fiber optic revolution has nearly passed us by. That commercial exploitation of optical communications has preceded, rather than following, amateur use is a function more of interest than of aptitude. To hams, fiber optics can be seen as a solution in search of a problem. As we begin to identify applications that can only be satisfied by wide-band optical links, we'll enjoy an opportunity to return to our accustomed role in technological development: as innovators of the highest order.

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7. B.P. Bergeron, "A Laser-Communications Primer—Part 2," *QST*, 74(10), 22–26, October 1990.
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Appendix: Sources of Components and Supplies

1. Digi-Key Corp., P.O. Box 677, Thief River Falls, Minnesota 56701, (800) 344-4539. Fiber optics educations kits, ESKA plastic optical fiber, AMP DNP connectors, plastic fiber tool kit.

2. Mouser Electronics, 2401 Hwy 287 N, Mansfield, Texas 76063, (800) 346-6873. Fiber optics educational kits, visible and infrared phototransistors and LEDs, plastic fiber tool kit.

3. MWK Industries, 198 Lewis Court, Corona, California 91720, (800) 356-7714. Diode and HeNe lasers, glass optical fiber (with and without connectors), fiber optics educational kits.

4. Industrial Fiber Optics, P.O. Box 3576, Scottsdale, Arizona 85271. Manufacturer of fiber optics educational kits, lab manual (distributed through MWK, Digi-key, and Mouser, above).

5. Fiber Sciences, P.O. Box 5355, Chatsworth, California 91313. Fiber optic voice transmitter/receiver kit.

6. Jameco Electronic Components, 1355 Shoreway Road, Belmont, California 94002, (800) 831-4242. Visible LEDs in a variety of colors, opto-isolators.

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THE WATKINS-JOHNSON HF-1000

A milestone in communications receiver development

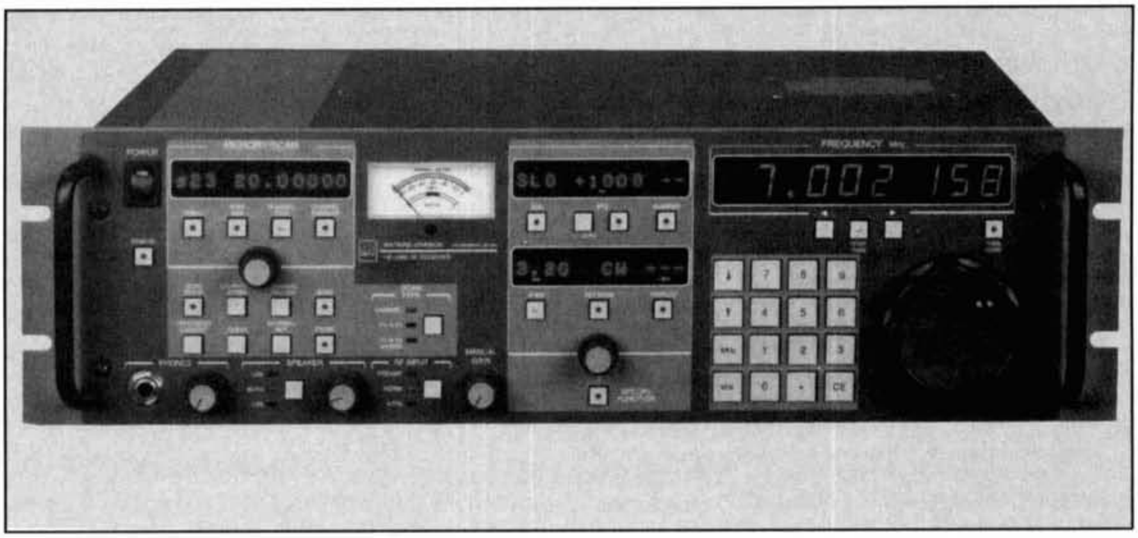
The Watkins-Johnson HF-1000 is the first affordable, stand-alone commercial receiver to use digital signal processing (DSP) at the IF level. In the HF-1000, DSP provides IF selectivity, demodulation, noise blanking, fine tuning, passband tuning, signal strength calculation, and several other features.

Although digital electronics has been part of communications receivers since the 1960s, its uses have been limited to such applications as frequency counters, synthesizers, memories, and "intelligent" microprocessor control. Around 1990, some receiver manufacturers began integrating digital signal processing (DSP) into the audio path, introducing audio filtering that typically outperformed its analog counterpart. Until recently, however, the state-of-the-art would not support the ultimate in digital implementation—DSP in the receiver IF.

The use of DSP in the HF-1000 represents a major turning point in receiver technology. Let's take a look at this receiver and see what makes it so unique.

The HF-1000, an overview

The Watkins-Johnson HF-1000 is a triple-conversion communications receiver that covers 5 kHz to 30 MHz continuously with 1 Hz resolution. The receiver ships from the factory with a total of 58 selectable IF bandwidths, ranging from 56 Hz to 8 kHz. It incorporates AM, synchronous AM, CW, FM, ISB, LSB,



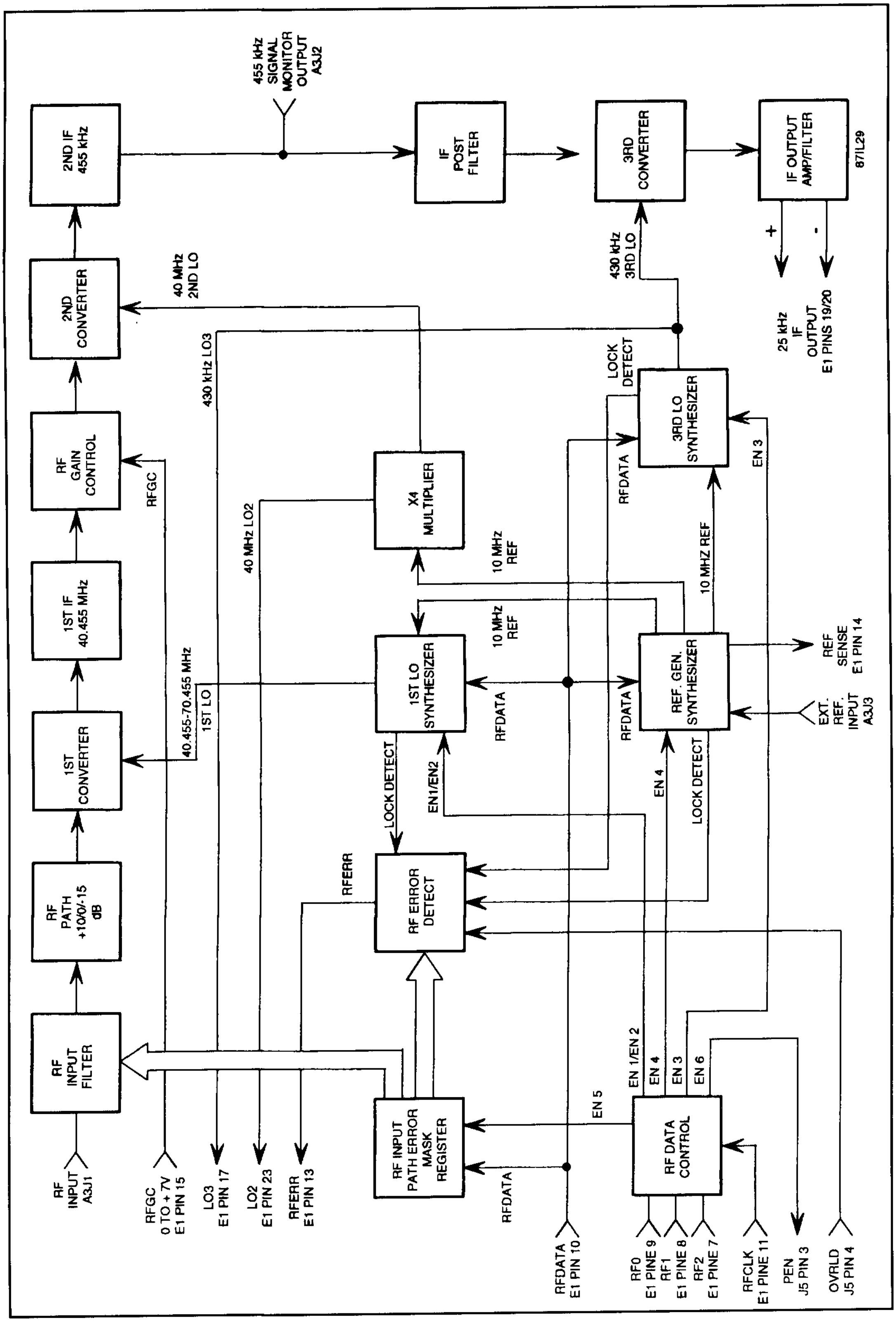


Figure 1. Type 797006 RF assembly block diagram. (Reprinted with permission from Watkins-Johnson.)

and USB demodulators, an adjustable noise blanker, an IF notch filter, a BFO adjustable over a ±8 kHz range, programmable AGC, and receiver passband tuning. The unit sports 100 programmable memories with multiple scan functions, a 10-dB RF preamp, a 15-dB RF attenuator, selectable sideband audio in the ISB mode, keypad and rotary frequency entry, calibrated manual gain adjustable in 1-dB increments, receive signal-level squelch adjustable

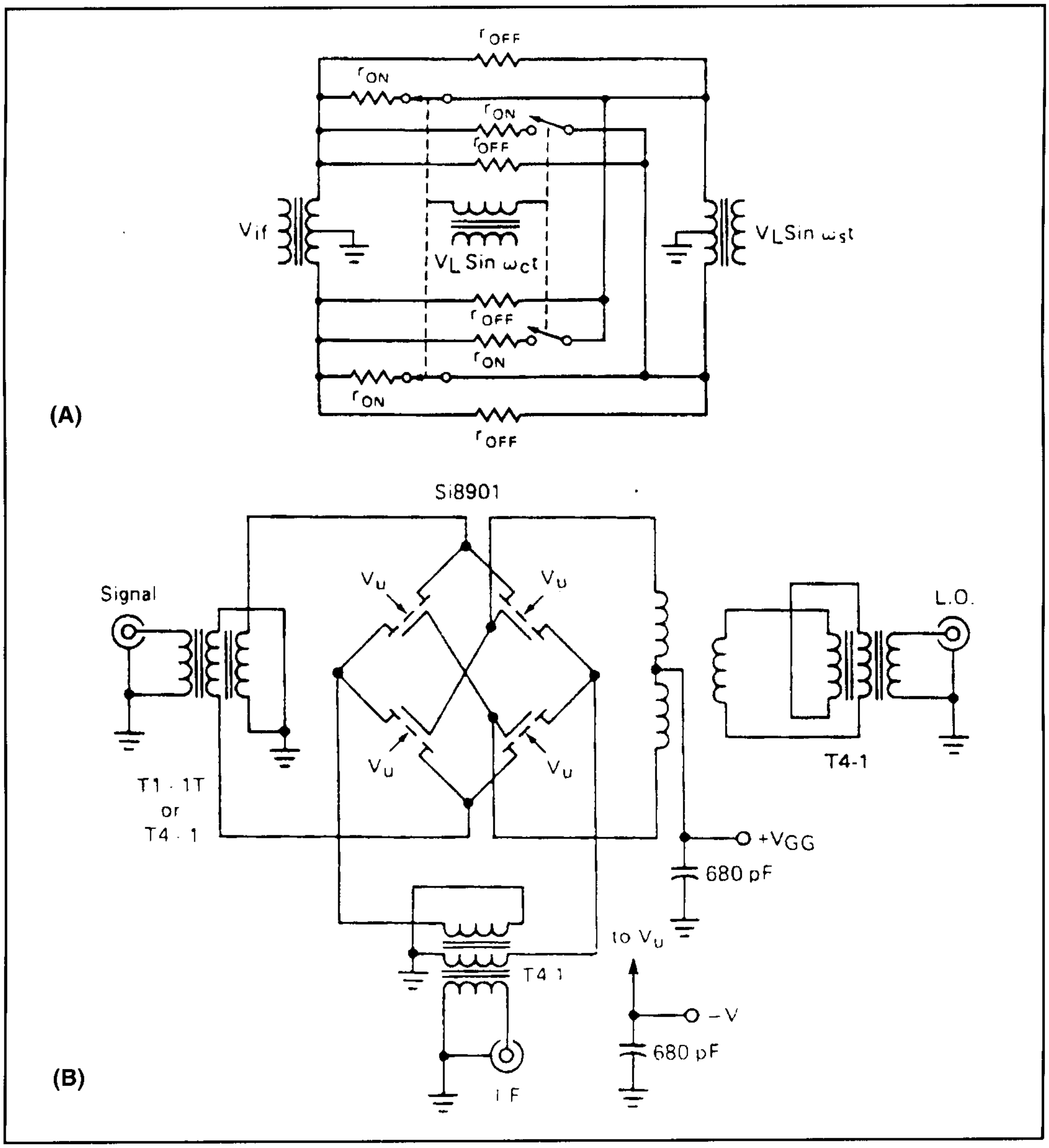


Figure 2. (A) Equivalent circuit of communication mixer. (B) Prototype commutation double-balanced mixer. (Reprinted with permission from Siliconix Application Note AN85-2.)

in 1-dB increments, S-meter calibrated in dBm, user-selectable tuning rate, RS-232 or CSMA remote control, and a host of other features. There's no question that the HF-1000 is adaptable to virtually any receiving application. Let's "lift the hood" on this unique product, and take a look at the inner workings of a digital communications receiver.

The HF-1000 RF assembly

One of the most impressive aspects of the analog portion of the HF-1000 is the superb dynamic range and image rejection characteristics of its front end. The third-order intercept point is specified at a minimum of +25 dBm at 20-kHz tone spacing, with a typical value of +30 dBm. The second-order intercept is specified at +60 dBm and the image rejection is an exceptional 90 dB. Unlike most broadband front ends that use a bank of switchable 1.5-octave Chebyshev low-pass filters ahead of the mixer for preselection, the HF-1000 uses nothing more than a 32-MHz low-pass roofing filter. As a result, the entire 0 to 30 MHz spectrum is presented to the first mixer. However, a special high-intercept mixer eliminates the need for a preselector—except in extreme cases (like military or maritime applications where the receive antenna may be only few feet away from multiple transmit antennas). For these installations, Watkins-Johnson manufactures an optional 11-band sub-octave preselector, the WJ-HF1000/PRE, which is under the control of the receiver's main microprocessor.

Let's take a closer look at the signal flow through the RF assembly (see **Figure 1**). Signals from the antenna pass through a 32-MHz roofing filter that provides 80 dB of ultimate attenuation. After passing through the front-end LPF, the 5 kHz to 30 MHz signals can be routed one of three ways depending upon the front panel control settings: 1) directly to the mixer, 2) through a low-noise bipolar preamp with approximately 10 dB of gain, or 3) through a resistive pad with 15 dB of attenuation. The signals are then routed to the first mixer, where they are upconverted to a first IF of 40.455 MHz. To provide 5 kHz to 30 MHz receive coverage, the first LO range is 40.455 to 70.455 MHz, generated by a low phase-noise synthesizer. We'll return to the synthesizer later; for now I'll concentrate on the signal path itself.

The secret to the high performance of the HF-1000 front end lies in Watkins-Johnson's use of a unique high-intercept mixer—the Siliconix SD5400CY. Unlike the more commonly used double-balanced diode or active FET mixers, the SD5400 is a quad-DMOSFET commutating mixer. Commutating mixers differ from their diode or active FET counterparts in that they rely upon the alternate switching of four DMOSFETs. By switching the FETs on and off, the phase of the signal carrier is reversed at a rate equal to the LO frequency (see **Figure 2A**).

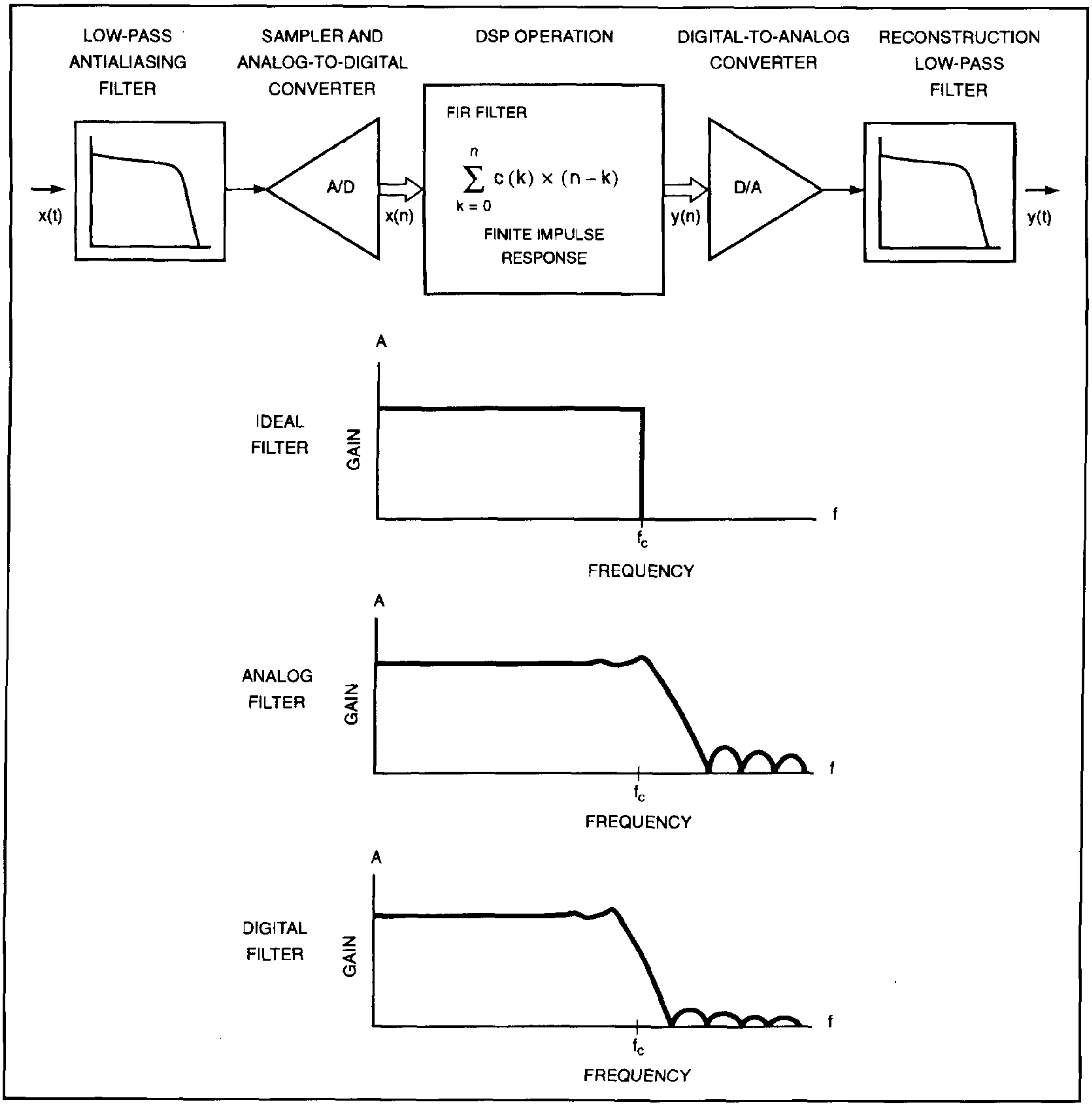


Figure 3. Digital signal processing. (Reprinted with permission of Motorola from the Motorola DSP56000/DSP56001 Manual, page 1-3.)

Figure 2B shows a typical schematic for the Siliconix Si8901 as a commutating mixer (the Si8901 and the SD5400CY are electrically identical). As this figure illustrates, signals from the antenna are routed through a balun to develop the necessary 180-degree phase differential, and then applied to the FET sources. The switched output signals from the drains are routed to another balun where they are combined and passed on to the receiver IF strip. The LO signal is fed into the FET gates via a third balun used to create a 180-degree phase differential between devices.

Ideally, a commutating mixer requires a square wave from the LO for excitation to provide "hard" on/off switching. This requirement can be circumvented with minimal performance loss by applying a small DC bias voltage to the FET gates. If the bias voltage is chosen carefully, the switching action of the FETs nears the ideal duty cycle of 50 percent. This bias serves another vital purpose. Because FETs are a voltage-driven component, the capacitive reactance of the gate changes with the signal excitation level. This has a detrimental effect on the mixer's intermodulation-distortion (IMD) performance. The application of a bias voltage minimizes the change in gate reactance, while providing positive switching action in the FETs, lowering mixer-induced IMD.

While conventional double-balanced mixers can be designed to provide a high intercept point, the price paid for this improvement is a substantial increase in the LO drive requirements. This is not true of the commutating mixer. For example, third-order intercept points as high as +39 dBm are possible with an LO level as low as +17 dBm in the commutating mixer, while a diode mixer might require as much as +35 dBm from the LO to equal this performance.[1]

After leaving the SD5400CY mixer, the first IF signal passes through a 30-kHz bandpass filter centered on the 40.455 IF frequency, and is then routed to the second conversion stage via a voltage-controlled attenuator. This attenuator provides 60 dB of amplitude control over the first IF to prevent strong-signal overload of the analog-digital converter on the digital assembly. The attenuator control voltage is developed by the DSP chip and is independent of the receiver AGC or manual gain control settings. After passing through the attenuator, the 40.455-MHz first IF is routed to a double-balanced mixer where it's combined with a 40-MHz second-LO to generate a 455-kHz IF output. A 455-kHz bandpass filter follows the second mixer, and the 455-kHz IF is split between an external IF output (pre-DSP) and the third conversion stage. In the third mixer, the 455-kHz IF is mixed with a 430-kHz LO to produce a 25-kHz third IF. After filtering, the differential output from the third mixer is routed to the digital assembly for A/D conversion. At this point, the overall gain of the receiver is just over 50 dB at an IF bandwidth of about 25 kHz.

In most respects, the synthesizers on the RF assembly are rather conventional. A 10-MHz oscillator provides the reference for the first and third LO synthesizers, as well as a 40-MHz second LO through a X4 frequency multiplier. The 10-MHz reference oscillator is specified to maintain a stability of ±1 PPM, which translates to a drift of no more than 30 Hz at 30 MHz. Should you require greater stability, the HF-1000 has provisions for an external clock of either 1, 2, 5, or 10 MHz. The HF-1000 will sense the presence of the external clock and phase-lock its internal 10-MHz reference to it. One unusual aspect of the first LO synthesizer, considering the tuning resolution of the HF-1000, is that it tunes in 1-kHz steps. Consequently, all fine tuning within these 1-kHz steps takes place in the DSP chip on the digital control assembly.

Digital Signal Processing, a brief tutorial

Before I move on to the digital assembly, I'd like to provide a brief overview of what DSP is, and how it works. While many of us have heard about DSP and what it can do, very little has been written about it at a basic level. This is due, in large part, to the mathematics involved in DSP. To completely understand the inner-workings of a DSP chip, one must be fluent in advanced calculus, linear transformations, differential equations, and vector algebra. There are a multitude of excellent books about DSP that deal specifically with the theory involved, a few of which are listed in the references. Many of these are difficult, if not impossible, to comprehend without a very thorough math background. However, it is possible to acquire a reasonable understanding of the "mechanics" of DSP without going to the depth typified by these texts.

Until recently, the only way to process a signal was to use analog technology. In analog signal processing, both passive and active components are combined to act on a signal in a prescribed manner. For instance, we are all familiar with capacitive and inductive reactance, and know that all components display these properties to one degree or another—depending upon the component and the frequency involved. By choosing specific component combinations, we can take advantage of the reactances contributed by each component to form a network that can modify a signal

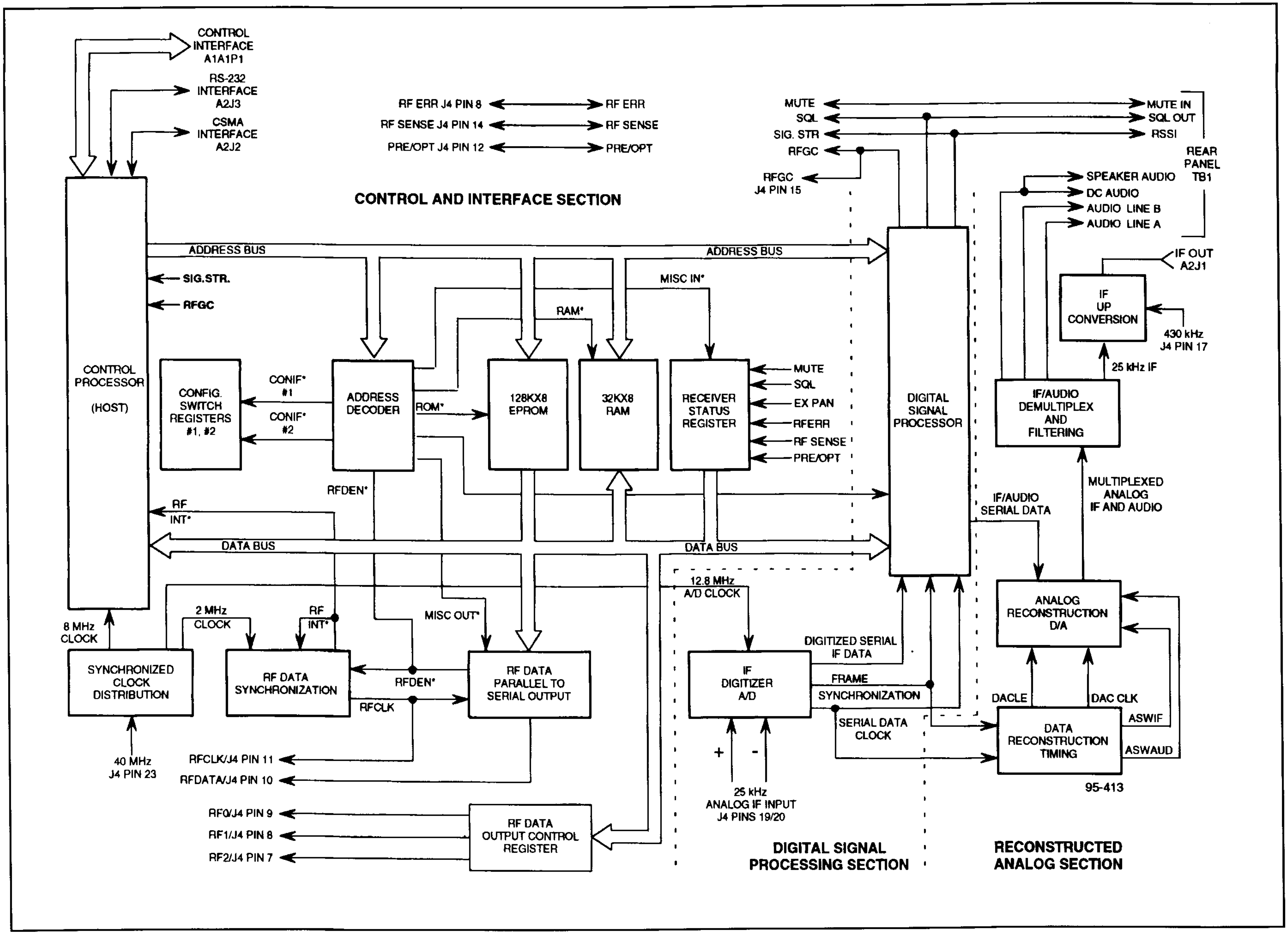


Figure 4. Type 797012 digital assembly functional block diagram. (Reprinted with permission from Watkins-Johnson.)

according to our desires. When active components are included, our calculations become more complex; but in all cases we can describe what's going on mathematically at any point in the circuit with respect to time using network analysis techniques.

In analog electronics, most work is done strictly within the time domain. In other words, we analyze how a signal varies in amplitude and phase as a function of time. While it's possible (and often desirable) to analyze analog signals in the frequency domain, doing so requires a strong working knowledge of linear transformations. However, the frequency domain is a powerful tool in network analysis, and modern computer technology has greatly simplified its use. The Laplace transform is a commonly used tool in frequency domain analysis of analog circuits.

One of the biggest drawbacks in processing a signal with an analog network is that if we want accuracy and precision, we need to use components with very tight tolerances. This is especially true in frequency-sensitive networks like filters. Another problem with analog networks is that we can only approximate the mathematics involved. For instance, textbooks may list pages of formulas pertaining to the design of a specific network. However, textbook performance can never be realized in actual practice because component tolerances, temperature variations, stray coupling, residual reactances, impedance mismatches, cost, and so on, all come into play. While it's true that we can minimize the effects of many of these variables, such compensation typically dictates the use of expensive, highly stable components and extensive shielding.

Now that we've looked at networks from an analog viewpoint, let's look at them from a digital perspective. In digital signal processing, the continuous time-domain signals we're used to in the analog world are sampled and quantitized to form a series of discrete digital words that correspond to the input signal. In other words, we take a snapshot of what the input signal looks like at a given point in time, quantify the information contained in the snapshot, and pass this data along to a processor. If this procedure is performed often enough, almost no information about the original continuous signal is lost. For many years this concept of obtaining discrete samples of a continuous signal was viewed as nothing more than a simulation tool. However, after careful analysis it became evident that this process could open the door to signal processing techniques that are difficult, if not impossible, to achieve by analog processing means.[2]

The first step in digital processing is to obtain an accurate sample of the input signal at regular time intervals. In many respects, sampling is like viewing a motion picture. Movie film consists of discrete samples of the light in a scene taken at a rate of 40 samples/second. However, when we view the film on a projector, our eyes integrate the discrete images into what appears to be continuous motion. In most cases the action on the screen looks to us as it would in real life. However, occasionally we will see things happen on the screen that didn't actually occur. For instance, if we are watching an old western and a wagon is tearing across the prairie to escape the outlaws, we may notice that at times the spokes of the wagon wheels appear to be standing still, or may even appear to be rotating backwards.[3] This effect is created when the repetition rate of an event equals or exceeds the sampling rate, and is referred to as aliasing. The only way to avoid aliasing is to make certain that the sampling rate is always at least twice the highest frequency to be sampled. While this is difficult to do in a movie where the film rate is fixed at 40 samples/second, it's much easier in digital sampling.

In digital sampling, we sample the incoming signal at a rate equal to what's known as the Nyquist rate. Simply put, the Nyquist rate is defined as 2BW, or twice the highest significant input frequency (including noise) to be sampled. To make certain that none of the input signals exceed one-half the Nyquist rate, a low-pass filter (called an anti-aliasing filter) precedes the input of the A/D converter (ADC). However, no filter is perfect, and in order to reduce the anti-aliasing filter requirements, some designers will oversample the input signal at 1.5 times the Nyquist rate or greater. While oversampling improves anti-aliasing performance, current DSP devices are limited in their ability to process high-frequency data signals—imposing limitations on the oversampling rate.

The sampling time is another important aspect of the sampling process, and is often referred to as the sampling aperture. Generally speaking, the higher the resolution of the ADC and the higher the input frequency, the narrower the sampling aperture must be. For instance, to realize the full resolution of a 16-bit ADC, the sampling aperture time must be about 5×10^{-8} seconds. A longer aperture time causes signal averaging, with a resulting loss of resolution.[4]

Sampling of the input signal is only part of the analog-digital conversion process. Once a continuous analog signal has been sampled, its amplitude must be quantitized by assigning it a numerical value and a polarity bit from a linear scale. The higher the resolution of the quantitizer, the more faithfully we can represent the signal in a digital format. As a result, quantization resolution is directly related to the dynamic range of the output of the ADC. For example, a

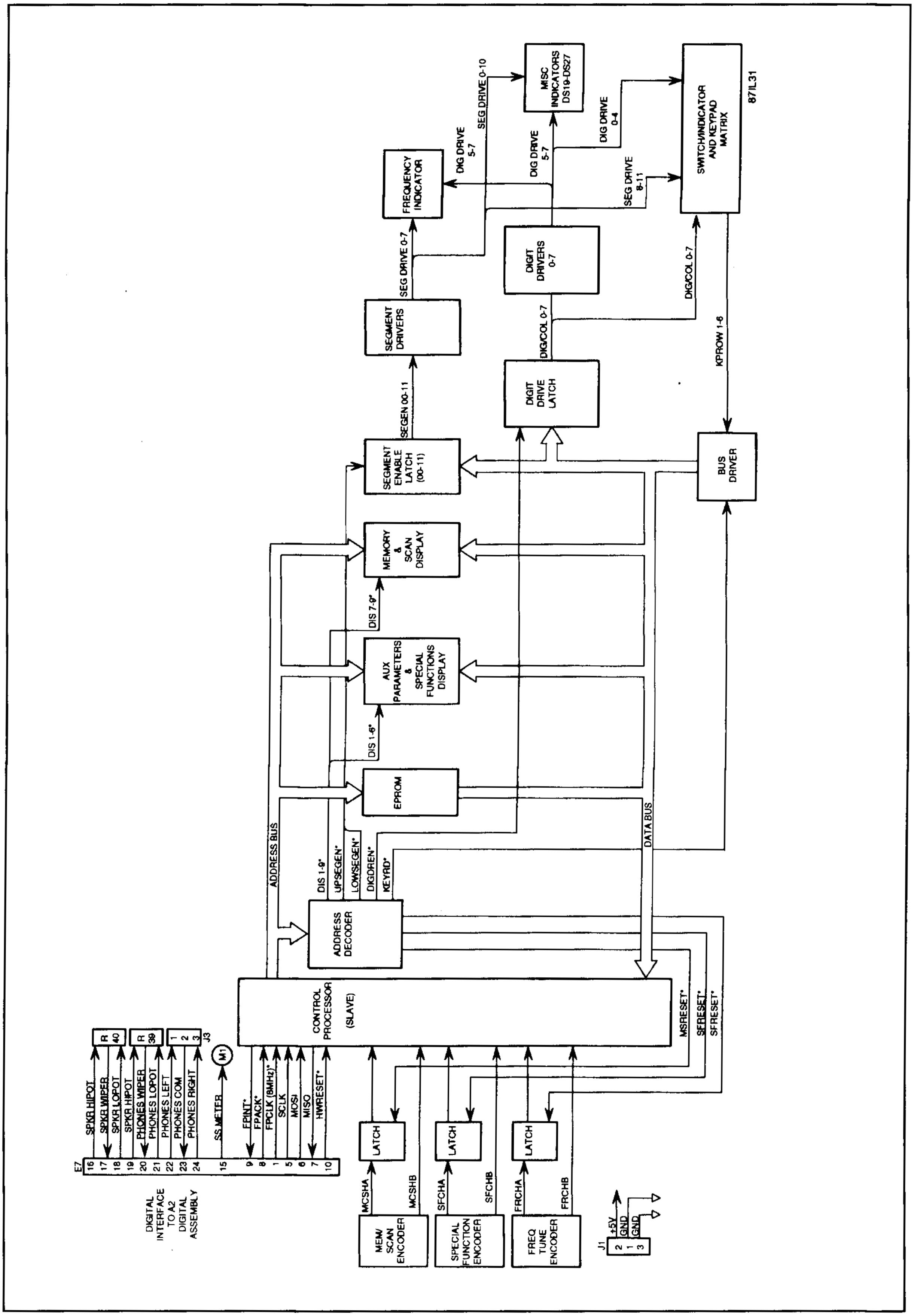


Figure 5. Type 797015-1 front panel assembly functional block diagram. (Reprinted with permission from Watkins-Johnson.)

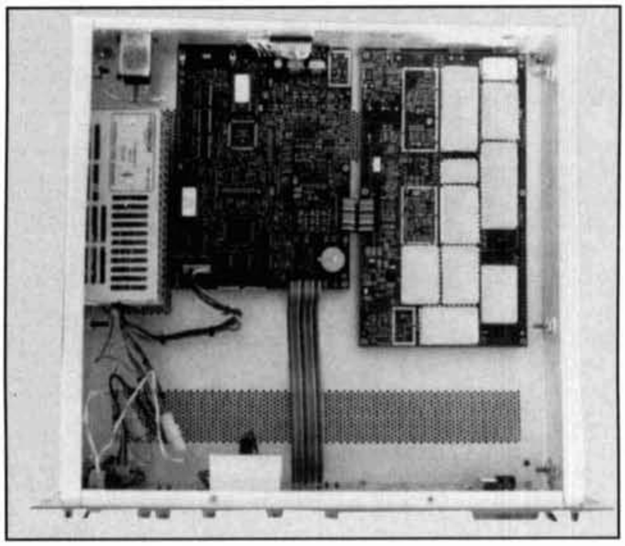


Photo A. View of RF assembly and digital assembly within HF-1000.

16-bit ADC has a resolution of $2^{(16-1)}$ or 1 part in 32,768. This equates to a dynamic range of 90 dB.[5] Even with this degree of dynamic range, it's important that the receiver incorporate some AGC before the analog-digital converter, to minimize the possibility of overloading this device.

A certain amount of error always occurs when a signal is quantitized, because very few samples match the linear quantization levels precisely. To compensate, the ADC rounds off each quantitized value to the nearest step. This quantization error creates noise. Consequently, high quantization resolution plays a large part in maintaining a high signal/noise ratio.

Once we have a quantitized bit stream corresponding to our input signal, we can manipulate this data in a digital signal processor. Depending upon our intentions, the DSP chip may be programmed to provide either recursive or nonrecursive filtering, or it may be programmed to provide demodulation, phase shifting, mixing, or a combination of these functions. Most DSP chips are based on the Harvard architecture, which uses separate data and memory space. This, in turn, allows simultaneous instruction prefetch and execution[6]. Consequently, a typical DSP can execute these functions so rapidly they appear to occur simultaneously.

Almost all data manipulation in a DSP device takes place in the frequency domain. The conversion from the time (data) domain to the frequency domain is performed using a linear transformation called the Fast Fourier Transform (FFT). By using the FFT, we can cause a DSP chip to manipulate the signal almost any way we desire via software. It's no longer necessary to have specific analog components dedicated to specific functions, such as filtering, demodulation, etc. If we need to do something specific to the signal, we simply write software to execute the necessary formula in the frequency domain and provide the desired result. For example, the DSP may be programmed to filter the signal using an FIR (Finite Impulse Response) filter (see **Figure 3**). In this example, a continuous time domain analog signal [x(t)] is converted to the data domain [x(n)] by an ADC. This data domain signal is processed by the DSP according to the formula for a finite impulse response (nonrecursive) filter, and the resulting data [y(n)] is converted back to a continuous analog signal in the time domain [y(t)] by a digital-analog converter.

Signal filtering was the first DSP application in communications receivers, but that's not the only function a DSP chip can perform. Because any type of modulation and demodulation can be expressed in the form of a function in the frequency domain, a DSP device can be used as a demodulator in a receiver or a modulator in a transmitter. For instance, the generation or demodulation of SSB signals is accomplished easily using the precise phase-shifting capabilities of a linear transformation known as the Hilbert Transformer, along with the modulation/demodulation of complex signals in the frequency domain.

There's really no limit to the type of signal that can be processed using DSP. This means that, in the future, it will be simple to design multi-mode receivers and transceivers with a very low parts count. A DSP device can also be used for a number of ancillary applications, like noise blanking, notch filtering, AGC, bandpass tuning, and signal strength determination, to name a few.

In analog signal processing, the tolerance and stability of the components dictate how well a network performs. In digital signal processing, the ability to make calculations without overflow is a key limiting factor. For instance, most DSP chips use fixed-point fractional arithmetic, where the numbers used for calculation within the chip fall in the range of -1 to $[+1-2^{(-n-1)}]$. If we assume 16-bit data, this corresponds to a range of -1 to $+1-2^{-15}$ or $+0.999969$. If a calculation results in a number outside this range, an overflow condition will occur. Most DSP chips use saturation arithmetic to limit the value of the numbers in the accumulators to a maximum (saturated) value appropriate to prevent overflow.

DSP is an electrical engineer's dream come true. Formulas for filters, which have been established in textbooks and can only be approximated with analog components, come one step closer to reality in a DSP device. As a matter of fact, DSP can accomplish a few things that are impossible in the analog world. For example, analog bandpass filters always display a certain degree of phase shift across their passband. However, an FIR filter implemented in DSP displays a phase-flat signal that's ideal for high-speed data communications where phase shift must be kept to a minimum.

In most applications, once the digital signal has been processed by the DSP, it must be converted back to analog. This is done using a sample-and-hold digital-to-analog converter (DAC) that reverses the sampling procedure outlined here. A sample-and-hold DAC maintains its output voltage at the level of the last numerical input, generating a continuous signal from the sampled data. Just as signals applied to an ADC converter must be bandlimited to less than half the Nyquist rate to minimize aliasing, regenerated analog signals from the output of a DAC must be low-pass filtered as well. A filter design similar to that used on the input to the ADC should suffice, and the resulting signal can be processed using conventional analog techniques.

The HF-1000 digital control assembly

The digital control assembly provides the HF-1000 with signal processing power far greater than anything we have known before. This assembly consists of three sections: 1) an ADC, 2) a digital signal processor, and 3) a DAC/signal demultiplexer. Also included on this card is a host microprocessor and interface circuitry to support RS-232 or CSMA (Carrier Sense Multiple Access) remote control. This allows all receiver functions to be controlled via an external computer (see **Figure 4**).

On the digital control card, the 25-kHz 3rd IF differential input from the RF assembly is routed to a Motorola DSP56ADC16 ADC that samples and converts the incoming signal into 16-bit, 2's complement serial data frames at a 100-kHz rate. Although the Nyquist rate for an IF of 25 kHz is only 50 kHz, WJ chose to oversample at twice the Nyquist rate to minimize the requirements of the ADC anti-aliasing filter. The ADC also provides frame synchronization and a serial data clock, used to reconstruct the digital signals processed by the DSP.

Following the ADC, the synchronous serial bit stream passes to the Motorola DSP56001-FE33 digital signal processing chip. The 56001 is a 24-bit, fixed-point processor using saturation arithmetic to minimize overflow errors. The 24-bit word size provides 144 dB of dynamic range, leaving plenty of room for calculations on 16-bit data. In addition, a 56-bit accumulator internal to the 56001 provides 336 dB of dynamic range to eliminate the possibility of error during any intermediate computations. The 56001 uses dual Harvard architecture with three independent memories and memory buses. This allows the chip to move two operands to its multiply/accumulator while simultaneously fetching a program instruction.[7] The 56001 runs at 16.5 million instructions per second (MIPS) when using the 33 MHz clock, and can execute a 1024-point complex Fast Fourier Transform in 1.98 milliseconds.[8]

To be useful, the processed serial data from the 56001 DSP chip must be converted back to analog form. However, the serial data from the 56001 contains additional information it didn't have when the signal came in—namely demodulated audio. The multiplexed IF/audio data stream passes through a DAC and then to a demultiplexer, where the frame synchronization and serial data clock signals from the ADC separate the audio and IF signals. The recovered 25-kHz analog IF is mixed with the 430-kHz 3rd LO to produce a processed 455-kHz IF output; the recovered analog audio is split between two line amplifiers and an internal monitor speaker amplifier. When the receiver is used in the ISB mode, the two line amplifiers each carry audio from one sideband. In any other mode, both line amplifiers carry identical audio signals. The internal monitor speaker amplifier includes a front panel switch that lets you select either upper or lower sideband audio in the ISB mode.

The core component on the digital assembly is a Motorola 68HC11 microcontroller. Virtually every aspect of the receiver is affected in one way or another by this controller. It does everything from executing a BITE (Built In Test Equipment) sequence when the unit is powered up to loading synthesizer data and DSP parameters, providing communications with the slave processor on the front panel, and providing communication via one of the remote-control I/O ports.

The HF-1000 front panel assembly

The HF-1000 front panel provides the essential human interface for the receiver (see **Figure 5**), and lets you change or adjust almost any parameter. The front panel is controlled by a microprocessor slaved to the main processor on the digital assembly. Because of this, WJ made extensive use of software-driven controls. For instance, a rotary control in the center of the front panel (called the Auxiliary Edit Control) can be used for anything from setting the demodulation mode to executing a BITE sequence, depending upon the settings of the electronically latching push buttons. The only analog controls available on the panel are for

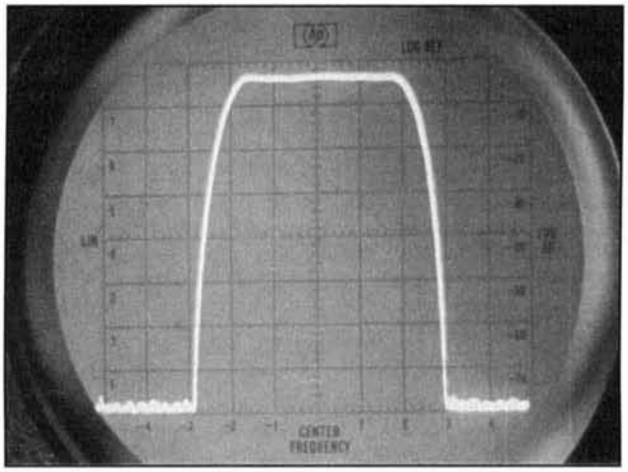


Photo B. IF frequency response with 2-kHz IF filter selected. Settings: vertical = 10 dB/division, dispersion = 500 Hz/division, resolution BW = 300 Hz.

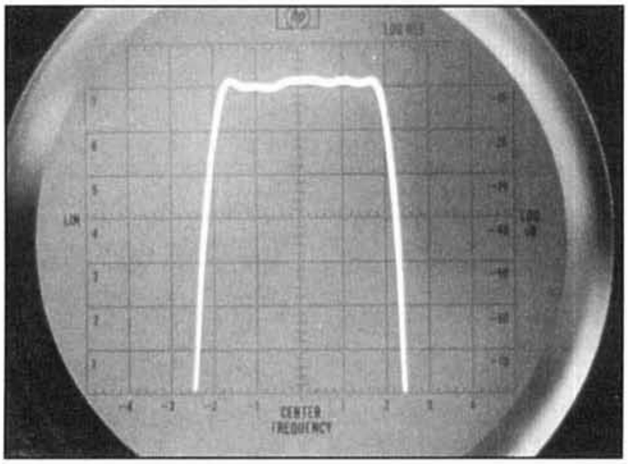


Photo C. IF frequency response with 2-kHz if filter selected. Settings: vertical = 2 dB/division, dispersion = 500 Hz/division, resolution BW = 300 Hz.

the monitor speaker and headphone volume, and the manual gain.

Packaging

The HF-1000 is packaged in a 19-inch relay-rack aluminum cabinet measuring 5.25 inches high by 19 inches wide by 20 inches deep. In spite of its size, the receiver only weighs 15 pounds. The unit is so deceptively light, that when I took my evaluation unit out of the box, I thought WJ had inadvertently sent me a non-working dummy unit! The HF-1000's weight is certainly a far cry from the receivers of yesteryear, where you ran the risk of getting a hernia just putting it into the rack.

To say the least, the HF-1000 cabinet is much larger than necessary for its circuitry. The digital and RF assemblies take up no more than about 50 percent of the available space on the bottom pan of the cabinet (see **Photo A**). Although a large portion of the total volume of the cabinet remains unused, the HF-1000 was packaged this way so it could replace existing rack-mounted gear in military or maritime applications where the depth of the receiver may be critical for cabling. The receiver is also deep enough to support the attachment of slide rails. Four plastic mounting feet are available for desk-top operation.

As you'd expect from WJ, the quality of components and workmanship in the HF-1000 is excellent. All circuit boards are thick glass-epoxy multi-layer cards with surface-mount components. Unlike an analog receiver, there are no potentiometers or trim caps to adjust. As a matter of fact, the only adjustment in the entire receiver is for the reference oscillator frequency.

Using the HF-1000

Despite its apparent complexity, the HF-1000 is surprisingly simple to use. I found I could execute about 90 percent of the receiver's features without referencing the manual. To help users develop a better "feel" for the control arrangement, WJ used a dark gray front panel, with light grey shading to draw attention to controls grouped by function. For instance, the controls that pertain to memory and scanner functions are grouped together on the left side of the panel with a light grey accent surrounding them, while controls associated with the DSP (bandwidth, mode, noise blanking, etc.) are grouped and accented in the center of the panel. The right side of the panel is dedicated to frequency entry—made either by numeric keypad or rotary control—with an accent around the keypad. To help you determine the status of the receiver at a glance, any key that "latches" when depressed has a small green LED in its center that lights when selected. All numeric and alphanumeric displays in the HF-1000 are green and, together with a smoked display lens, form a control panel that's very easy on the eyes.

Extensive software-driven controls on the front panel keep the number of knobs and switches to a minimum. To understand how this works, let's look at the receiver operating mode control.

If you want to select the CW mode, you can either press the DET MODE key until "CW" appears on the display, or press DET MODE once and rotate the Auxiliary Edit knob until "CW" appears. You can also select bandwidth, AGC parameters, noise blanking, and so on, simply by pressing the key associated with that function. While the sequencing takes some getting used to, it soon becomes second nature.

One aspect of the HF-1000 that I really liked is the method of frequency entry. The engineers at WJ acknowledge that we may think of frequency in either kHz *or* MHz. To address this human idiosyncrasy, they've made it possible to key the desired frequency in either format by depressing the appropriate MHz or kHz key to execute your entry. While this may sound like a small feature, you'd be amazed what an improvement it makes. If you prefer to browse through a band rather than enter a specific frequency, the rotary tuning can be set up to change frequency in decade increments between 1 Hz and 10 MHz. To indicate the tuning resolution at a glance, the digit corresponding to the tuning increment dims slightly at a 1 Hz rate. If you're tuning through a band where all stations are on a given spacing, you can select the STEP TUNE mode. In this mode, you program the receiver to step in any increment you desire up to 25 kHz. For instance, when tuning the European or Pacific broadcast band where stations are on 9 kHz spacing, simply tune the receiver to one end of the band, program 9.000 kHz as the step size, and depress "STEP TUNE." Depressing the up/down arrow keys on the keypad or turning the rotary tuning control will cause the receiver to step through the band in 9-kHz increments.

Remote control

Yet another important feature available in the HF-1000 is its remote control capability. All receiver functions can be read and changed by remote control. The unit will support both RS-232 (with XON/XOFF flow control) and CSMA (Carrier Sense Multiple Access). Both remote control modes run at any of the standard baud rates between 75 and 9600 bps. The RS-232 commands are sent as conventional ASCII characters, and the message format is simplicity itself. For example, a query requesting the status of the AGC is executed as AGC?. The receiver will return AGC X, where X corresponds to a number representing the status of that control (a chart in the manual translates these messages). When you query the receiver regarding its frequency (FRQ?), the receiver will return the tuned frequency to 1 Hz resolution.

Changes to any of the receiver's parameters are made in a similar format, where the numeric argument fits a *forgiving numeric representation* (nrf). In the nrf format, you need only enter enough digits of the command to make it unique. In the event a change command is attempted for a non-default setting (such as requesting a bandwidth the receiver doesn't support), the unit will default to the closest available setting. Likewise, if a frequency is entered that exceeds the receiver's precision, the unit will round up or down instead of truncating the numeric argument.

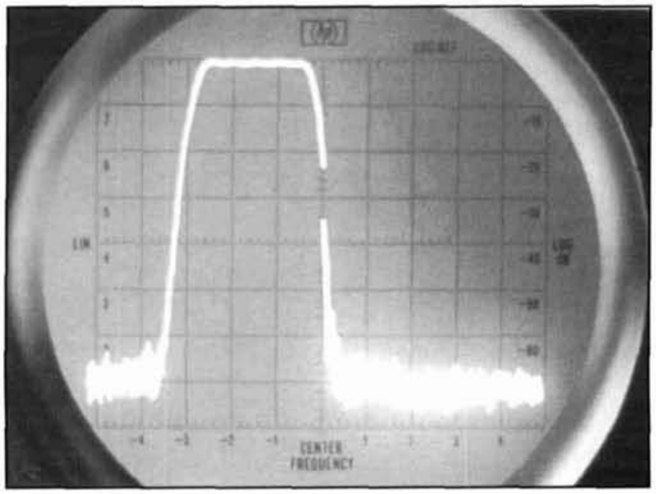


Photo D. IF frequency response with 56 Hz IF filter selected. Settings: vertical = 10 dB/division, dispersion = 20 Hz/division, resolution BW = 100 Hz.

The control command examples above are only applicable when using the receiver's RS-232 interface. If you opt to use the CSMA interface instead, all commands are carried out in a data packet format consisting of two hex preamble bytes, the receiving unit's hex address byte, the transmitting unit's hex address byte, a hex control code byte, a hex command byte, one or more variable-length BCD data bytes, and a hex end-of-message byte. The HF-1000 can be programmed to respond to any one address up to decimal 63.

Scanning and memories

No modern communications receiver is complete without frequency memories and a scanning function. The HF-1000 sets a new standard for this aspect of receiver operation, from the standpoint of both ease of use and functionality. The HF-1000 includes 100 programmable memories that store not only the frequency but the mode, AGC settings, manual gain level, BFO frequency, and squelch level. Although you should be able to store bandwidth as well, a bug in the current software prevents you from doing so. (I brought this to the attention of WJ and they intend to fix it in their next software release.) Entering a frequency into memory is simple; just rotate the memory edit control to display the desired memory location and press "CHANNEL STORE." All previously selected parameter settings will be written to this memory location. The frequencies in memory may be reviewed by pressing the "CHANNEL VIEW" button and rotating the edit control. Unfortunately, the channel view function won't display any of the receiver parameters stored in a given memory location.

One area where the HF-1000 really shines is

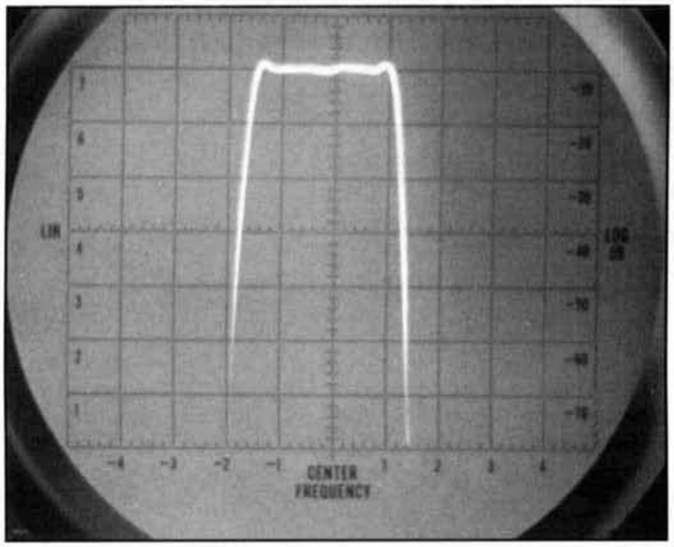


Photo E. IF frequency response with 56 Hz IF filter selected. Settings: vertical = 2 dB/division, dispersion = 20 Hz/division, resolution BW = 100 Hz.

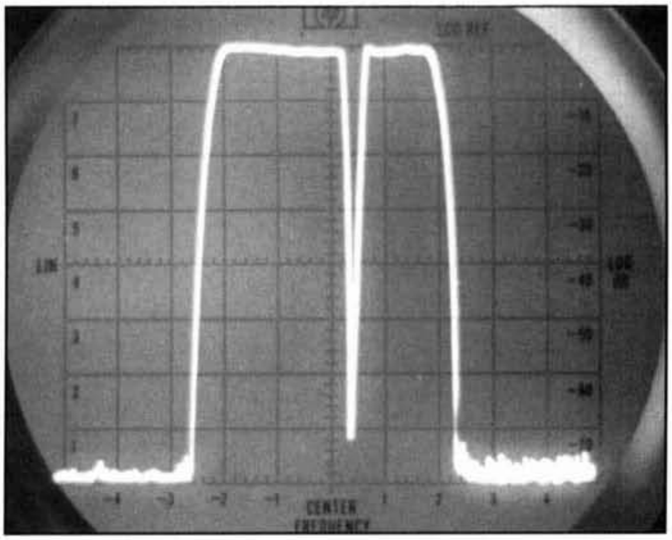


Photo F. IF frequency response with 8-kHz filter selected and 5-kHz notch filter enabled. Settings: vertical = 10 dB/division, dispersion = 2 kHz/division, resolution BW = 300 Hz.

in its ability to scan. In this application, the DSP really improves the functionality of this feature, as the receiver includes a squelch control that can be set in 1-dB increments. By programming the desired squelch threshold in dBm, only signals that meet or exceed this level will stop the scanner. This is a vast improvement over the trial-and-error method of setting the squelch in analog receivers. The HF-1000 can be set up to scan either memory locations or a specified frequency range. Channels that you want to retain in memory but exclude when scanning can be toggled between "included" and "skip." An "i" or "s" will appear on the display beside the memory location. The channel dwell time is programmable from 0.1 to 99.99 seconds, or it may be set to "infinite."

So, what's it like to use a digital receiver? It's unbelievable! The receiver's almost crunch-proof front-end combined with DSP makes the HF-1000 the most enjoyable receiver I've ever operated. The skirts of the IF bandpass are so steep that the receiver brings a whole new meaning to the word "selectivity." When I swept the IF filters using an H/P 8553B-8552B Spectrum Analyzer and an H/P 8443A Tracking Generator, I found that all of the filters easily met or exceeded their specified shape factors. In addition, they displayed an exceptionally flat passband with almost no discernible ripple (see **Photos B** through **F**). **Photos B** and **C** show the swept response of the 2-kHz IF filter. In **Photo B**, the spectrum analyzer was set up for a vertical sensitivity of 10 dB/division with a dispersion of 500 Hz/division, and a resolution bandwidth of 300 Hz. As this picture shows, the –60/–3 dB shape factor was an impressive 1.3. **Photo C** depicts the passband ripple of the 2-kHz filter with the analyzer vertical sensitivity set to 2 dB/division. As you can see, ripple was less than 0.3 dB P-P. In **Photo D**, the 56-Hz IF filter was swept with the analyzer set up for 10 dB/division vertical sensitivity, and a dispersion of 20 Hz/division. (The trace is off-center due to spectrum analyzer drift at this narrow dispersion.) Once again, the –60/–3 dB shape factor was an impressive 1.3 (try to emulate that shape factor with an analog filter of the same bandwidth!). **Photo E** magnifies the 56-Hz filter response to show the passband ripple using a 2 dB/division vertical scale. Again, total ripple was less than 0.3 dB P-P. Finally, **Photo F** illustrates the effectiveness of the notch filter. In this photo, the 8-kHz IF filter was selected, and the 5-kHz notch filter was enabled. The vertical sensitivity was 10 dB/division, the dispersion was 2 kHz/division, and the resolution bandwidth was 300 Hz. As this photo shows, the total depth of the 5-kHz notch was an impressive 72 dB, and the –3 dB notch width was only 700 Hz. The –60/–3 dB shape factor for the IF filter measured 1.25. If there's any one aspect of the HF-1000 that outperforms anything I've ever seen before, it's the IF selectivity. As the photographs indicate, the DSP emulates textbook filter performance—even at extremely narrow bandwidths.

Armed with the results of these measurements, one of my tests included tuning across the crowded 49-meter international broadcast band at night with the IF bandwidth set to 4.4 kHz. As you move through the band, there's no evidence whatsoever of the familiar 5-kHz interchannel beat note, and the receiver almost seems to "drop" into each 5-kHz channel. On

CW, the narrow filters combined with their steep skirts provide unbelievable selectivity under the most crowded band conditions. With 58 bandwidths available in the HF-1000, it seems unlikely that you'll encounter a situation in which you cannot find the appropriate degree of selectivity.

While selectivity is certainly important, other factors such as front-end dynamic range, noise blanker performance, and AGC effectiveness, all play a part. When I was looking at dynamic range, the HF-1000 passed one of my most difficult tests—low intermodulation on the AM broadcast band. At my test location, I have several high-power broadcast stations that induce about 0.5 volts into my antenna system. Most communications receivers, even those with excellent front-end selectivity like the Collins R-390A, display intermodulation products at certain frequencies in the broadcast band using this antenna. However, the HF-1000 is the first receiver I've ever tested that doesn't show any signs of these spurious signals (unless the preamplifier is turned on, at which point the situation changes dramatically). The HF-1000 did display a few intermodulation products in the 1.6 to 1.7 MHz range, but they were quite weak. No other receiver I've tested has performed this well.

The noise blanker is another unusually effective portion of the receiver. In many respects, the blanker design is much like the analog device used in the Drake R8.[9] This device incorporated a pulse differentiator and an audio hold circuit that eliminated blanking "holes." While the exact function used to provide blanking in the HF-1000 isn't quite clear, the DSP executes a similar action. I'm almost certain that the DSP performs its blanking analysis in the frequency domain, where the characteristic spectra of impulse signals is readily distinguishable. The blanker in the HF-1000 is extremely effective; in many cases it can completely eliminate impulsive interference. The 10 threshold levels are a bit excessive, however, as I found that the lower settings (i.e., 1 through 7) have a very minimal effect in most instances.

I tested the receiver in all of its demodulation modes, and found nothing unusual in their operation. Of the seven modes available, the full complement of 58 bandwidths is only available in the CW, FM, AM, and synchronous AM modes. In the LSB and USB modes, 16 bandwidths are available from 0.9 to 3.2 kHz, and eight are available in the ISB mode (1.8 to 3.2 kHz). Surprisingly, in spite of its implementation in the DSP, the AM synchronous detector won't hold reliable lock on weak SSB[12] transmissions, such as HCJB on 17.490 MHz. This was its only shortcoming, as the detector provided superb synchronous detection performance on full-carrier AM signals.

One aspect of the HF-1000 that really caught my attention was, of all things, the "S" meter. In a typical analog receiver, the S-meter is accurate only when the RF gain is fully advanced and the front-end preamplifier or attenuator is turned off. In the HF-1000, the S-meter reading is unaffected by any gain settings in the receiver. For example, if you're tuned to a signal that reads −110 dBm on the S-meter and you turn on the preamplifier, you'll hear the S/N ratio of the signal improve; but, the S-meter will continue to read −110 dBm. WJ chose this approach for one simple reason: An S-meter should indicate the signal strength, not how much the receiver is manipulating the signal. While it takes a bit of getting used to, this is by far the most accurate method of measuring signal strength I've ever seen on a communications receiver.

Conclusion

Clearly, with the introduction of the HF-1000, Watkins-Johnson has made a brilliant move into the future of communications receivers. Soon, such DSP implementations will become commonplace, not only in commercial gear but in our homebrew equipment as well. As DSP technology becomes more powerful, fewer conversion stages will be required, with all the associated benefits. However, even with the design limitations imposed by the current state-of-the-art, WJ has proven that a well-designed analog RF section combined with DSP can provide truly exemplary performance.

Anyone that looks upon the DSP revolution with disdain should think twice. I'll be the first to admit that the signal processing that takes place in the digital receiver isn't intuitive, like that in its analog counterpart, nor is there anything particularly romantic about surface-mount technology. Like the many milestones in analog receiver development over the years, this was the next vital step. When properly implemented, DSP can run rings around our long established analog circuits. Unlike analog circuits that require actual component changes or additions to alter their performance or application, DSP allows us to make massive changes via a keyboard. Where hams of yesteryear spent hours with a diddle-stick stagger-tuning their IF transformers, improving their VFO linearity and front-end tracking, etc., hams of the future will "diddle" with their receivers using a computer communicating with the receiver's DSP. Although it's not perfect, DSP is the closest we've come to realizing the ultimate receiver.

One final note. Today's digital receiver is nothing more than a vastly improved communications tool. The medium is not the message, as some have implied. The digital radio provides us with a greatly improved means of communicating with one another via RF. In the end, we decide what language to use.

Acknowledgments

I'd like to take this opportunity to thank Mr. Mike Cox with the Watkins-Johnson company for his help in procuring an evaluation receiver, as well as providing insight into the design of the unit. I'd also like to thank Mr. Ben Scott and Mr. Steve Lansdown with Motorola for providing documentation on the Motorola DSP devices used in the HF-1000. Finally, I'd like to thank Mr. David Capella with Siliconix for providing information on the design of high-performance commutating mixers. ■

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PRODUCT INFORMATION

Ten-Tec DSP Based HF Monitor

Ten-Tec, Inc. has introduced a DSP based HF monitor receiver that covers .5–30 MHz on SSB, CW, ISB, AM, Synchronous AM and FM. RX-330A provides +30 dBm 3rd order performance and is designed specifically for remote controlled applications. A multi-drop RS-232 interface permits simultaneous operation of multiple receivers on a single network. The design flexibility of DSP provides 57 standard selectivity choices from 100 Hz to 16 kHz.

For additional information, contact Tom Salvetti at 800-231-8842; or write to Ten-Tec, Inc., 1185 Dolly Parton Parkway, Sevierville, TN 37862.

New Features for AEA's PK-96 Packet Controller

The PK-96 1200/9600 bps Packet controller from Advanced Electronic Applications, Inc. can now be a component in a TheNet network at 1200 or 9600 bps. The TheNet compatibility of the PK-96 allows node-builders to add a 9600 bps port to an existing mountain-top network. The PK-96 has always been able to connect to a TheNet network at 1200 bps. Being able to connect to a TheNet network lets a packet user on one frequency to connect with a network located on a hill and communicate with other packet users on different frequencies. The network also allows cross-frequency communication so that all users can communicate with each other in one forum, regardless of frequency.

Dave Roberts, G8KBB, has written a version of TheNet X1J especially for the PK-96. The PK-96 can now be part of the network. A special version of TheNet is now available for the PK-96 at 1200 bps and 9600 bps. This means that network builders can add a 9600 bps port to an existing mountain-top network. The PK-96 utilizes HDLC hardware, comes with 32K RAM and is upgradable to 128K, and the adjustment controls are on the back panel.

There are two ways that network operators can acquire TheNet software for the PK-96. One, AEA will send you an initialization disk and an EPROM, you fill in the parameters and burn your own EPROM. Two, AEA will send you an initialization disk to fill out (listing the parameters you wish to have set on your PK-96), you then send the disk back to AEA. AEA will take this information and burn a chip for you and send you the EPROM in the mail. The first option is $10.00. The second option is $30.00 plus $5.50 shipping and handling. This version of TheNet was designed specifically for the PK-96.

For more information, contact AEA at 206-774-5554; or write: Advanced Electronic Applications, Inc., P.O. Box C2160, Lynnwood, WA 98036 (fax: 206-775-2340).

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SOURCE DATA DISPLAY PROGRAM FOR ELNEC

Use this stand-alone program to plot or print data using ELNEC files

In the past, antenna analysis was most often performed by experts. Such analysis was tedious, complex work that required a knowledge of higher-level mathematics. Nowadays, there are a number of antenna analysis programs on the amateur radio market that provide fast and accurate methods of analysis, and don't require the user to be an antenna expert.

One very popular program, ELNEC, was developed by Roy Lewallen, W7EL. ELNEC is user-friendly and contains many excellent features.The program provides for graphical output of impedance when making a frequency sweep. It does this by generating files that can be read directly by MicroSmith—a program sold by the ARRL. The graph produced is in the form of a Smith chart. However, I want a bit more versatility and additional capabilities than those offered by ELNEC, so I designed a stand-alone program to meet my needs. My program is written in BASIC, and either graphically plots or prints a table of these parameters using a file from ELNEC.

ELNEC source data format

When you implement ELNEC's frequency sweep option, source data is stored in a frequency sweep data file. Once a sweep has been completed, you must use the program's

```
                              Source Data
Frequency=14 MHz

Source 1                Voltage=8.9715E+01 V. at -31.314 deg
                        Current=1.0000E+00 A. at 0.000 deg
                        Impedance=76.6465-J 46.6271 ohms
                        Power=7.6647E+01 watts
                        SWR (50 ohm system)=2.322 (75 ohm system)=1.833

                              Source Data
Frequency=14.2 MHz

Source 1                Voltage=8.3259E+01 V. at -19.209 deg
                        Current=1.0000E+00 A. at 0.00 deg
                        Impedance=78.6232-J 27.3934 ohms
                        Power=7.8623E+01 watts
                        SWR (50 ohm system)=1.862 (75 ohm system)=1.430
```

Figure 1. Display of source data frequency sweep using "browse."

```
Include path if not in C:\ELNEC (.GAM is added to the file)
FILE NAME?

1:TABLE
2:TABLE TO PRINTER
3:PLOT ON SCREEN
4:NEW FILE
5:EXIT
```

Figure 2. PLOTZS selection menu.

"browse" function to examine the results in the file. The browse function is very similar to a text editor; it lets you open and read the data in a file. To give you an idea of how this works, I made a frequency sweep of source data from a dipole. ELNEC's browse function displayed the results in **Figure 1**.

Data can be displayed for only three frequencies at a time, because this amount of data fills the entire screen. To examine the remaining results, you must scroll through the data file using the up/down arrow keys. Keep in mind that, no matter how large the file is, only three frequencies can be displayed at a time. You can send a copy of this file to a printer if you exit out of ELNEC and use the DOS PRINT command; however, the printout for a large number of frequencies may be somewhat cumbersome in this format.

This isn't necessarily a negative point—especially if you only need source data for a few frequencies. On the other hand, if your analysis requirements incorporate many frequencies, this type of format can make it tedious to review the results. Also, when exam-

ANTENNA INPUT IMPEDANCE and VSWR

1/2 wavelength 40 meter dipole 60 feet above ground
Zo=50 ohms 11-05-1994 19:38:14

F (MHz)	RE(ohms)	IMAG(ohms)	VSWR
7	79.89534	-33.79345	2.012771
7.01	80.10319	-31.28772	1.960635
7.02	80.31097	-28.7804	1.912086
7.030001	80.51868	-26.27466	1.86729
7.040001	80.72609	-23.77039	1.826346
7.050001	80.93372	-21.26318	1.789319
7.060001	81.14114	-18.75719	1.756411
7.070002	81.34867	-16.25037	1.727747
7.080002	81.55598	-13.74292	1.703477
7.090002	81.76326	-11.23657	1.683764
7.100002	81.97059	-8.728268	1.668709
7.110003	82.17812	-6.219482	1.658432
7.120003	82.38533	-3.710814	1.652989
7.130003	82.59229	-1.203735	1.6524
7.140003	82.79964	1.306762	1.656642
7.150003	83.00674	3.816407	1.665632
7.160004	83.21397	6.326173	1.679257
7.170004	83.4211	8.837159	1.697366
7.180004	83.62816	11.34716	1.719767
7.190004	83.83537	13.85925	1.746297
7.200005	84.04256	16.37256	1.776756
7.210005	84.24977	18.88672	1.810952
7.220005	84.4569	21.39917	1.848665
7.230005	84.66435	23.91577	1.889815
7.240005	84.87138	26.42981	1.934138
7.250006	85.0789	28.94884	1.981636
7.260006	85.28602	31.46350	2.032007
7.270006	85.49368	33.98352	2.085342
7.280006	85.7012	36.50281	2.14142
7.290007	85.90868	39.02234	2.200182
7.300007	86.11639	41.54481	2.261623

Figure 3. Impedance and VSWR table.

ining a large number of data points, you may find it difficult to comprehend how the data is behaving over frequency because you have a limited view of the information.

PLOTZS program

My BASIC program, PLOTZS, uses an ELNEC-generated file to display the source data. ELNEC's frequency sweep menu provides the option of creating this file—a MicroSmith file—which contains the information needed to display the source data. A MicroSmith file has an ASCII format and is structured as follows: reference impedance Zo, frequency #1, reflection coefficient magnitude @f1, reflection coefficient phase @f1,→ Fn, reflection coefficient @fn, reflection angle @fn. The PLOTZS program reads a designated MicroSmith file and then calculates the impedance and VSWR over the swept frequency range. Impedance and VSWR calculations are based on **Equations 1, 2,** and **3** below:

$$Z_{in} = \left(\frac{1+\rho}{1-\rho}\right) \times Z_o$$

noting the ρ is complex (contains magnitude and phase) then (1)

$$Z_{in} = Z_o \left(\frac{1 + \rho \cos \Theta + j \rho \sin \Theta}{1 - \rho \cos \Theta - j \rho \sin \Theta}\right) \tag{2}$$

$$\text{VSWR} = \frac{1+\rho}{1-\rho} \tag{3}$$

I wrote the program in Microsoft QuickBasic version 4.5. Because my goal was to allow other users to modify or copy the program easily, PLOTZS was kept as simple as possible. Although QuickBasic doesn't require line numbers, I included them to make the program compatible with other types of BASIC. If you look at **Figure 2**, you'll note that MicroSmith files have a ".GAM" file extension, which PLOTZS automatically truncates onto the file name when you type it in. As a result, you need only remember the file name and don't have to worry about file extensions.

Now that I've discussed the program's core features, let's give PLOTZS an actual example to run. Using ELNEC, calculate the source data for a 1/2-wavelength 40-meter dipole, 60 feet above ground. With ELNEC running (I use version 3.04), enter the frequency sweep mode and select source data. Next, select SN, type in a name for the MicroSmith file to which you want the source data saved, and enter the frequency sweep limits. Then return to the main menu, run ELENC, and exit out of the program when you've completed your analysis. Start PLOTZS. The menu in **Figure 2** will appear on the screen.

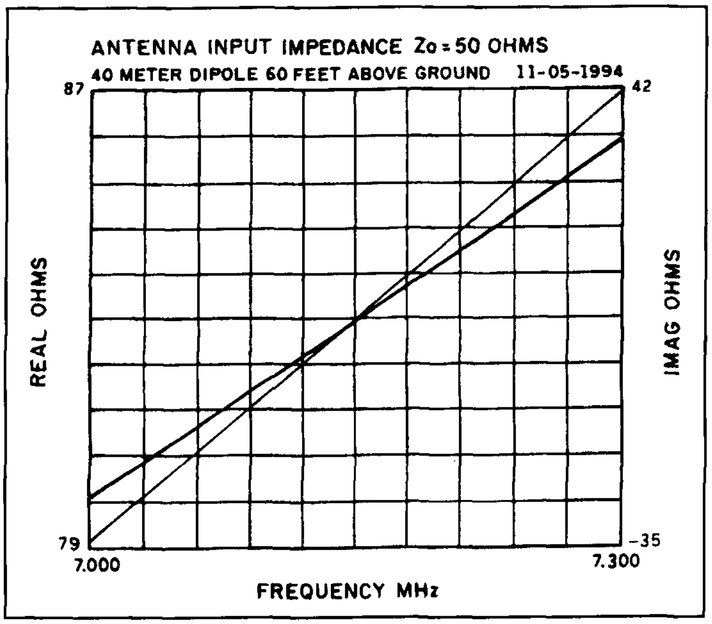

Figure 4. Impedance plot for 40-meter diople. The heavy line represents the real part, plotted in green. The thin line is the imaginary part, plotted in red.

After entering the MicroSmith file name (remember that .GAM is added to the name), make a selection from the five choices in the menu. If you choose one of the first two selections, you have the option of displaying a table of the source data on the screen or sending it to a printer. For any of the first three selections (1, 2, or 3), you may enter a line of text for a title or description. When you select a table from the menu, a specified printing area is set up using the view print command in QuickBasic. This allows data to be printed only in lines 5 to 25 on the screen. The program also detects the number of lines being printed and pauses the screen when the table is full. When this condition is detected, the program prints the —— MORE—— message at the bottom of the table indicating the screen is paused and there's more data. To view the remaining data, press any key. Without this feature the source data would scroll continuously until it reached the end of the file, making it impossible to read—especially on a fast computer. Now let's display the source data from our example in table form, as seen in **Figure 3**.

If you select number 3, PLOT ON SCREEN, from the menu, you'll see the notations 1:Impedance or 2:VSWR on the screen. You can plot the impedance or VSWR and enter a line of text for each one. In the plotting routine, the X and Y axis of the graph is set up for ten major divisions. The program calculates the maximum and minimum data points then autoscales the graph accordingly. The top left

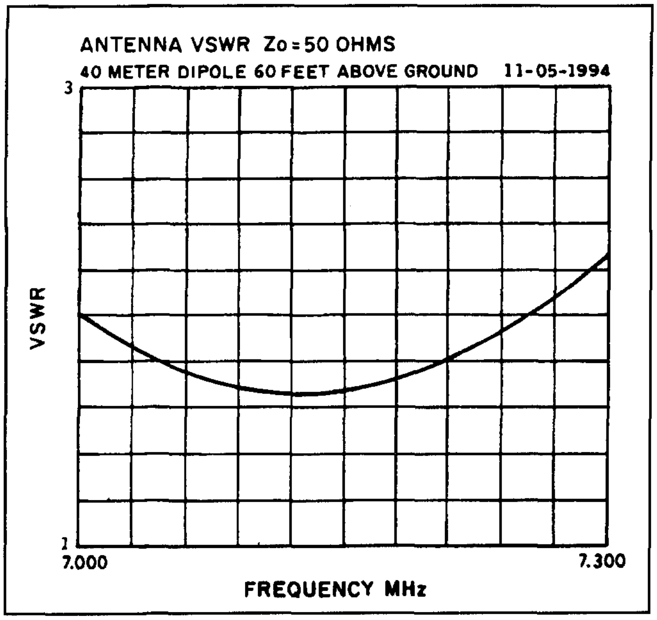

Figure 5. VSWR plot for 40-meter dipole.

side of the graph is reserved for the title or description you typed in previously. The impedance is plotted as R±jX, where the real part is plotted in green and the imaginary part is in red. A plot of the 40-meter dipole's impedance and VSWR is shown in **Figures 4** and **5**. To send a copy of the graph to your printer, press the (Shift-Print Screen) key on the keyboard. Note that to print the graphic information displayed on the screen correctly, you must execute Graphics.Com at the MS-DOS prompt *before* running PLOTZS. To return to the main menu just press any key.

Because my computer, and those of many of others, has a VGA (video graphics adapter 640 dots by 350 dots, with 16 colors), I took advantage of this high resolution and wrote the program to operate in this mode. I could have expanded PLOTZS to automatically detect and change the required program parameters for other graphic modes (i.e., CGA, EGA, MCGA, HERCULES), but this would have defeated the purpose of keeping the BASIC program code simple. Those of you with an EGA system can use the quick fix below. Simply change the following lines in the program:

```
840 SCREEN 8: VIEW (80,75)-(550, 190), , 7
920 LOCATE 23.8
930 LOCATE 23,66
940 LOCATE 23,32
1150 LOCATE 5,1
1160 LOCATE 21,1
1180 LOCATE 21,71
```

Conclusion

As the examples illustrate, source data is now presented in a format that's easy to read and analyze. In addition, you have the capability of printing a hard copy of this data. By saving your MicroSmith files, you can build a library of source data for your various antenna designs and retrieve them at any time using POLTZS. Although PLOTZS must be run separately from ELNEC, it makes a great addition to this program. ■

APPENDIX 1 PLOTZS QUICKBASIC CODE

```
100 REM**PROGRAM TO PLOT OR PRINT SOURCE DATA FOR AN ELNEC (.GAM)
FILE**
110 REM WRITTEN BY TOM CEFALO JR WA1SPI 10/17/94
120 CLEAR : CLS : PI = 3.1415927#: CNV = PI / 180: GOSUB 1260
130 PRINT : PRINT "INCLUDE PATH IF NOT IN C:\ELNEC (.GAM is added to file)"
140 INPUT "FILE NAME"; FILE$ = FILE$ + ".GAM"
150 OPEN FILE$ FOR INPUT AS #1: C = 0 'FIND SIZE OF .GAM FILE
160 IF EOF(1) THEN 180
170 INPUT #1, DUMMY: C = C + 1: GOTO 160
180 S = (C - 1) / 3: DIM FS(S), RHO(S), ANG(S), RE(S), IM(S), VSWR(S)
190 D$ = DATE$: T$ = TIME$: S = S - 1
200 CLOSE #1:  OPEN FILE$ FOR INPUT AS #1: PRINT  :  PRINT
210 INPUT #1, ZREF: C = 0  'PUT DATA INTO ARRAYS
220 FOR C = O TO S
230 INPUT #1, FS(C): INPUT #1, RHO(C): INPUT #1, ANG(C): NEXT C
240 CLOSE #1
250 FOR C = O TO S
260 RE1 = RHO(C) * COS(ANG(C) * CNV): IM1 = RHO(C) * SIN(ANG(C) * CNV)
270 ZIN = SQR((ZREF*(1 + RE1)) ^ 2+(ZREF*IM1)^ 2)/SQR((1 - RE1)^^2+(IM1)^ 2)
280 THETA = ATN(IM1  /  (1 + RE1)) - ATN (-1 * IM1  /  (1 - RE1))
290 RE(C)  = ZIN * COS(THETA):  IM(C) = ZIN * SIN(THETA)
```

```
300 VSWR(C) = (1 + RHO(C))  /  (1 – RHO(C)): NEXT C
310 PRINT  “1:TABLE”: PRINT “2:TABLE TO PRINTER”: PRINT  “3:PLOT ON SCREEN”
320 PRINT “4:NEW FILE”:  PRINT “5:EXIT”:  INPUT “ENTER SELECTION”; FLAT1
330 ON FLAG1 GOSUB 370, 490, 580, 350, 360
340 CLS : GOSUB 1260: PRINT : GOTO 310
350 ERASE FS, RHO, ANG, RE, IM, VSWR: GOTO 140
360 CLS : END
370 REM ***********PRINT DATA TO SCREEN***********
380 PRINT “For a”; ZREF; “ohm system”
390 CLS : PRINT DATE$, TAB(20); “ANTENNA INPUT IMPEDANCE”, T$
400 PRINT : PRINT “F(MHz)”, TAB(16); “RE(ohms)”, “IMAG(ohms)”, “  VSWR”
410 PRINT “--------------------------------------------------”
420 VIEW PRINT 6 TO 25
430 FOR C = O TO S: PRINT FS(C), RE(C), IM(C), VSWR(C)
440 IF C=17 OR C=36 OR C=55 OR C=74 OR C=94 OR C=113 THEN GOSUB 470
450 NEXT C
460 IF INKEY$ = “ ” THEN 460 ELSE VIEW PRINT: CLS : RETURN
470 PRINT “------------MORE------------”
480 IF INKEY$ = “ ” THEN 480 ELSE VIEW PRINT 6 TO 25:  : CLS 2: RETURN
490 REM ***********DATA TO PRINTER***********
500 INPUT “ENTER TABLE TITLE (return for none)”; TITLE$
510 LPRINT TAB(10); “ANTENNA INPUT IMPEDANCE and VSWR”: LPRINT
520 LPRINT : LPRINT TITLE$
530 LPRINT “Zo=”; ZREF; “ohms”, D$, T$: LPRINT
540 LPRINT “ F (MHz)”, TAB(16); “RE(ohms)”, “ VSWR”
550 LPRINT “-----------------------------------------------------”
560 FOR C = O TO S: LPRINT FS(C), RE(C), IM(C), VSWR(C)
570 NEXT C: CLS  : RETURN
580 REM***********PLOT DATA ON SCREEN***********
590 INPUT “1:IMPEDANCE  2:VSWR”; FLAG2
600 INPUT “ENTER GRAPH TITLE (return for none)”; TITLE$
610 REM***********SCALE X-AXIS***********
620 X1  = FS(0): X2 = FS(S)
630 ON FLAG2 GOSUB 640, 760: RETURN
640 REM***********SCALE Y-AXIS FOR REAL PART***********
650 Y1 = RE(0): Y2 = Y1: FLAG3 = 1
660 FOR C = O TO S
670 IF RE(C) > Y2 = RE(C)
680 IF RE(C) – Y1 < 0 THEN Y1 = RE(C)
690 NEXT C: GOSUB 1210: GOSUB 830: GOSUB 850: GOSUB 870: GOSUB 960
700 REM***********SCALE Y-AXIS FOR IMAG PART***********
710 Y1 = 0: Y2 = 0: Y1 = IM(0): Y2 = Y1: FLAG3 = 0
720 FOR C = O TO S
730 IF IM(C) > Y2 THEN Y2 = IM(C)
740 IF IM(C) – Y1 < 0 THEN Y1 = IM(C)
750 NEXT C: GOSUB 1210: GOSUB 850: GOSUB 1020: RETURN
760 REM***********SCALE Y-AXIS FOR VSWR***********
770 Y1 = VSWR(0): Y2 = Y1: FLAG3 = 1
780 FOR C = O TO S
790 IF VSWR(C) > Y2 THEN Y2 = VSWR(C)
800 IF VSWR(C) – Y1 < 0 THEN Y1 = VSWR(C)
810 NEXT C: GOSUB 1210: GOSUB 830: GOSUB 850: GOSUB 870
820 GOSUB 1060: RETURN
830 REM***********SET VIEWPORT AND WINDOW***********
840 SCREEN 12: VIEW (80, 70) – (550, 405), , 7: RETURN
850 REM***********SET-UP WINDOW***********
860 WINDOW (X1, Y1) – (X2, Y2): RETURN
870 REM***********DRAW GRIDS***********
880 X3 = (X2 – X1) / 10: Y3 = (Y2 – Y1) / 10: X4 = X1: Y4 = Y1
890 FOR C = 1 TO 9
900 X4 = X4 + X3: LINE (X4, Y1) – (X4, Y2), 7
```

```
910  Y4 = Y4 + Y3: LINE (X1, Y4) - (X2, Y4), 7
920  NEXT C: LOCATE 27, 8: PRINT USING “###.###”; X1
930  LOCATE 27, 66: PRINT USING “###.###”; X2
940  LOCATE 28, 32: PRINT “ FREQUENCY MHz”
950  LOCATE 4, 11: PRINT TITLE$: LOCATE 4, 58: PRINT DATE$: RETURN
960  REM***********DRAW REAL PART***********
970  LOCATE 1, 20
980  PRINT “ANTENNA INPUT IMPEDANCE Zo=”; ZREF; “ohms”
990  Y$ = “REAL ohms”: GOSUB 1110: GOSUB 1150
1000  FOR C=0 TO S-1: LINE(FS(C), RE(C)) - (FS(C+1), RE(C+1)), 10: NEXT C
1010  RETURN
1020  REM***********DRAW IMAGINARY PART***********
1030  Y$ = “IMAG ohms”: GOSUB 1110: GOSUB 1170
1040  FOR C = O TO S - 1:LINE(FS(C), IM(C)) - (FS(C + 1), IM(C + 1)), 12: NEXT C
1050  GOSUB 1190: RETURN
1060  REM***********DRAW VSWR***********
1070  LOCATE 1, 25: PRINT “ANTENNA VSWR  Zo=”; ZREF; “ohms”
1080  Y$ = “VSWR”: GOSUB 1110: GOSUB 1150
1090  FOR C = O TO S-1:LINE(FS(C), VSWR(C)) - (FS(C+1), VSWR(C+1)), 10: NEXT C
1100  GOSUB 1190: RETURN
1110  FOR C = 1 TO LEN(Y$): N$ = MID$(Y$, 1, C)
1120  IF FLAG3 = 1 THEN LOCATE C + 11, 6 ELSE LOCATE C + 11, 73
1130  IF FLAG3 = 1 THEN COLOR 10 ELSE COLOR 12
1140  N$ = RIGHT$(N$, 1): PRINT N$: NEXT C: COLOR 15: RETURN
1150  LOCATE 5, 4: PRINT USING “#####”; Y2
1160  LOCATE 26, 4: PRINT USING “#####”; Y1: RETURN
1170  LOCATE 5, 71: PRINT USING “#####”; Y2
1180  LOCATE 26, 71: PRINT USING “#####”; Y1: RETURN
1190  IF INKEY$= “ ” THEN GOTO 1190
1200  SCREEN 0: WIDTH 80: COLOR 7: CLS : RETURN
1210  REM***********ROUND OF GRAPH NUMBERS***********
1220  IF INT(Y2) - Y2 = 0 THEN 1240
1230  IF SGN(Y2) = 1 THEN Y2 = INT(Y2) + 1 ELSE Y2 = FIX(Y2)
1240  IF INT(Y1) - Y2 = 0 THEN RETURN
1250  IF SGN(Y1) = 1 THEN Y1 = INT(Y1) ELSE Y1 = INT(Y1) - 1: RETURN
1260  COLORO, 7: PRINT “T. CEFALO Jr.”; TAB(33); “PLOTZS PROGRAM”; TAB(75);
“WA1SPI”
1270  COLOR 7, 0: RETURN
```

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QUARTERLY DEVICES

The secrets of "high-tech scrounging"

These days, trade publications and journals are rife with advertisements and product announcements for a veritable smorgasbord of exotic new RF devices. Make no mistake; these mouth-watering displays are put there to tempt us! Component manufacturers want us to know about these new devices—and they want us to try them out (after all, today's innovative inventions become tomorrow's lucrative products).

However, seeing a device in a product review—and actually getting three or four in hand to try out—are two totally different propositions. Many new parts are downright difficult to find, and others may be heavily advertised long before they're ever released to distributors. Furthermore, even if we *do* find a source, small-quantity pricing on new products may be unreasonably high for the unfunded hobbyist, writer-experimenter, or basement entrepreneur—especially when you take into account those inevitable puffs of smoke that may accompany our first attempts at using any unfamiliar device.

For designers on a budget, there *has* to be a better way to get these new components onto the bench—and fortunately, there is! This edition of "Quarterly Devices" deals with the secrets of *high-tech scrounging*; that artful process which every resourceful designer must master in order to gain access to the world of high-tech R&D.

Why manufacturers provide engineering samples

Picture this scenario: the chief design engineer at Advanced High-Tech Radioworks, Inc. browses through his new copy of *ECN* (*Electronic Component News*). Suddenly, he spots a product release describing the newly invented ultra low noise XQB-FET from XYZ Devices. Realizing his prayers for a low-noise bullet-proof 10-GHz amplifier have been answered, he leaps to his feet and yells, "Yes! Yes! I must have this device!" In his excitement, will he cut a corporate purchase order to request five or six samples from a local distributor? Heck no; processing the paperwork would cost more than the parts are worth—and the distributor probably doesn't even know the new part exists! Instead, he calls the XYZ application engineer on the phone, asks a few pertinent technical questions, then requests a data sheet, application notes, and some samples. The next morning, a UPS Red Label package is sitting on his desk.

At first blush, this may look like a windfall—our designer just raked in half-a-dozen exotic state-of-the-art ultra-low noise transistors via overnight delivery for the price of a phone call! But consider the other half of the equation; XYZ has a brand new product on their hands that few people know about—and $250,000 in development costs to recoup! In this situation, *time is money*! It's very important to XYZ's management that customers learn about the new transistor quickly, find uses for it, and start placing orders. What's more, the actual cost per unit in materials and labor for these samples is probably only a fraction of the published small-quantity price. So, shipping a few freebies over to High-Tech may prove to be a good investment.

Although our designer may never get his 10-GHz project off the ground, there's always a possibility he *will* succeed, leading his company to purchase several thousand pieces of the XYZ device. Beyond that, our successful designer may go on to extol the virtues of XQB-FETS in professional journals and at seminars, thereby encouraging others to buy.

Putting it another way, if you own a company, you know that sales and marketing is unbearably expensive—but essential if you wish to stay in business. There are many ways to market a product, and the best marketing strategies usually depend upon type of product being offered. Manufacturers of heavy machinery or complex electronic test equipment don't have the luxury of passing out free samples to convince customers to buy.

Fortunately, high-tech RF component manufacturers, like drug companies, are in a different position. For one thing, they have an enormous investment tied up in professional research staff and facilities. Even if their products are small in size and cost almost nothing to produce, the amount of up-front money expended on development can be staggering. This investment must be recovered as soon as possible to maintain profitability, and the product's sale price will reflect that reality. At the same time, because the part itself is inexpensive to fabricate and easy to ship, sampling may be the most economical option for promoting it. The point I'm coming to is this; don't feel guilty about asking manufacturers for samples! Just as drug companies like to give pill samples to physicians, many electronic component manufactures like to get component samples into the hands of product designers, technical authors, and even serious experimenters. In this case, you're the doctor!

Identity crisis

Having said that sampling is a legitimate and economical sales strategy, lets look at the other side of the coin. Obviously, no manufacturer can afford to hand over unlimited quantities of goodies to every electronic dabbler who wants play with them. Not everyone can *qualify* to be the doctor! While you don't have to send a notarized copy of an EE degree and verification of your corporate title to be eligible for samples; you should be able to justify how your application might benefit the company at some future time. For example, will it result in a new design approach, a new product, a magazine article, a new communication record, or technological breakthrough, could it yield favorable publicity for the manufacturer? If companies are going to give you free stuff, they have a legitimate right to know what's in it for them. And, most important of all, you must be able to put on a professional face when dealing with the professionals in their sales organization.

Consider this scenario: you have XYZ's product announcement in front of you and the phone is comfortably cradled on your shoulder. A butter-smooth female voice on the other end of the line is asking the $64,000 question: "Sir, what is your title and what company do you represent?" If you happen to be a senior design engineer with Tektronics, you don't have an identity problem. But what if you're amateur radio station WØOPS working on a new preamplifier for your moonbounce setup? Or Rick Littlefield working on a construction article? And what if you're Sam Jones, laid-off engineer and attic entrepreneur, trying to invent something marketable so you can resume feeding your wife and kids on a regular basis? Do you put on fake glasses with a big nose and moustache and pretend to work for a non-existent company with a made-up name? I don't recommend it!

The fact is, you can tell the truth about who you are—and get what you need—if you're cool. For example, you may be WØOPS without EE degree or corporate title, but you are also an independent RF designer developing a new LNA for a working weak-signal space communication system. If you're Rick Littlefield building a simple pre-amp construction project for "Tech Notes," you're also a communication-system designer working on a new LNA concept for publication in a major technical journal that has world-wide distribution. If you're unemployed Sam Jones, you're also a professional engineer developing a new 10-GHz amplifier module for a small high-tech start-up company called SJ Enterprises. XYZ may not grant you an open account with a $10,000 line of credit on the strength of these introductions; but if you put on a professional face, they'll probably ship you some samples.

Incidentally, it is a misconception to think you *have* to hold an engineering degree from a four-year university to be a considered a product designer (although it sure helps). A surprising number of competent gainfully employed RF designers in the United States *don't* have college degrees in EE, having learned their craft in tech schools, on the job, as radio amateurs, and as hard-core hands-on experimenters. The point is, if you anticipate the identity question and formulate a positive answer ahead of time, you won't get caught off-guard. Remember to ask for all relevant spec sheets and application notes—you'll need these to use the product. And, if you have specific questions that relate to your application, jot them down ahead of time. This way, you'll be more organized, articulate, and confident when you present your needs. Finally, if you are a radio amateur, don't introduce yourself by saying, "Hi, this is Ted, WØOPS, and I do moonbounce". The sales and marketing representative with the butter-smooth voice may conclude *you're* from out-of-space and treat you accordingly.

What products are fair game for sample requests

When it comes to sampling, components tend to fall into categories. The first category might be labeled "hot new items." These devices are in transition between development and production; the kind of products I like to target for "Quarterly Devices." And, because they are not yet in wide distribution, they're usually only available as engineering samples directly from the factory. This introductory phase is something of a honeymoon stage for new products, where technical authors, aggressive designers, and experimenters clamor for samples and data sheets—and where manufacturers are usually eager to oblige in order to build rapid acceptance and a lucrative market.

Following the introductory phase, successful products usually drop into a second category where the manufacturer continues to provide technical advice and access to samples on a prescriptive basis. This on-going service, part of the company's sales and marketing effort, enables designers to call and discuss specific circuit objectives with a technical sales representative or application engineer. On the basis of this consultation, the manufacturer may recommend the *most appropriate* component in their line and specify the necessary data sheets, application notes, and samples. Some IC manufacturers may even provide a protoboard or complete prototype kit to get you started (these may or may not cost money—depending on complexity and real cost).

During the consultation process, the application engineer may take your order for samples directly over the phone, refer you to another extension or sample line, or ask you to submit a written request to a particular person within the company. Others may direct you to contact an area sales representative or local vendor to fill the sample request. This is done to establish a point-of-sale relationship between you and the distributing agent who will handle your account if you become a buyer.

Anytime you talk to a product consultant or distributor about samples, be sure to ask for 100-lot and 1000-lot pricing. This figure will help you evaluate how cost-effective the device will be, should your design go into production. Price may rule a device out in some applications, even though the part may perform exceptionally well from a technical standpoint.

Finally, there are the well-established products and old experimenter's standbys that are simply not appropriate to sample. For example, the operating parameters, typical applications, and pricing of parts like the LM386, 2N3904, or 741 are widely publicized and widely known. These devices have been around for years and are readily available at cut-rate prices from multiple sources. Consulting an application engineer about their virtues—or asking a manufacturer for samples—would be frivolous.

To summarize, I suggest you make sample requests for new products directly to the sales and marketing office of the manufacturer. Sample requests for more established products should probably follow the same path—especially if you need data sheets, application notes, catalogs, and technical guidance with product selection. Don't contact your local distributor for design samples unless the manufacturer instructs you to.

While some industrial distributors may have a sampling policy, it will usually only apply to electronic equipment manufacturers who are quantity buyers and regular customers. Also, don't be surprised if custom-product houses or manufacturers who sell direct have somewhat more stringent sampling policies than other manufacturers.

Finally, please don't abuse the privilege or wear out your welcome! Limit requests to those devices that require technical support or that are difficult to locate and purchase in small quantity. For everything else, dig out your checkbook, VISA card, or purchase-order forms and obtain what you need the old fashioned way—through normal distribution channels!

Where to find out about new electronic components

Electronics publications are probably the single richest source for learning about newly introduced components. Many professional engineering journals and experimenter magazines feature a "new products" section devoted solely to announcing new offerings from electronic manufacturers. New-product announcements are generally written from information contained in news releases provided by the manufacturer, and do not constitute a critical product review or endorsement by the technical staff of the magazine. In addition to product announcements, journals and magazines often feature theoretical design or construction articles wrapped around recently marketed electronic devices. These application articles are usually written by independent technical authors or by an applications engineer who works for the device manufacturer. Finally, during the past two or three years, an increasing number of publications have adopted regular columns similar to "Quarterly Devices" that focus specifically on providing how-to-do-it application information for new products.

In addition to subscription-driven journals and periodicals, there are now a number of product-information publications that contain *only* new-product releases and manufacturer advertisements. These are often published in tabloid format, and sometimes offer free subscriptions. One valuable source for information on the latest electronic components is *ECN*

(*Electronic Component News*).* Another way to stay informed about new products—especially from the larger semiconductor manufacturers—is to maintain a library of current catalogs, component selection guides, and product handbooks. Handbooks usually provide a compilation of recent data sheets and technical application notes for all products in a particular product area.

Finally, if you have a specific component selection problem you can't resolve from your print resources, you can always go straight to the source. More than once, I've tracked down the exact solution I needed by calling a manufacturer's application engineer and saying, "This is what I want to do, here's how I want to do it, what part do you recommend?" If there's a particular part or special solution required, they'll probably have the answer. Indeed, a *truly helpful* application engineer may even steer you to a competitor, or diplomatically inform you that your idea is nuts—and that you ought to take a different approach altogether!

If you *do* call for engineering assistance, be sure to outline your design objective or problem beforehand, so your presentation will be organized and you won't waste the engineer's time. In addition, be ready to write *fast*—and don't be afraid to ask questions! In this computer-dominated digitally aligned world, even the most seasoned graduate-level EEs are allowed to ask silly questions about RF!

Conclusion

I depend on the ready availability of engineering samples in my own work, so the last thing I want is to "bite the hand that feeds me" and unleash a wave of nuisance requests for free parts on RF-component manufacturers. However, the fact remains that many *legitimate* builder-designers simply don't know how gain access to valuable new devices that are emerging in the marketplace. This, in turn, impacts on journals like *Communications Quarterly*—and other technical publications—by making good construction articles more difficult to find. Indeed, it was an invitation to speak on this topic to designers at the VHF/UHF Forum at the Dayton Hamvention™ this past April that tipped the balance and prompted me to write this column. While some catalog distributors like Newark Electronics and others do their best to service the designer segment of the electronics market, the fact remains that there are times when engineering samples obtained directly from the manufacturer may be the *only* realistic avenue of procurement. Fortunately, when approached with a modest and legitimate request in a courteous and business-like manner, most U.S. manufacturers are more than happy to respond and provide support. After all, technical authors, independent designers, and high-tech experimenters often *are* the doctors who prescribe what components will find their way into tomorrow's manufactured products. ■

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*ECN, Chilton Company, Chilton Way, Radnor, Pennsylvania 19089.

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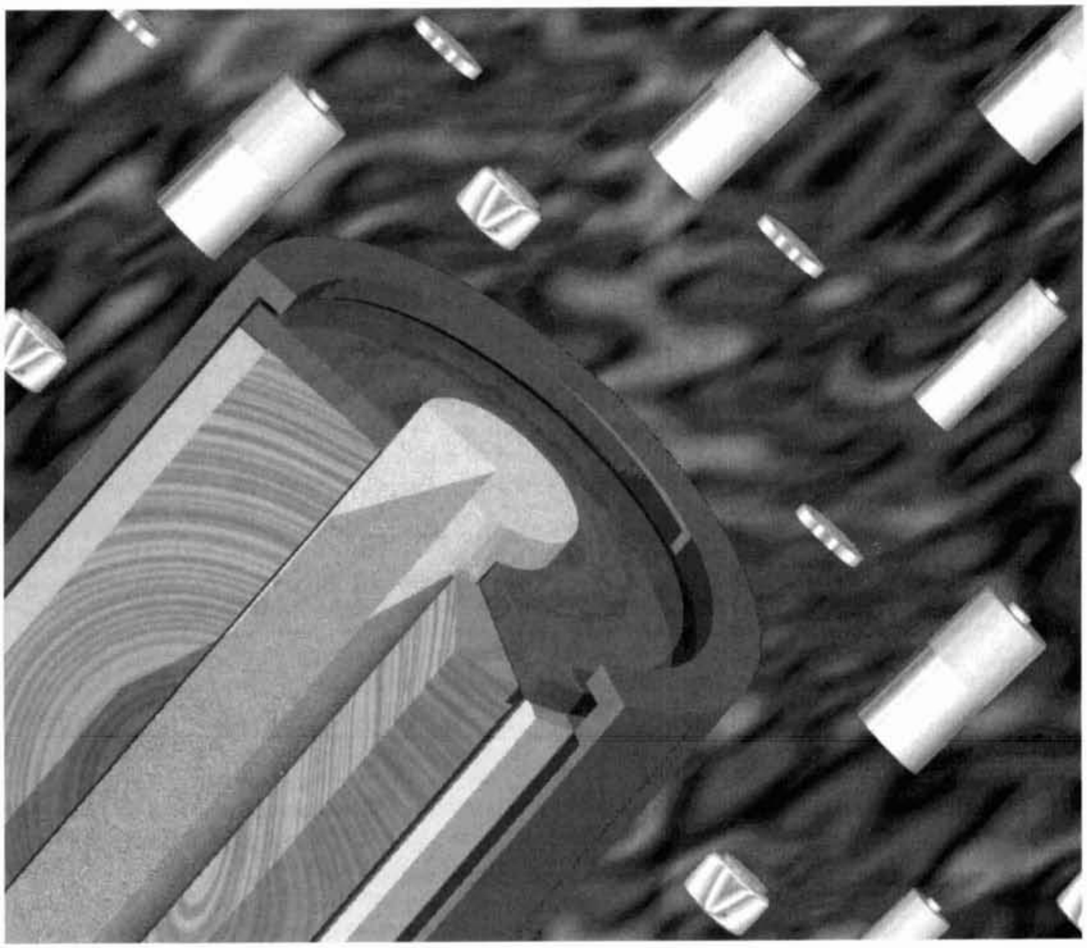
STORAGE CELL TECHNOLOGY

How to select and care for cells that fit your needs

Can you imagine a world without cellular phones, pocket pagers, laptop computers, portable tape players, hand-held transceivers, or pocket penlights? Probably not. For better or worse, our society has become heavily reliant on its electronic gadgets and their related technologies. Given this dependency, it's virtually impossible to leave our technological wonders behind as we move about our daily activities. As a result, there's an ever-increasing pressure to sever the umbilical cord of traditional power and data cables that hamper our mobility. Although portable electronic devices rely on a number of technological inno-



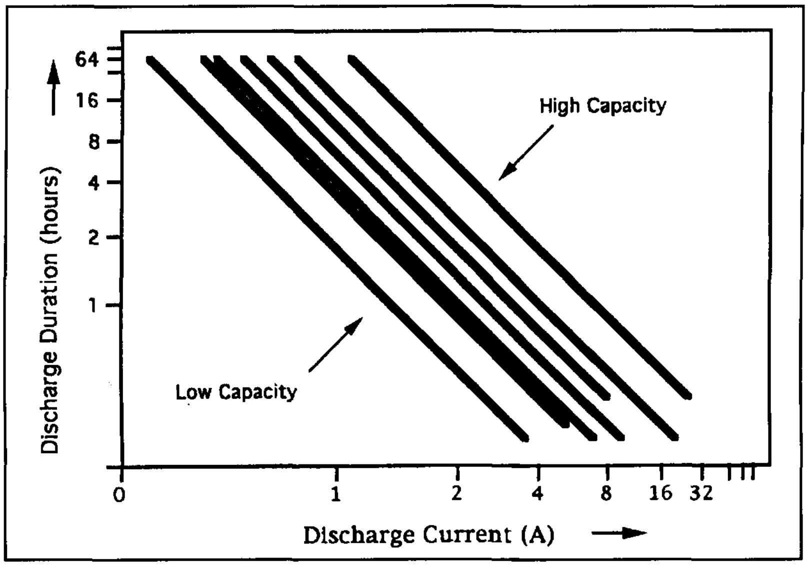


Figure 1. Ampere-hour selection charts, which relate discharge current with duration, are useful in identifying the best cell design or manufacturer for a particular application. On the chart, each diagonal line represents a particular battery or cell type. For example, the diagonal to the far left might represent a AAA nickel cadmium cell, while the diagonal to the far right might represent a heavy-duty AAA nickel cadmium cell from another manufacturer.

vations—including those of hybrid IC construction, compact antenna design, and low-power microprocessors—the limiting factor in miniaturization and portability is storage cell technology. (Note that although a battery is a collection of electrochemical storage cells, the term battery and cell are often incorrectly used interchangeably.)

Take a look around your home. How many battery-operated appliances can you identify? Aside from a hand-held transceiver, you may have a portable TV, portable radio, electronic watch, cordless wall clock, rechargeable electric shaver, cordless electric toothbrush, hand-held video game, camera, and a flashlight or two. Even plug-in devices like desktop computers, clock radios, and telephone answering machines use some sort of storage cell for maintaining a system clock, dynamic RAM, or other components in an energized state.

Because batteries are normally hidden from view, advances in storage cell technology aren't always readily apparent. However, as a result of market pressure from manufacturers of cellular phones, pagers, and laptop computers, there have been significant advances toward developing a variety of affordable, compact, long-lasting cells that don't compromise our environment. However, just as with any other electronic component, selection of the proper storage cell should reflect the circuit requirements, operating conditions, physical size constraints, and economic considerations. Follow along for a brief introduction to storage cell characteristics and information on how to select and care for cells that fit your needs.

Physical characteristics

To the casual observer, size and terminal voltage are the two main variables to consider when evaluating cell types. However, there are often significant electrical differences in cells of the same size and shape. Using a given cell designed for applications other than those intended can result in premature cell failure or damage to the battery-powered device. Consequently, the size, weight, and shape of a cell are often designed to suit a particular class of applications. For example, the ubiquitous, inexpensive, easy to replace, general purpose C and D cells are ideal for generic consumer applications ranging from flashlights to portable radios. Conversely, small, lightweight, coin or button cells are ideal for hearing aids, watches, calculators, and similar low-power, compact devices.

The most popular standard cell sizes include D, C, Sub C, 2/3A, AA, AAA, N, and a wide assortment of button or coin cells. In addition, there is a seemingly endless supply of specialty cell packing, from flat rectangular sheets, cubes, and cylinders to spheres. Each is intended for specific applications ranging from photography to artillery systems to satellite backup power. Even among cells of the same size and shape, there are considerable options in construction and packaging. For example, AA cells are available with standard friction-mount connections, solder tabs, and axial leads. In addition to single cells, there is a variety of multicell pack designs in which individual cells are either encased in a molded plastic housing, shrink wrapped, or part of a reusable cell clip assembly. There are also battery packs in which the individual cells are inseparable, such as the standard 6-volt lantern and 9-volt rectangular designs, which are manufactured in sealed metal casings.

In general, with added weight and size (or cost) come increased reliability and greater output capacity. Regardless of the application, an important goal in selecting an appropriate cell type is usually one of minimizing size, weight, and cost while maximizing output capacity. The move toward increased energy density has been one factor behind the popularity of encapsulated battery pack designs. For example, some early hand-held VHF transceivers were powered by ten series-connected AA nickel cadmium cells—a battery pack that added considerable weight and volume to the transceivers. Not only did these units frequently suffer from intermittent problems with one or more of the 24 contact points (two per cell), but the potential damage due to cell leakage was a constant concern.

In contrast, today's sealed battery packs are extremely compact, available in a variety of sizes and capacities, and are relatively impervious to shock, vibration, moisture, and other environmental factors. In addition to providing for mechanical stability, encapsulation reduces the number of terminals exposed to possible corrosion. Also, the reduced number of friction connections minimizes intra-cell resistance, and therefore the internal resistance of the battery pack as a whole. Snap-on cell packs greatly enhance ease of use, as one can avoid fumbling with individual cells and mistakenly mixing charged with discharged cells.

Cell packs also minimize the likelihood of the inadvertent substitution of one cell type for another, thereby avoiding potential component and cell damage. In some cases, a device can be destroyed if a cell based on the wrong type of chemistry is used, even if voltage and package size are appropriate. For example, many camera flash manufacturers specify AA alkaline cells for their units. This is because many of these high-drain devices rely on the internal resistance of the alkaline cells to limit the current surge into the flash units. The substitution of nickel cadmium cells, with their relatively low internal resistance, can result in excessive current flow that could damage the cells and, more likely, the flash circuitry.

Electrical characteristics

The electrical characteristics of a cell are a function of its chemistry, size, and shape, as well as the manufacturing techniques and quality of materials used in construction. Therefore, it's virtually impossible to determine cell specifications by visual inspection alone. Fortunately, most cell blister packs at least mention the nominal terminal voltage, and some even go as far as to list the capacity in ampere-hours (AH). The AH figure is computed by multiplying the current in amps by the time in hours that a cell can deliver current while maintaining a terminal voltage above a specified value (see **Figure 1** for a generic AH selection chart). For example, a AA nickel cadmium cell capable of delivering 500 mA for 1 hour or 250 mA for 2 hours would have a rating of 0.50 AH. The AH rating is especially useful when comparing cells from different manufacturers, or different cells from the same manufacturer (e.g., standard versus heavy-duty cells). For instance, the heavy duty cell might be three times as expensive as a standard cell, and yet only deliver twice the capacity.

In the absence of printed figures, weight can be used as a good relative indicator of AH ratings. For example, some nickel cadmium C cells are simply AA cells encased in C-sized shells, and these lighter-weight cells only provide the AH capacity of AA cells. In general, heavier cells of the same size and chemistry commonly have more of the reactive elements involved in the electrochemical reaction, and therefore more capacity.

For information other than terminal voltage and AH rating, you'll probably have to look at detailed catalog listings and manufacturer literature. Some of the many parameters listed in this type of literature include: nominal, minimum, and maximum terminal voltage; average, peak, and minimum output current; typical discharge curves; optimal charge conditions—whether standard, trickle, quick, or rapid

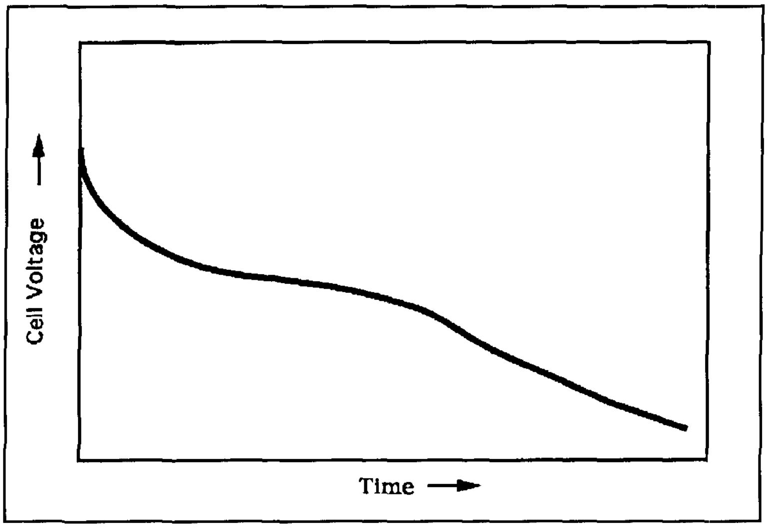


Figure 2. The discharge curve for a typical carbon-zinc cell. Note that this and the following discharge curves assume a constant fixed load. The actual curve for a given cell depends on a variety of factors, including the design and age of the cell, as well as the nature of the load, type of service and ambient temperature.

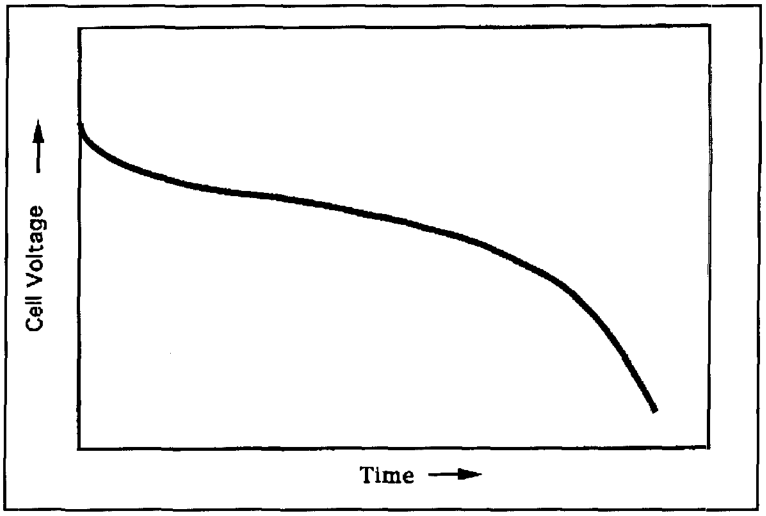


Figure 3. The discharge curve for a typical alkaline cell.

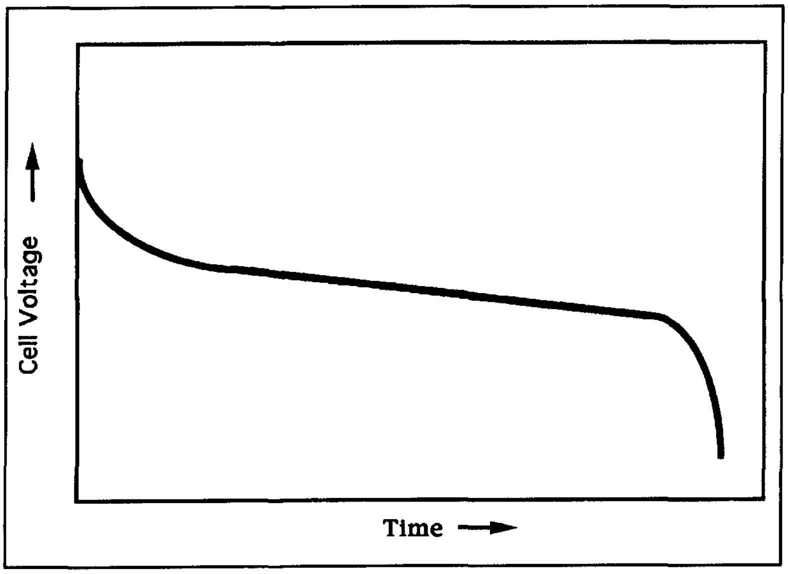


Figure 4. The discharge curve for a typical nickel-cadmium cell. The curve for a typical metal nickel-hydride cell is virtually identical.

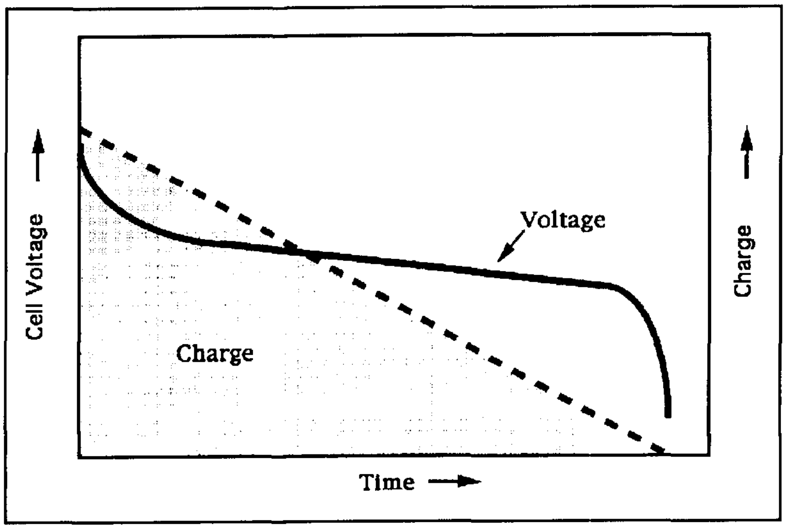


Figure 5. Terminal voltage during discharge versus cell charge for a typical nickel-cadmium cell. Note the nonlinear relationship between the cell charge versus terminal voltage.

charge; optimal charging controls—whether temperature, voltage, or time; optimal ambient, maximum, minimum, average, charge, and discharge temperatures; and shelf life as a function of time and temperature. Other parameters frequently listed that aren't strictly electrical in nature, but that affect cell operation, include optimal atmospheric pressure and shock and vibration limits.

Discharge curves (see **Figures 2** through **10**) provide a considerable amount of data on a particular cell design in a fairly intuitive form. These plots of output voltage versus time describe, for a given temperature and load, how a given cell design can be expected to perform over time. Altering the ambient temperature or the load will, of course, alter the curve somewhat. In comparing discharge curves, the most readily apparent difference is typically the slope of the curve. For example, while the output voltage of an alkaline cell tends to drop in a relatively linear fashion with time, the output voltage of a zinc mercuric oxide cell (**Figure 8**) is virtually constant until it's exhausted.

In the majority of cell designs, the relative change in output voltage as a function of discharge time is related more to the chemistry involved than the capacity remaining in the cell. **Figure 5** compares the discharge curve for a typical nickel cadmium cell versus the charge remaining in the cell over time. Note that the output voltage remains relatively constant until the cell is totally exhausted. This disparity in output voltage versus charge remaining is much less pronounced in lead acid cells than with any other cell chemistry.

Cell chemistries

Storage cells are electrochemical devices in which chemical energy is transformed into electrical energy, usually with an efficiency far less than 100 percent. This electrochemical reaction can be observed in rusting iron, in the traditional grade-school experiments involving coins inserted into lemons, and in the corrosion that occurs when dissimilar metals, like copper and aluminum, are joined. In many instances, electrochemical corrosion is an aggravation at best. The bimetallic corrosion that occurs when aluminum antenna elements are connected directly to copper hardware or cables has been the bane of many radio amateurs. However, the same electrochemical reactions responsible for corrosion can also be harnessed to provide electrical energy.

Recent advances in storage cell capabilities have been attributed to the development and application of new metal alloys, carbon materials, and polymers. However, the electrochemical reactions that form the basis for most commercially viable storage cells are limited to relatively few chemistries (see **Table 1**). Regardless of the materials involved, the basic electrochemical reaction is one in which electrons from one material flow across to another material. In general, the material giving up electrons corrodes, while the material receiving electrons generates either hydrogen or some other gas. There is usually some form of electrolyte involved in electrochemical reactions—typically an aqueous solution of a salt or other compound, either in liquid or paste form. The electrolyte minimally provides electrical connectivity between the reactive materials, and may actually be a major component in the elec-

Primary Cell Chemistries

Carbon Zinc
Mercury Oxide
Manganese Dioxide
Alkaline Manganese
Silver Oxide
Zinc Air
Zinc Chloride
Lithium Carbon Monofluoride
Lithium Sulphur Dioxide
Lithium Thionyl Chloride
Lithium Iodine
Lithium Manganese Dioxide
Lithium Copper Oxyphosphate
Lithium Sulfuryl Chloride
Lithium Bromine Complex
Lithium Iron Sulfide
Nickel Metal Hydride

Secondary Cells Chemistries

Lead Acid
Nickel Cadmium
Alkaline Manganese
Silver Oxide Zinc
Nickel Iron
Silver Oxide Cadmium
Carbon Lithium
Gas Recombinant
Copper Oxide Lithium
Nickel Metal Hydride
Vanadium Lithium
Nickel Metal Hydride
Lithium Ion
Lithium Polymer
Lithium Molybdenum Disulfide

Table 1. Common primary (disposable) and secondary (rechargeable) cell chemistries. Note that some chemistries can be used to manufacture both primary and secondary cells.

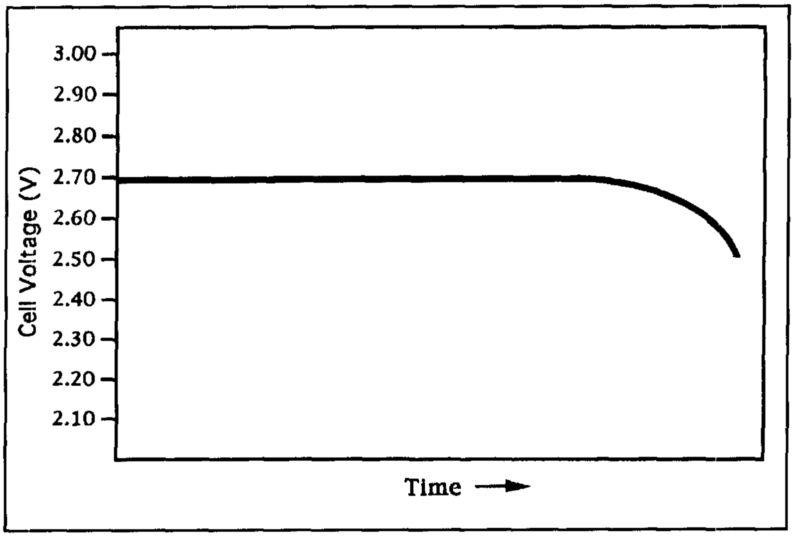


Figure 6. Discharge curve for a typical lithium-polycarbonmonofluoride cell. Note the terminal voltage is relatively constant until late in the life of the cell.

trochemical reaction. For example, salt water can act as an electrolyte that enhances the bimetallic corrosion which occurs when copper and aluminum are joined.

The electrochemical reaction is relatively quiescent in most cell designs until the ionic equilibrium is upset, such as when a low resistance path for current flow (a load) is provided. The consumption of reactive elements and electrolyte, together with a buildup of chemical byproducts from the electrochemical reaction, eventually diminishes output voltage and overall cell performance. In general, it follows that the greater the initial quantity of reactive elements, the greater the *capacity* of the cell in terms of output current and operating time. In contrast, the output *voltage* is a function of the atomic structure of the elements involved. That is, a nickel-cadmium cell, whether AAA, AA, C, D, or the size of a cinder block will provide approximately 1.2 volts. Note that the theoretical output voltage, a function of the *electropotential* difference between the materials involved, is usually only approached in a practical cell design. For example, although nickel cadmium cells can theoretically provide an output potential of 1.35 volts, the practical limitations imposed by impurities, manufacturing techniques, and other factors effectively limits the output to 1.2 volts.

Aside from output voltage, the most important distinction between storage cell chemistries is their relative reversibility. When a load is applied to a cell, an electrochemical reaction occurs until one or more of the chemicals involved are exhausted. When chemistries such as carbon zinc, zinc mercury oxide, zinc air, or lithium manganese dioxide are involved, the electrochemical process is generally thought of as irreversible. These primary cells are based on irreversible chemistries and are intended to be discarded after use. In contrast, cells based on nickel-cadmium, lead-acid, nickel metal-hydride, silver-cadmium, or copper oxide lithium chemistries are usually designed to be recharged. Secondary or rechargeable cells are manufactured so the electrochemical reaction that occurred during discharge can be safely reversed by supplying energy to a partially discharged cell (see **Table 1** for a listing of primary and secondary cell chemistries). Despite the relative inefficiency of this electrochemical reversal, the cost associated with recharging a cell is generally only a few cents per cycle.

In addition to the relative reversibility of a

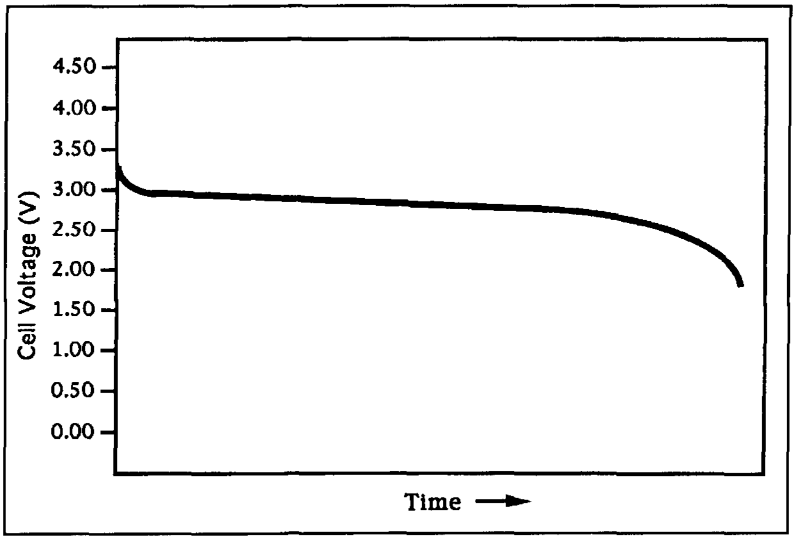


Figure 7. Discharge curve for a typical lithium-maganese dioxide cell. Note the initial drop in terminal voltage and the relatively constant terminal voltage throughout the life of the cell.

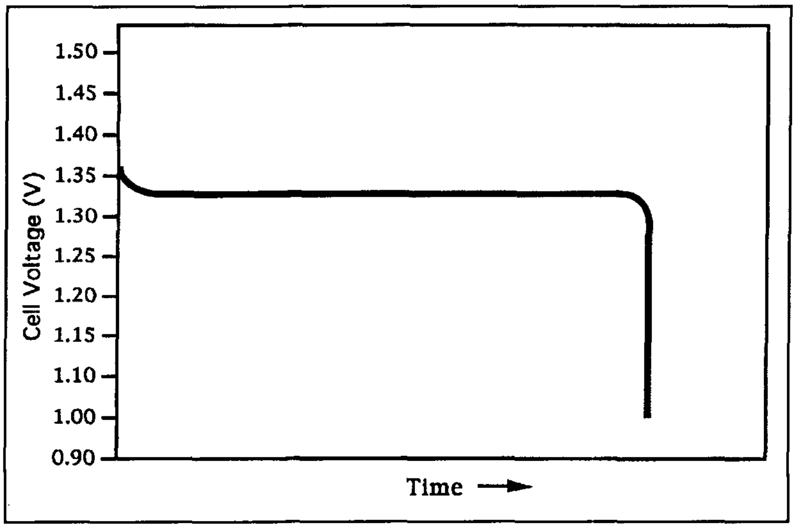


Figure 8. Discharge curve for a zinc mercuric oxide cell. After an initial dip, terminal voltage remains flat until the cell is exhausted. The terminal voltage drops precipitously at the end of the cell life.

particular chemistry, there are other distinctions worth noting. These include terminal voltage, peak output current, capacity, discharge curve, internal resistance (the lower the better), initial and long-term operating costs, and shelf life. These and other parameters associated with the more common chemistries are outlined below.

Carbon-zinc

The most common primary cell type, the inexpensive carbon-zinc cell, has changed little in the past few decades. The electrochemical reaction involves the conversion of zinc into salts and electricity. A porous carbon rod at the center of the cell is surrounded by a manganese-dioxide mix and an electrolyte paste—an aqueous solution of ammonium chloride and zinc chloride, which forms the conducting medium between the carbon rod (+) and the outer zinc cylinder (–). Gases produced by the electrochemical reactions are sealed in, and are controlled by the chemical mix. However, because in many designs the mix is incapable of controlling the gassing that might occur during an attempt to recharge a carbon-zinc cell, they should never be placed in a charger unless specified by the manufacturer.

Carbon-zinc cells provide a terminal voltage of 1.5 volts at modest capacities. Shelf life is somewhat limited, with a self-discharge rate of near 6 percent/month. The internal resistance of a carbon zinc cell is initially very low, but increases with time, use, and low ambient temperatures. In many respects, the ordinary carbon-zinc cell is the quintessential primary cell. It's inexpensive enough to buy in quantity for products like toys, radios, and flashlights, and it's designed to be discarded when exhausted. However, the sheer volume of carbon-zinc cells in landfills underscores the need for longer lasting or reversible chemistries.

Zinc-chloride

Zinc-chloride cells are heavy duty versions of their carbon-zinc counterparts, providing about 50 percent greater energy density and better low-temperature performance. A major difference between the cell designs is that the electrolyte used in a zinc-chloride cell is an aqueous solution of zinc chloride without the ammonium chloride used in carbon-zinc cells. Zinc-chloride cells, which provide an output voltage of 1.5 volts, are more expensive than general purpose carbon-zinc cells.

Alkaline manganese dioxide

Alkaline manganese dioxide or simply "alkaline" cells, like those based on carbon-zinc and zinc-chloride, provide 1.5 volts output with a considerably greater output capacity—on the order of five times that of carbon-zinc cells. Also, like carbon-zinc and zinc-chloride cells, the negative electrode consists of the outer zinc container. The positive electrode is formed of manganese dioxide, and the electrolyte is an aqueous, *alkaline* solution of potassium hydroxide.

Alkaline cells are great for heavy use applications, from communications gear to photo flashes, video cameras, and tape players. Low temperature performance is good, and the internal resistance is very low. Although alkaline cells may be perfect for high current drain applications, their relatively high cost makes them uneconomical for general purpose use.

Nickel-cadmium

Cells based on nickel-cadmium chemistries are the most popular form of secondary cell in use today. These 1.2-volt cells are based on a reaction of cadmium (–) and nickelic hydride (+) in an aqueous solution of potassium hydroxide. Although their initial cost is high, nickel cadmium cells provide excellent performance over a wide temperature range, have a very low internal resistance, and are resistant to shock and vibration.

Nickel cadmium cells are available in a seemingly endless variety of sizes, shapes, and capacities, for applications ranging from electric drills to laptop computers. Chargers are readily available; most electronics magazines and handbooks feature at least one or two nickel cadmium charger projects. Despite their high initial cost (see **Figure 11**), nickel cadmium cells can be cycled hundreds of times, making them an inexpensive and reliable power source over the life of the cell.

The main problems with nickel cadmium cells are memory effects and the toxicity of cadmium. Due to concerns over the effects of cadmium on the environment, there are now strict regulations regarding disposal of nickel cadmium cells. Many manufacturers have responded to this concern by establishing recycling centers and programs. Manufacturers have also made great strides in minimizing the memory effects attributed to nickel cadmium chemistries. This bothersome effect occurs when a cell "remembers" the state of charge before it was recharged, and uses this as the new set point for its fully discharged state. That is, cell voltage drops prematurely even though a significant amount of charge remains. Memory effects can be minimized by not recharging a nickel cadmium cell until it is actually fully discharged.

Through new manufacturing techniques, nickel cadmium cells have roughly doubled in capacity over the past few years. The "high capacity" nickel cadmium cells sell for more than normal capacity nickel cadmium cells, but the extra time between charges is often worth it. Despite advances in nickel cadmium technology, performance and environmental problems remain. New chemistries and technologies are being introduced in response to these challenges.

Rechargeable alkaline manganese

A relative newcomer to the storage cell market, rechargeable alkaline manganese (RAM) cells have been positioned as direct competition to both conventional alkaline and rechargeable nickel cadmium cells. Rechargeable alkalines provide 1.5 volts output at capacities somewhat less than those available from nonrechargeable alkalines of the same size. Although rechargeable and nonrechargeable alkalines rely on the same chemistries, rechargeable alkalines are constructed to withstand the physical changes associated with the recharging process without damage. Attempting to recharge a conventional alkaline cell can result in a potentially explosive mix of excessive heat and gassing.

The most notable advantages of rechargeable alkaline cells over nickel cadmium cells include: greater shelf life (with a self-discharge rate of only 1 percent/month, rechargeable Alkalines have a shelf life of five or more years compared to two or three months for nickel cadmium cells); no memory (alkalines can be recharged before full discharge); environmentally friendly (no cadmium and only trace amounts of mercury); greater capacity (rechargeable alkalines provide up to three times the capacity of comparable nickel cadmium cells); ease of initial use (nickel cadmium cells must be charged before initial use; rechargeable alkalines are ready to use out of the pack); and price (rechargeable alkalines are generally cheaper than nickel cadmium cells).

Although they provide a number of attractive features, rechargeable alkalines are not without their limitations. Perhaps most significant is that the number of charge/recharge cycles is limited to approximately 25, compared to several hundred for a typical nickel cadmium cell. Because of the variability in how individual cells respond, rechargeable alkalines are usual-

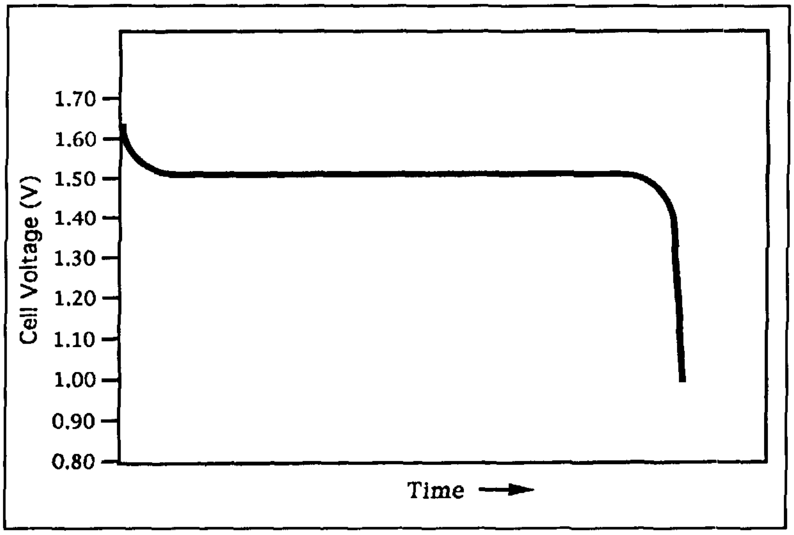


Figure 9. The discharge curve for a zinc silver oxide cell is in many respects identical to that of a mercuric oxide cell. However, note the less abrupt initial and final drop in terminal voltage.

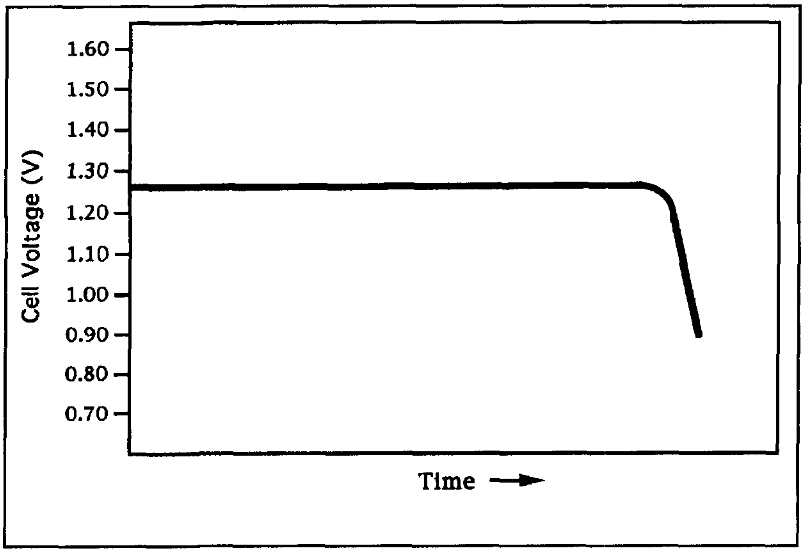


Figure 10. The discharge curve for a typical zinc-air cell is virtually flat until the cell is depleted. At the end of cell life, there is a rapid and linear drop in terminal voltage.

ly sold with a charger designed to monitor individual cells during charging. In addition, unlike nickel cadmium cells, capacity declines with each use. After ten or fifteen uses, rechargeable alkalines provide only about one third of their original capacity.

Rechargeable alkalines provide about 80 percent of the capacity at about double the cost of nonrechargeable alkalines. In addition, rechargeable alkalines don't last as long as standard alkalines because approximately 13 percent of the cell volume is dedicated to separators, expanders, and catalysts designed to limit the expansion, contraction, and pressure buildup associated with the recharging process. Finally, rechargeable alkalines can't be mixed with conventional alkaline cells, and alkalines can't be properly recharged in chargers designed for nickel cadmium cells.

Nickel metal hydride

Nickel metal hydride (NiMH) cells are positioned to overtake the nickel cadmium cells as the most popular secondary cell type. Nickel metal hydride cells provide the same output voltage as nickel cadmium cells (1.2 volts), but at twice the capacity and without any memory effects or toxic cadmium. Nickel metal hydride cells also charge faster than nickel cadmium cells (about 1-1/2 hours versus 3 to 8 hours for AA cells) and are capable of sustaining hundreds of charge/discharge cycles. Like nickel cadmium cells, nickel metal hydride cells use nickelic hydride for the positive electrode with a potassium hydroxide electrolyte. However, instead of toxic cadmium, nickel metal hydride cells use titanium-zirconium or rare earth alloy for the negative electrode.

On the down side, nickel metal hydride cells are expensive—about double the price of nickel cadmium cells of the same size. They also suffer from poor high-power performance, a relatively short shelf life, and relatively high internal resistance, compared to nickel cadmium cells. Also, because nickel metal hydride and nickel cadmium charging systems are incompatible, nickel metal hydride cells are not drop-in replacements for nickel cadmium cells.

Zinc mercuric oxide

Zinc mercuric oxide cells, in the form of buttons or coins, are commonly used in watches, hearing aids, and pocket calculators. These primary cells provide an output voltage of either 1.35 or 1.4 volts, depending on the chemistry and construction used. The electrochemistry behind this design is based on a zinc negative electrode and a mercuric oxide positive electrode, with an electrolyte of potassium or sodium hydroxide. The main liabilities of zinc mercuric oxide cells are high cost and poor low-temperature performance.

Zinc silver oxide

Zinc silver oxide cells are in many respects identical to zinc mercuric oxide cells. These cells, which are also normally produced in button or coin packages, provide 1.5 volts output and modest capacities. As in zinc mercuric oxide cells, the electrochemistry behind this design is based on a zinc negative electrode and an electrolyte of an aqueous solution of potassium or sodium hydroxide. However, in this case, silver oxide is used in place of mercuric oxide. Both chemistries share the trait of poor performance at low temperatures.

Lithium

In general, cells based on lithium chemistries provide the best shelf life, capacity, and discharge characteristics of any cell type. Both primary and secondary lithium chemistries are available (see **Table 1**). Output voltages range from 1.5 to 3.0 volts, depending on chemistry and construction. For instance, lithium manganese dioxide, lithium poly-carbon, lithium vanadium pentoxide, and lithium carbon cells provide 3.0 volts output, while lithium iron disulfide and lithium copper oxide cells provide 1.5 and 1.55 volts, respectively. The electrolytes used in lithium cells are typically more exotic than those used in lesser cells; e.g., lithium phosphorous oxynitride for a lithium vanadium pentoxide secondary cell.

Although lithium cells are usually very expensive, they provide features generally unavailable with any other cell type. Lithium cells can deliver high peak power, operate over a wide temperature range, are lighter than alkaline or nickel cadmium cells of the same size, and have a shelf life in excess of 10 years. The extended cell life is due to oxidation of the lithium anode when the cell lies dormant; this oxidation insulates the lithium and prevents discharge from leakage. Their extraordinarily low self-discharge rate makes lithium cells ideally suited for applications ranging from watches, calculators, and computer memory backup to laptop computers and emergency lighting. The higher voltage available with lithium (3.0 volts versus 1.2 or 1.5 volts) allows fewer cells to be used in a battery pack to provide the same output voltage, and fewer cells translates to greater reliability.

Typical secondary lithium cell designs support hundreds or thousands of charge/discharge cycles, and some designs are capable of considerably more. Thin-film lithium vanadium pentoxide cells that are incorporated directly on ICs are capable of supporting 10,000 or more cycles. Primary lithium cells should *never* be recharged because the potential for a hydrogen gas explosion is great.

Aside from their relatively exorbitant cost, the reputation of lithium cells suffers due to the effects discarded lithium cells have on the environment. Also, because lithium is relatively unstable (lithium is volatile in the presence of moisture), federal regulations limit the amount of lithium in a cell to 1/2 gram—the capacity of a AA lithium battery. There is hope that environmental issues will be adequately addressed by new designs based on lithium compounds and graphite instead of pure lithium.

Zinc air

Zinc-air cells are surrounded by the same "hi-tech" mystique characteristic of lithium cells. These button or coin cells, which provide 1.4 volts at modest output capacities, rely on a zinc-alloy (–) electrode and an air-breathing electrode (+) composed of a carbon membrane that extracts oxygen from the air. Zinc-air cells are a less toxic replacement for zinc mercuric oxide cells, providing twice the capacity at 60 percent of the weight of zinc mercuric oxide cells. The rechargeable zinc-air designs are capable of sustaining 25 to 30 charge/discharge cycles, but degrade with exposure to air. Both rechargeable and nonrechargeable zinc-air cells are prone to zinc-oxide dendrite growth that can cause cells to short-circuit. Zinc-air cells are a moderately priced and environmentally sound replacement for the zinc mercuric oxide button cells used in hearing aids, pagers, and other compact devices.

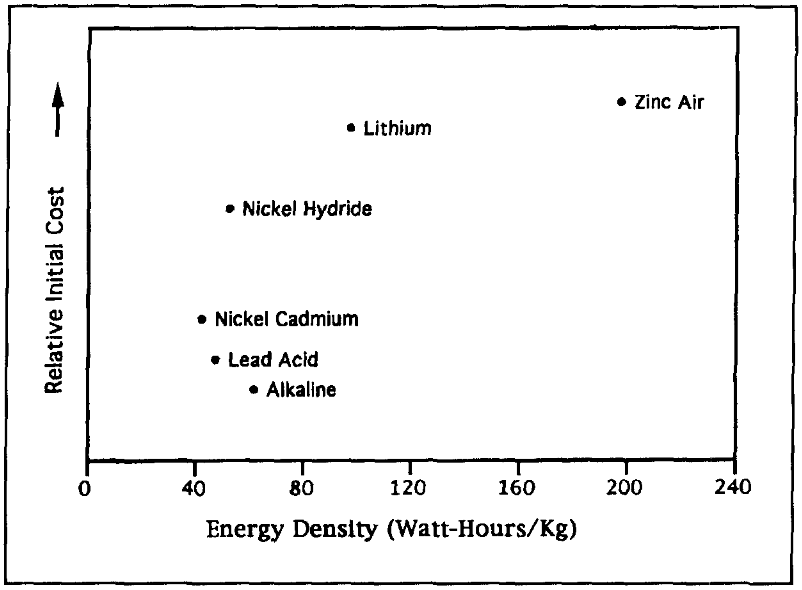


Figure 11. Energy density versus relative initial cost for common secondary cell chemistries. In general, higher density is associated with exponentially greater cost.

Lead acid

Lead acid cells are an old standby for applications ranging from automobiles to uninterrupted power supply (UPS) systems because this chemistry combines prolonged standby and cycle life with high energy storage capacity. Lead acid cells are fast charging, have a low self-discharge rate (a one year shelf life is typical), and low internal resistance. These cells, which provide 2.0 volts output when fully charged, can withstand between 200 and 1400 charge/discharge cycles, depending on how deeply they are discharged during each cycle (see **Figure 12**).

Conventional lead acid chemistry is based on sponge lead (–) and lead oxide (+) and a sulfuric acid electrolyte. As the cell discharges, the sulfuric acid solution is diluted; i.e., its specific gravity is reduced. Measuring the specific gravity of the electrolyte gives an indication of cell charge. However, because liquid electrolyte designs have a number of limitations (including dehydration, positional sensitivity, and gassing), sealed cells, using either trapped or gelled electrolytes, are becoming increasingly common. Unlike other cell chemistries, the open circuit terminal voltage of lead acid cells is indicative of residual capacity.

Although flooded cell designs may be sufficient for automotive applications, most electronic applications are better suited to gelled electrolyte or gell-cell designs. Gell cells don't

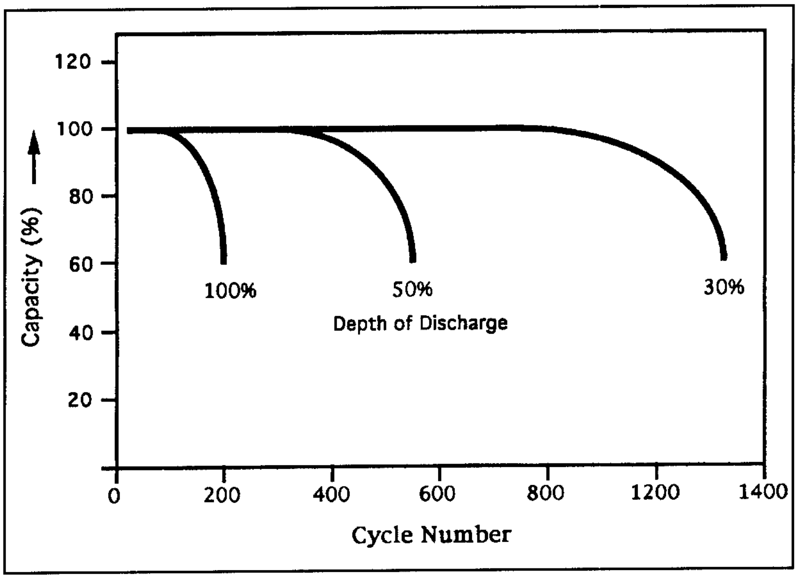


Figure 12. Cell life versus depth of discharge for a typical lead-acid cell. Repeated, deep discharges signficantly shorten cell life. Deep cycle lead-acid cells are better suited for repeated, deep discharges.

gas as much as flooded cells, and are safer to use near electronics. They are fully sealed (excessive gassing is handled through a pressure release valve); support short duration, high discharge rates; handle repetitive deep-cycle discharges well; and provide good low-temperature performance. Gell cells have applications in UPS systems, communications and office equipment, photography, toys, power tools, medical equipment, and emergency devices.

The shelf life of a lead acid cell, whether it uses a flooded or gelled electrolyte, is dependent on storage temperature. Lower temperatures slow any electrochemical processes that can result in discharge by a factor of two for every 10 degrees C. For example, moving a cell from 40 to 30 degrees C doubles shelf life. However, lead acid battery capacity is maximum at room temperature to about 50 degrees C. Decreased temperature, like high discharge rates, decreases capacity.

Lead acid cells should never be completely discharged. Discharging a cell down to 0 volts can cause cell polarity reversal, which can render a battery useless. Even less than complete discharge conditions (e.g., down to a cell voltage of 1.75 volts) can result in increased cell impedance, which leads to lower recharge current flow. Excessive discharge can also result in the formation of metallic whiskers or dendrites between plates, which can effectively short circuit the cell.

Selecting the right cell

Selecting the most appropriate cell for a commercial appliance is usually a simple matter of locating a suitable replacement cell by consulting a chart at your local electronics dealer. There tends to be very little room for experimentation when you're dealing with applications that require button cells with specific dimensions, or a laptop computer that requires a specific battery pack from a single manufacturer. The move toward standardized battery packs for laptop computers (Duracell has introduced such a line for Compaq laptops) and other devices has made locating the proper battery pack much less difficult. However, until these and other battery packs are offered in multiple capacities and with alternative chemistries, it will be impossible to customize device performance to fit individual needs.

Whether you're working with standard cell configurations (e.g., AA, C, or D cells), or building your own battery-powered device, you can alter circuit performance dramatically by making intelligent decisions about cell chemistry, capacity, and packaging. The first step is to match the requirements of your device with an appropriate cell design. Let's look at the options for an ordinary flashlight that requires two C cells. If you plan to use the flashlight in your basement for a few minutes, once or twice a week, then low-cost, general purpose carbon-zinc cells probably make sense. However, if the flashlight is intended to be used in your car during the winter, possibly for hours at a time, then you should consider heavy-duty alkaline cells. If you intend to use your flashlight for several minutes every day, it will be more economical to install rechargeable nickel-cadmium or alkaline cells. On the other hand, if the flashlight is for emergency use only, and may sit idle for a year or more between uses, you should consider the more expensive lithium cells because of their greater shelf life.

When considering power sources for devices more complex than a flashlight, there's generally more involved than determining the desired run time, operating current, and space available. You should carefully consider the capacity and energy density, low-temperature performance, shelf life and charge retention, the discharge profile, size, availability, and both initial and operating cost of the available cell or battery pack designs. It's also important to consider the nature of the portable device in terms of power needs and the type of power management system (if any) it contains. Although there are considerable differences among cells based on the same chemistry, there are a few general statements that hold true for all. Rechargeables can generally deliver most of their capacity when discharged at a high rate. Conversely, primary cells loose capacity at high discharge rates, but because they have a higher rated capacity, they can provide good performance at moderately high discharge rates. This is why primary cells are rarely used in laptop computers—they can't handle the high power drains associated with these devices for more than a few minutes. While rechargeables can deliver more of their capacity at lower temperatures, primary cells maintain a higher performance over a wide temperature range. In general, primary cells have a greater shelf life than secondary cells. In terms of discharge characteristics, primary batteries generally have a more sloping discharge profile than secondary cells (compare **Figures 2** and **7**). That is, secondary cells generally discharge within a relatively narrow voltage band.

Most manufactures offer cells for different classes of applications, even though they are based on the same chemistries. Standard nickel cadmium cells are available in a variety of sizes and models, and are designed for general office and communications equipment. Rapid charge (RC) nickel cadmium cells are manufactured with advanced gas absorption characteristics, so they can be recharged in about an hour. High temperature (HT) nickel cadmium cells use a modified electrolyte stable enough to withstand the high temperatures associated with continuous charging at low currents. High capacity (HC) nickel cadmium cells, intended for audio and communications equipment, provide about 20 percent greater output than standard cells through the use of high density plates and electrolytes. High discharge/rapid charge (HD/RC) cells, intended for applications such as power tools and toys, have improved high discharge and enhanced gas absorption characteristics. Finally, high capacity/rapid charge (HC/RC) cells, intended for audio, video, and communications equipment provide approximately 70 percent greater capacity than RC cells by using of a foam nickel positive electrode and an enhanced negative electrode paste.

Although optimum cell size is often dictated by the application, the availability of a particular cell design should also be taken into account when selecting a cell type. All cells must be replaced eventually, and few of us live near fully stocked electronics parts centers that carry some of the more exotic cell types. If convenience is a major concern, choose standard size alkaline cells; these are the most readily available cell types. Although rechargeable pack designs are becoming standardized, they can be difficult or even impossible to locate at times, especially when the device to be powered has been discontinued.

Cost and convenience are often two overriding concerns when it comes to cell selection. For example, secondary cells have a relatively high initial cost, but long-term operating costs are generally much less than those of primary cells. However, it may be inconvenient to carry a bulky or heavy recharger on trips, or take the time to recharge cells. In such situations, it may make sense to use more expensive, but more convenient, primary alkaline cells.

Extending cell life

Extending cell life is a matter of providing a reasonable environment, being attentive to proper recharging techniques, and using power management techniques whenever possible.

Proper care

Getting the most out of a cell or battery pack isn't very difficult. Regardless of the design, cells should be kept clean, away from moisture or temperature extremes, and should not be subjected to excessive shock or vibration. For example, leaving a battery-powered device in the sun generally isn't a good idea. Also, while excessive temperatures can affect cell life and long-term performance, most cell types won't work at all below certain temperatures. At temperatures below −12 degrees C, alkaline and zinc mercuric oxide batteries are useless, zinc silver oxide cells provide markedly diminished capacity, and lithium cells provide reduced voltage and capacity. Below −18 degrees C, nickel cadmium, lithium, and lead acid cells are the only options available, and from −40 to −65 degrees C, only lead acids cells are viable. It's important to note that these figures are ambient temperatures, and not necessarily the outside

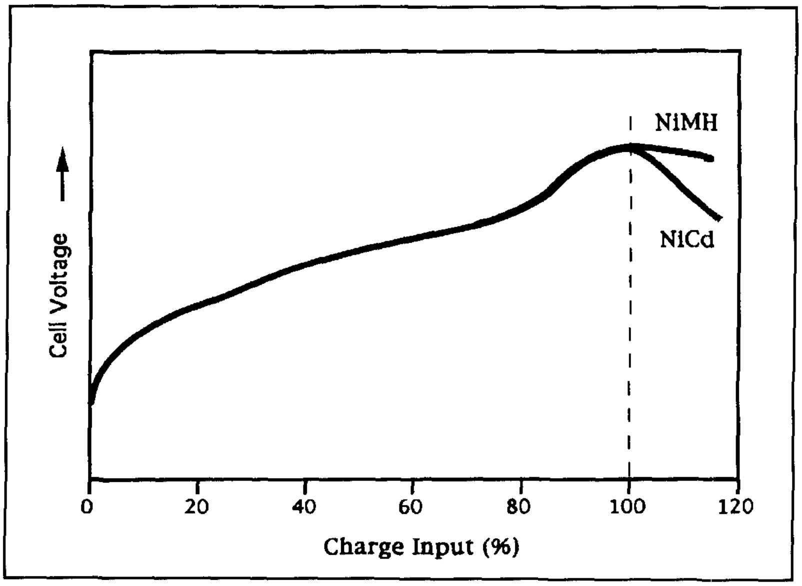


Figure 13. The charge cycles for nickel cadmium and nickel metal-hydride cells differ little up until the point of full charge. After that point, the drop in terminal voltage is significantly more pronounced in nickel cadmium cells compared to nickel metal-hydride cells.

temperature. Most battery-powered devices can be used outdoors in extremely cold weather *if* they are kept warm inside your clothing when not in use.

In addition to controlling the operating, charging, and storage environment, it's important not to subject a cell to electrical abuse. Never short circuit a cell intentionally, and never attempt to charge a primary cell or to use a charger intended for another chemistry. Because all secondary cells have discharge limits, they shouldn't be allowed to discharge fully. For instance, nickel cadmium cells shouldn't be discharged below 1.0 volt, and most lead acid cells should be maintained above 1.75 volt. Discharging a cell below the published limits not only reduces storage capacity but markedly decreases the possible number of charge/discharge cycles (see **Figure 12**). If you're designing a circuit from scratch, think of adding some sort of automatic cut-off switch to disconnect the load from the battery pack as soon as terminal voltage drops below some predetermined level.

Recharging secondary cells

The point of investing in secondary cells is be able to extend their useful lives by recharging them repeatedly when their capacity has been depleted. To achieve the greatest number of charge/discharge cycles and realize the greatest storage capacity, charging should be appropriate to the cell use and chemistry. The most common charging strategies are:

1. **Constant current.** Charging current is held constant by varying the charging current.
2. **Constant voltage.** Charging voltage is held constant by varying the current available.
3. **Float charge.** A constant voltage is applied across a cell to maintain capacity.
4. **Trickle charge.** A constant current, on the order of a few mA, depending on cell capacity, is used to maintain cell capacity.

A good charging strategy for lead acid cells is to use constant voltage charging up to full capacity, and then to maintain the cells with a trickle charge. However, the challenge in working with lead acid or other cell chemistries lies in determining exactly when full charge has been reached. Because most cell designs generally don't perform well when overcharged, a variety of techniques have been developed to halt charging when a fully charged state has been reached. The most common techniques include temperature cutoff, delta temperature cutoff, voltage drop, and voltage plateau.

1. Temperature cutoff. Fast charging is terminated when the cell temperature peaks, based on initial cell temperature. This technique works well with nickel cadmium cells, which absorb heat as they charge. However, because nickel metal hydride cells are exothermic, their temperature tends to rise throughout the charge, making the eventual peak at full charge less prominent.

2. Delta temperature cutoff. The charge is terminated when a relatively large incremental temperature rise is detected in the cell. This approach, which reduces the charging system's sensitivity to ambient temperature, is a preferred approach for charging nickel metal hydride cells.

3. Voltage drop or negative delta V. The charge is terminated when, after full charge, cell terminal voltage drops. This method of controlling cell charging is commonly used with both nickel cadmium and nickel metal hydride cells. Although both nickel cadmium and nickel metal hydride cells display a drop in terminal voltage when they go into overcharge, the drop is much less pronounced in nickel metal hydride cells (see **Figure 13**). Voltage measurements must, therefore, be more accurate when nickel metal hydride cells are used. The voltage drop approach has an advantage over temperature-based methods in that it does not require temperature sensors on the cell for operation. It's important to note, however, that cell voltage during charge is affected by both temperature and pressure, and these factors should be considered in charge monitoring systems that rely heavily on cell voltage.

4. Voltage plateau or zero delta V. This is a variant of the voltage drop method of control where the charge is terminated at the peak of the voltage curve, just before the drop. This approach, which minimizes the risk of overcharge, is especially useful with nickel metal hydride cells because they are extremely intolerant of overcharging.

Charge monitoring techniques can be combined with various charging strategies that are optimized for a particular cell chemistry and construction. For example, consider the optimum charging system for nickel cadmium cells. Standard charge is best for standard and HC designs, quick charge can be used with Standard, HC, and HD/RC cells, and rapid charge can be used with HC/RC and RC designs. Temperature cutoff works well with RC and HD/RC cells, while trickle charge works best with HT cells. In general, charging methods designed for nickel metal hydride cells can be used for nickel cadmium cells, but not vice versa. For example, quick charging should never be used with nickel metal hydride cells because this approach shortens cell life.

Although charge monitoring techniques may be optimal for use with battery packs designed for laptop computers and portable transceivers, they tend to be too expensive for many applications. For instance, many inexpensive and yet very functional charging systems for standard size nickel cadmium cells give the user the responsibility of discontinuing charge. These chargers, which provide a constant current or voltage charge, are intended to be used for a set number of hours and then disconnected. Allowing cells to charge for longer than the prescribed time results in overheating and cell damage. Despite this danger, simple charging systems are popular because they are both readily available and affordable.

Power management

With proper care and charging, cell life can be extended to approach design limits. However, to realize a cell's full potential life span, some form of power management should be used. Power management involves tailoring cell power demands to fit cell characteristics. For example, laptop computer power management systems commonly control the state of the disk drive as a function of use or time between disk writes. Similarly, the timing between spin-up, the most power intensive operation in portable computing, can be carefully controlled. The use of lower-power drives, efficient switched power supply designs, CPU sleep modes, and slow-refresh DRAM all contribute to extending cell life.

A popular method of estimating the state of a cell or battery pack, especially with laptop computer systems, is to determine the charge remaining, time remaining at present use, and end of useful life by modeling battery internal resistance as a function of battery temperature, voltage, current, and age, as well as time, disk accesses, and CPU activity. These models or simulations are based on heuristics derived from published cell specifications and known physical properties. For instance, it's generally accepted that cells age as a function of both time and temperature, and this progression is linear as long as the temperature remains within a recommended range. However, at elevated temperatures, aging increases exponentially by a factor of 2^x, where x = multiples of 10 degrees C over the reference temperature.

Simulations, based on general assumptions, are adequate for providing estimates of cell status. However, the most accurate methods available for energy management rely on actual measurements. Monitoring cell voltage is a step in this direction, but this simplistic measurement can be unreliable because the absolute cell voltage is a function of temperature, internal pressure, and battery age.

The most accurate method of determining cell status (on the order of 1 percent) incorporates measuring the Coulombs as they enter and leave the cell or battery pack, as well as monitoring the temperature, voltage, age of the cell, and other parameters. In other words, some means of monitoring battery current and integrating it numerically over time is required. This measurement and integration is commonly performed with the aid of three devices: a current-sensing device, an A/D converter, and a microprocessor to perform integration and communication of results. The most common approach for current sensing is to use a low value (0.01 to 0.5 ohm) series resistor and measure the voltage drop across it. Hall sensors can be used for high current applications. The A/D converter is used to measure the voltage across the series resistor, and the microprocessor integrates the A/D output. Additional measurements, such as ambient temperature, are frequently performed with the aid of an additional A/D converter, which also feeds the microprocessor.

In addition to performing integration, the microprocessor can be used to store (usually in nonvolatile EEPROMs) and retrieve a history of temperature extremes, the number of charge/discharge cycles, and other parameters to gauge the expected life of a cell. Once calculated, information such as percentage of full charge, instantaneous voltage, current, temperature, pack capacity, charger-control information, low-battery warnings, and battery-error conditions can be displayed on LED or, more commonly LCD displays, or made available via a serial link.

The most advanced cell monitoring systems are actually an integral part of the cell, not a charger or battery-powered device. The advantage these built-in energy gauges have over external monitors is that their intelligence need not be duplicated in external chargers. This allows for the manufacture of cheaper chargers, and chargers that can be used for a variety of battery types. On the down side, internal gauges can add 25 percent or more to the price of a battery pack—depending on the operating current range, size and shape of the gauge, type of display used, interface hardware, and resolution of the display and A/D converter hardware.

The future

The perfect storage cell technology has yet to be created. However, the growing demand for portability and increased environmental consciousness will likely lead to cell designs with more intelligence, greater density, longer life, and the capability of more charge/discharge cycles. New electrode and electrolyte materials should also reduce the price of nickel metal hydride, lithium, and other technologies to the point where they can compete with more common cell chemistries.

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BOOK REVIEW

G-TOR™: The New Mode

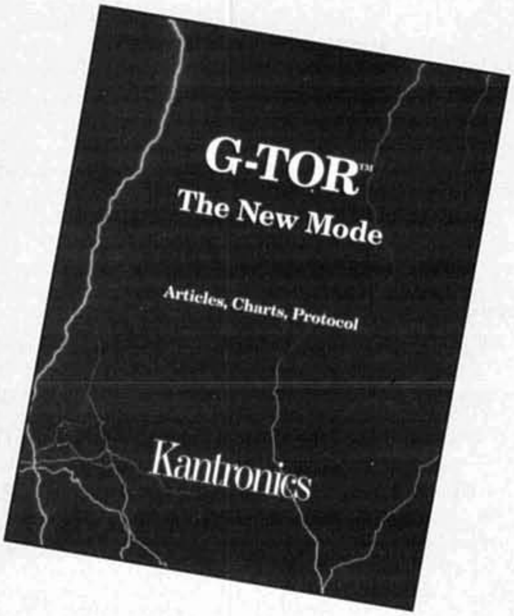
From Kantronics

Kantronics has released a 98-page information guide describing features of the G-TOR communications mode. The book, G-TOR: The New Mode, is a collection of articles, charts, and protocols that have appeared in a variety of publications including: *QEX*, *Communications Quarterly*, and *Digital Journal*.

This new Kantronics collection contains twelve articles that discuss the aspects and uses of this new mode of communications. Titles include: "Hybrid ARQ for HF Data Transmission," by Glenn E. Prescott, WB0SKX, and Phil Anderson, W0XI; "G-TOR: The New HF Digital Mode for the KAM Plus and KAM Enhancement Board" by Kantronics Company, Inc.; and "G-TOR: The Protocol," by Michael Huslig, KB0NYK; Phil Anderson, W0XI; Karl Medcalf, WK5M; and Glenn Prescott, WB0SKX. Most of the authors have been involved in some phase of inventing Kantronics newest HF mode, so the information discussed comes from those in the know!.

G-TOR is an acronym for Golay Teleprinting Over Radio. M.J.E. Golay discovered an error correcting code in 1949 which is the foundation of G-TOR protocol. The foreword of *G-TOR: The New Mode* gives a brief description of what G-TOR is and why it was invented.

If you're looking for a book about G-TOR—Kantronics has it. Who understands a product better than its inventors?



G-TOR: The New Mode is available from book sellers, authorized Kantronics dealers, and Kantronics. For more information, contact your dealer or Kantronics at 1202 E. 23rd Street, Lawrence, Kansas 66046-5006; phone: 913-842-7745; fax: 913-942-2021.

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MODELING AND UNDERSTANDING SMALL BEAMS: PART 2

VK2ABQ squares and Moxon rectangles

Miniature directive antennas appeal to hams with limited space. Commercially, the Butternut HF5B has enjoyed good success. However, its price tag has led numerous hams to look for homebrew antennas. The folded X-Beam, examined in Part 1 of this series, was brought to ham attention by W2EEY as a simplified birdcage and empirically perfected by W9PNE. It has some proponents and a few critics. In the United States, little else seems available to the homebrewer.

The VKs and Gs have long been familiar with a square antenna about the same size as the folded-X. The basic idea for the antenna is simple: take a single quad loop and tip it 90 degrees to put the wire in the horizontal plane. At the midpoints of the sides (calling the feedpoint wire the front and the parallel wire to it the rear), cut the loop and insulate the cut ends from each other while preserving the loop. It's reported that the VK2ABQ design used coat buttons for insulators. The antenna now looks like a 2-element parasitic beam with a driven element and a reflector. It provides gain and front-to-back differential. Folding the ends inward, relative to a Yagi in normal linear configuration, improves the front-to-back ratio at the loss of some theoretically possible forward gain. Moreover, loops for several bands (typically, 10, 15, and 20) can be laid out concentri-

A Sampling of Recommended Dimensions for the VK2ABQ "Square" Beam

Source*	Moxon, p. 168; Hawker p. 334	Hawker, pp. 315–316		
Arm length	6'2"	6'0"	5'9"	5'11"
Perimeter length	34'9"	33'11"	32'6"	33'5"
Side length	8'9"	8'6"	8'2"	8'4"
Formula/side	248/f (MHz)	242/f (MHz)	232/f (MHz)	238/f (MHz)

* See Note 1 at end of text for references cited here. All dimension in feet and nearest inches.

Table 1. A sampling of recommended dimensions for the VK2ABQ "square" beam.

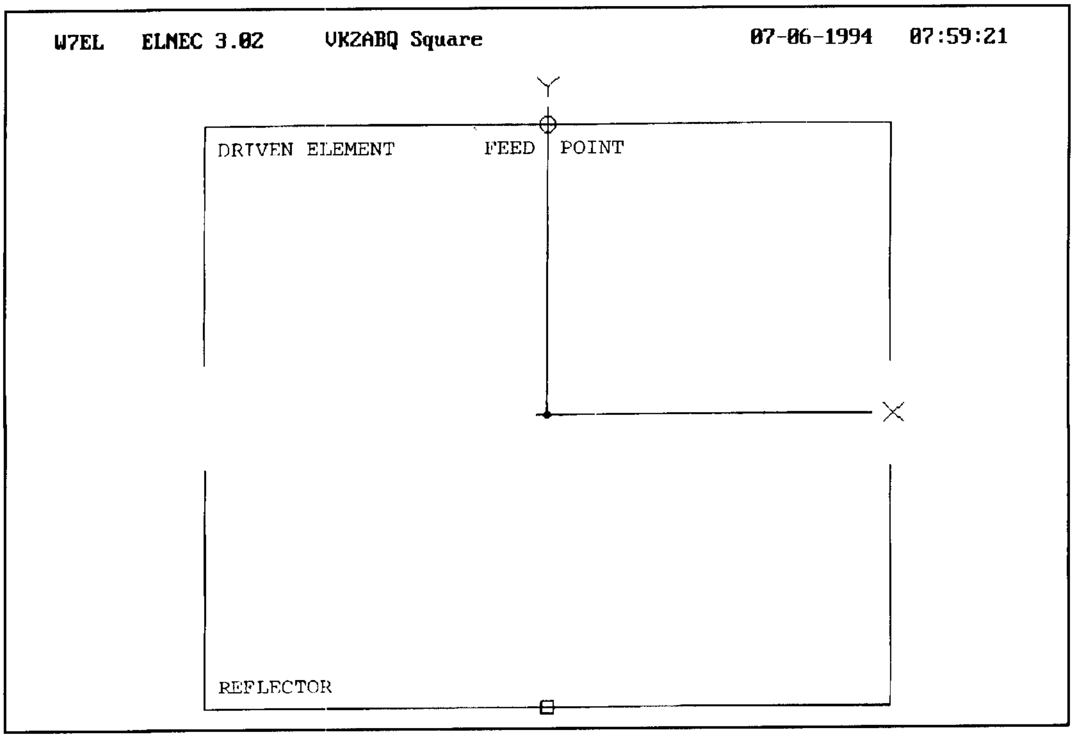
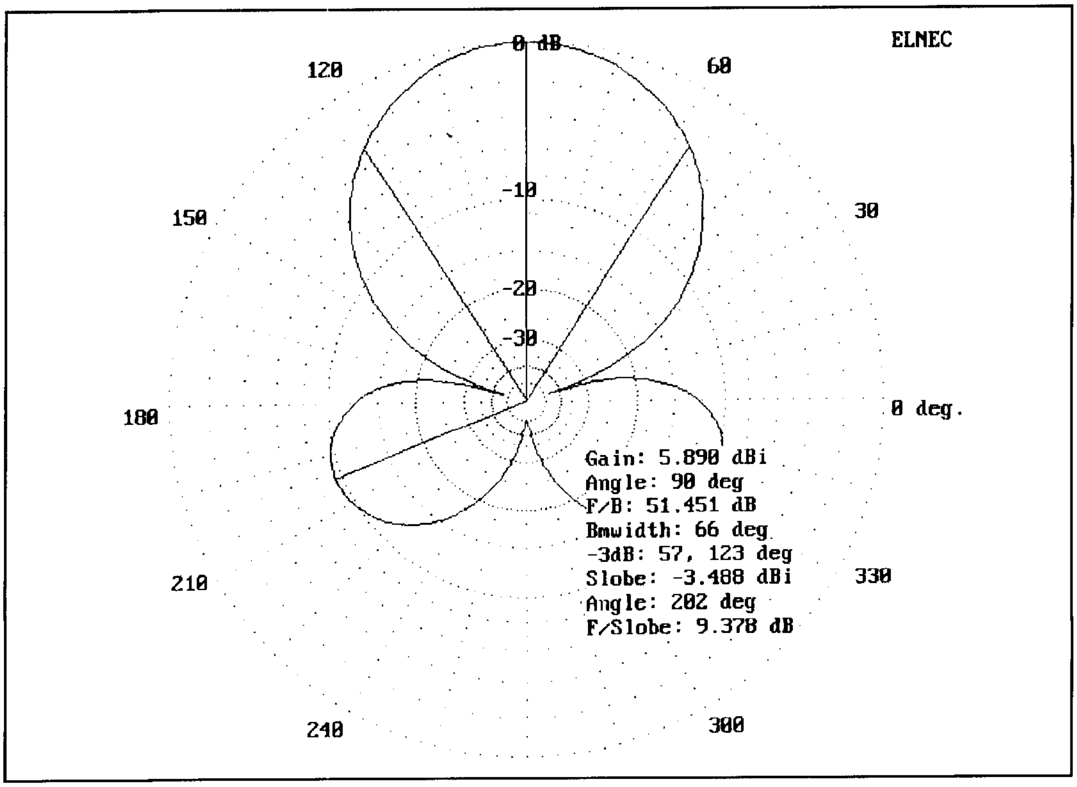


Figure 1. General outline of a VK2ABQ "square" beam.

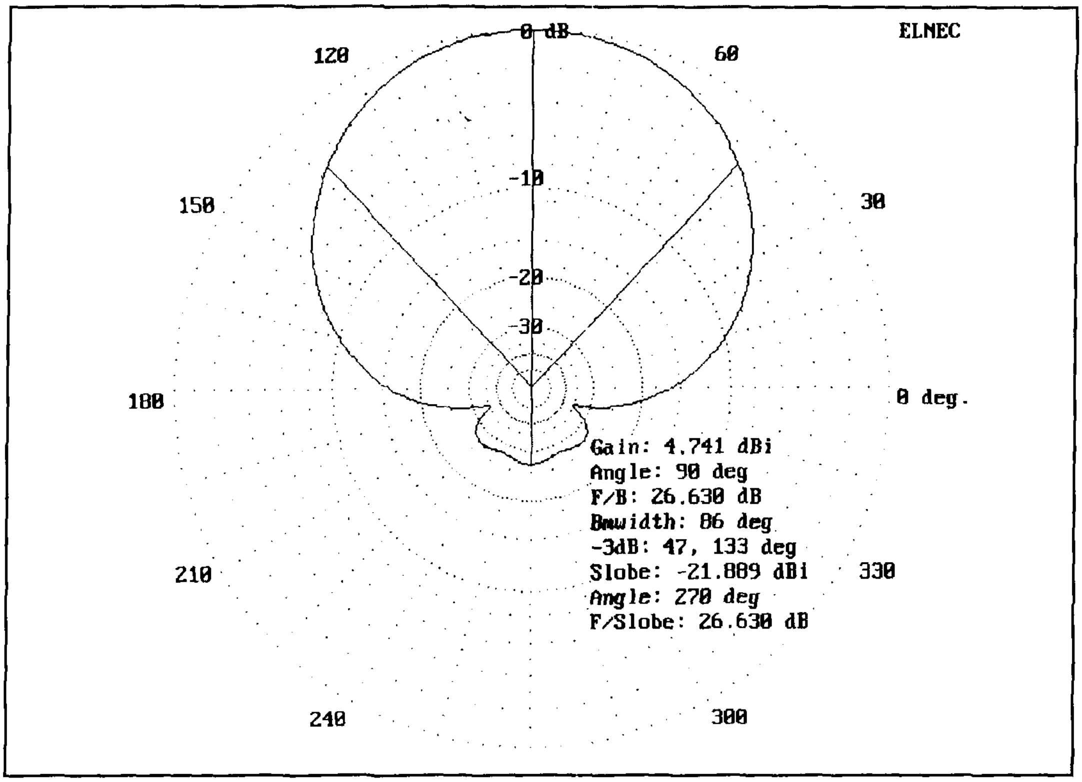


```
Gain: 5.890 dBi
Angle: 90 deg
F/B: 51.451 dB
Bmwidth: 66 deg
-3dB: 57, 123 deg
Slobe: -3.488 dBi
Angle: 202 deg
F/Slobe: 9.378 dB
```

Figure 2. Free space azimuth pattern of a folded X-Beam per Anderson.

cally and fed from a single coaxial cable. **Figure 1** shows the general layout.

One difficulty the builder faces when trying to replicate the antenna lies in finding the right dimensions. The problem isn't a lack of dimensions, but too many sets. **Table 1** and its notes list several sets of dimensions taken from a couple of British sources.[1,2,3] Apparently, the antenna is somewhat sensitive both to the wires for the bands not in operation and to the



```
Gain: 4.741 dBi
Angle: 90 deg
F/B: 26.630 dB
Bmwidth: 86 deg
-3dB: 47, 133 deg
Slobe: -21.889 dBi
Angle: 270 deg
F/Slobe: 26.630 dB
```

Figure 3. Free space azimuth pattern of VK2ABQ model number 6 (Table 1).

method of construction. Different builders have used different amounts of metal in the hub and support spokes, leaving the new builder to play endlessly with wire lengths and providing few clues as to what the goal should be. Although I've only scanned the literature, it appears that American builders have largely ignored the design. In fact, no one seems to have modeled the antenna to find out what it may do for amateur operation.

L.A. Moxon, in his *HF Antennas for All Locations*, provides the essential clue: "the main benefit [of a beam] accrues from the reduction of interference during reception, though the 4 to 6 dB gain provided by typical amateur beams is an important bonus and probably the reason which carries the most weight with the majority of amateurs."[4] Here's a theory of beam operation quite un-American in its style. Instead of gain, Moxon strives for front-to-back ratio as the most crucial aid to ham operation. His statement is an affirmation of the "good ears" theory of operation. Even more, it forms the basis for his rectangular improvement upon the VK2ABQ square.

Moxon's revelation of the operative notions behind his compact beam-building efforts provided the clue that made possible a venture into modeling these beams with MININEC. The goals were to ascertain their general performance capabilities and to find patterns of development toward optimum performance. By

A Sampling from the Series of VK2ABQ "Square" Antennas Modeled

Antenna	Dimensions (feet)				Reflector	Gain	Front-to-Back	Source Z
	X	Y	Space	El. Length	Load (±X)	(dBi)	(dB)	(R ± X)
1.	8.8	8.8	0.2	17.4	0	4.2	16.3	133 + 23
2.	9.0	8.8	0.8	17.0	+45	4.5	22.4	103 - 14
3.	9.1	8.8	1.0	16.9	+60	4.3	22.2	94 - 28
4.	9.2	8.8	1.2	16.8	+60	4.6	30.6	94 - 19
5.	9.4	8.8	1.4	16.8	+60	4.7	34.2	88 - 24
6.	9.8	8.8	1.6	17.0	+47	4.7	26.6	88 - 8.0

Note: All performance values are calculated free space figures.

Table 2. A sampling from the series of VK2ABQ "square" antennas modeled.

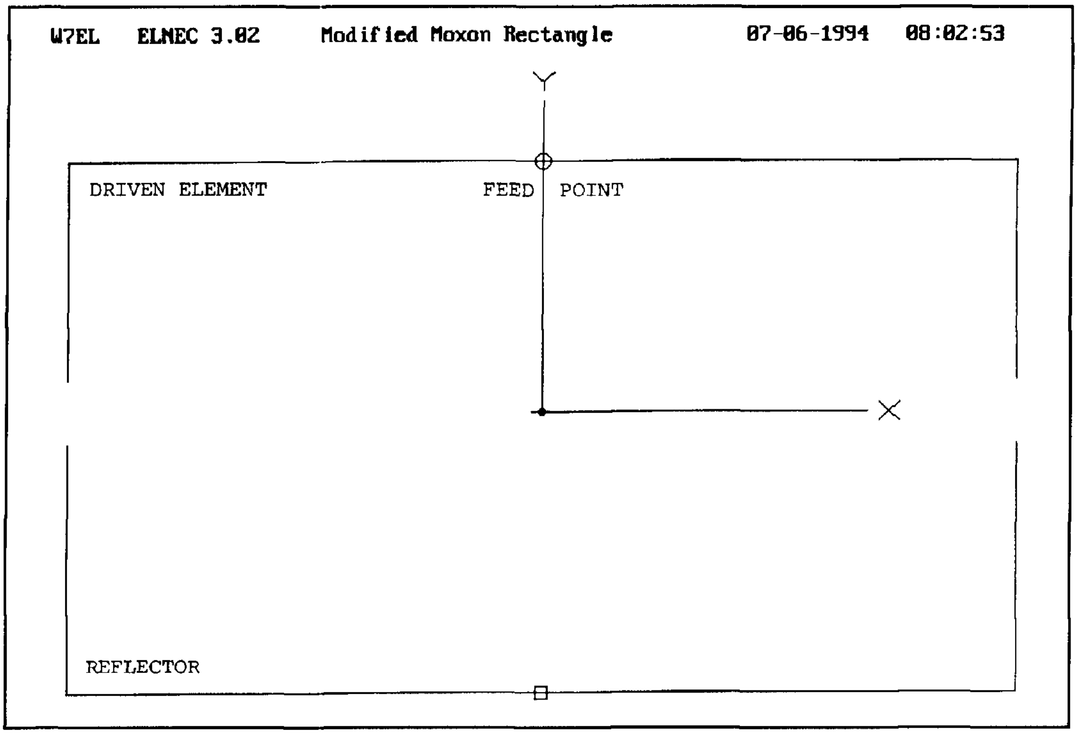


Figure 4. General outline of a Moxon "rectangle" beam.

judiciously loading the reflector, one can find the maximum front-to-back ratio fairly quickly. Then, by adjusting dimensions, the modeler can create a pure loop; that is, one with little or no reactance at the driven element source and with little or no requirement for reflector loading.

Finally, there was the task of discovering whether the model dimensions play out in practice. For this exercise, I chose a single band antenna, a 10-meter version of an optimized Moxon rectangle to be precise. Construction minimized metal throughout. The results brought up several interrelated questions. First, given the complex geometry of this antenna, would MININEC reliably model reality? Second, was the antenna too sensitive to any metal in its plane to reflect its idealized MININEC model? Third, would the antenna live up to its theoretical promise? Finally, where does the VK2ABQ/Moxon antenna fit in the world of miniature or small or simple antennas?

This article tries to provide some tentative answers to a few of these questions by taking a systematic look at this "fallen-quad" beam. I'll examine a progression of models that begins with the VK2ABQ and ends up with an opti-

A Sampling from the Series of Moxon "Rectangular" Antennas Modeled

Antenna	Dimensions (feet)				Reflector	Gain	Front-to-Back	Source Z
	X	Y	Space	El. Length	Load (±X)	(dBi)	(dB)	(R ± X)
1.	11.2	6.6	0.2	17.6	-20	5.3	22.5	115 + 86
2.	11.0	6.6	0.2	17.4	-5	5.2	21.3	114 + 69
3.	10.4	6.6	0.2	16.6 DE 17.0 Re	+30	5.3	18.7	103 + 5.1
4.	11.0	6.6	0.8	16.6 DE 17.0 Re	+35	5.5	37.0	80 – 3.6
5.	11.0	6.7	0.8	16.6 DE	+20	5.5	35.0	81 – 4.2
6.	11.2	6.6	0.8	16.6 DE	+5	5.5	33.6	79 – 2.7

* Models from this point onward use unequal lengths for the driven element and the reflector.

Note: All performance values are calculated free space figures.

Table 3. A sampling from the series of Moxon "rectangular" antennas modeled.

mized Moxon rectangle. Then I'll look at the construction and performance of a real model. My work has some limitations, however. First, it doesn't model multiband versions of the antenna. Second, I haven't explored the use of metallic masts and hub spiders. Nonetheless, the results are both promising and useful. They provide an understanding of the VK2ABQ/Moxon beam potential, and they form a basis for constructing some interesting real antennas for both limited space and portable operation.

The VK2ABQ square

Moxon's search for a little gain and a lot of front-to-back ratio excludes the folded X-Beam from consideration here. **Figure 2** shows why. Although the front-to-back ratio of an X-Beam can be considerable in the narrow path directly opposing maximum gain, there are quartering rear sidelobes that never drop far below about 10 dB less than maximum gain. On 10 meters in the United States, such a pattern, which can yield a forward gain slightly higher than either of the designs I'll explore here, may satisfy the ham with limited space. Elsewhere in the world—on 20 and 15 especially—those rearward lobes would increase QRM levels excessively. However, you can sacrifice gain if the overall front-to-rear-area ratio can be improved. Here lies the inspiration behind Fred Caton's invention, the VK2ABQ square.

Using the original design, optimized for least reflector loading and least reactance at the feedpoint, but retaining the close-spaced element ends, early models achieved respectable performance. **Figure 3** shows the performance of an optimized model, while **Table 2** supplies the dimensions and analysis figures of the models that led up to this performance.

Beginning with a design only slightly smaller than the largest encountered in British sources, I modeled antenna 1. Because all sources on the VK2ABQ recommended extremely close spacing of the driven element and reflector ends, I held this spacing at 0.2 feet or less. The resulting inductive reactance at the feedpoint showed that driven element was long. Moreover, the front-to-back ratio, while slightly better than a typical 2-element Yagi, wasn't up to expectations.

Tackling the second problem first, I began to increase the spacing between element ends. This move shortened the element lengths, as I held the front-to-back (Y) dimension constant. The front-to-back ratio began to improve dramatically, as models 2, 3, and 4 demonstrate. However, to achieve this calculated performance, it was necessary to insert an inductive load into the center of the reflector element—suggesting that the reflector was short for opti-

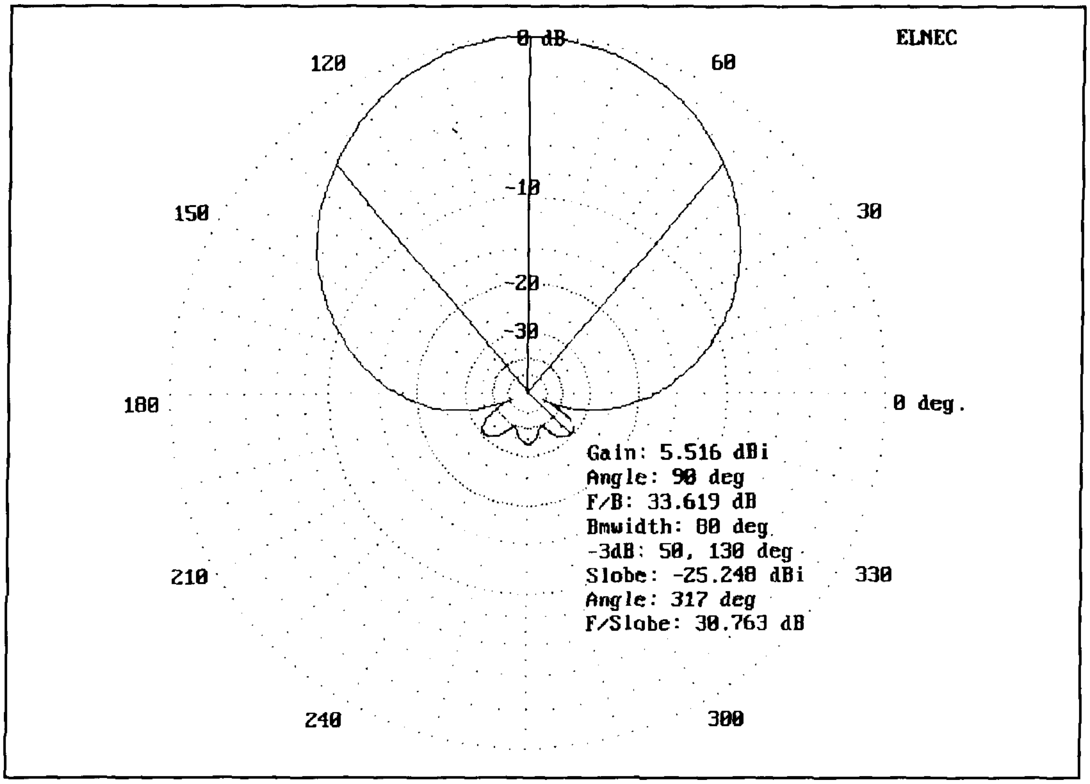


Figure 5. Free space azimuth pattern of Moxon rectangle number 5 (Table 2).

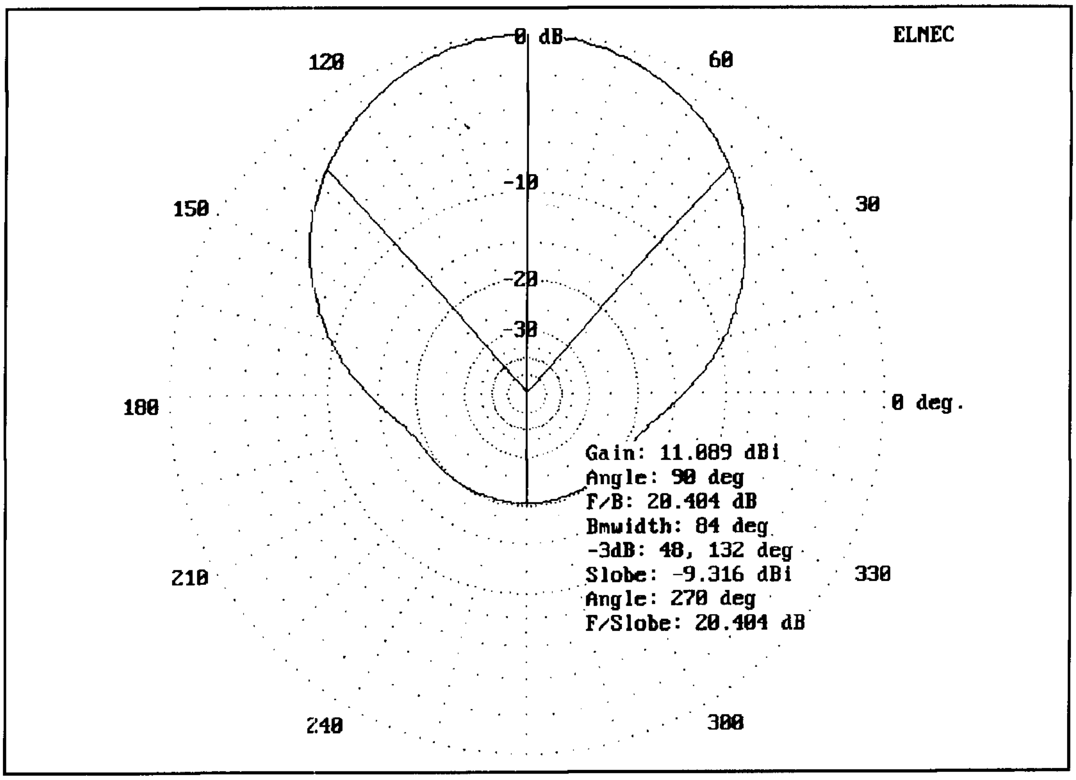


Figure 6. Azimuth pattern of Moxon rectangle number 6 20 feet above average earth.

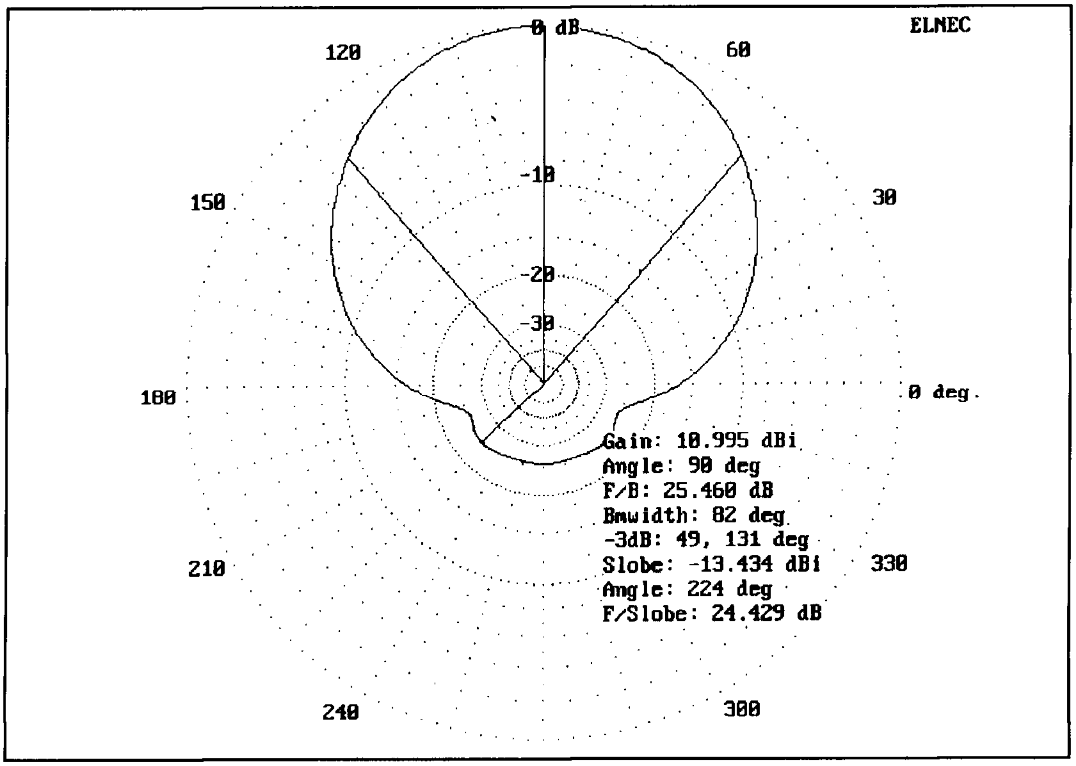


Figure 7. Azimuth pattern of Moxon rectangle number 6 35 feet above average earth.

mum performance. Note that the elements are the same length in all models of the VK2ABQ, a design that is counterintuitive for someone familiar with Yagi configurations.

Model 5 achieves the best front-to-back performance, but at the cost of considerable inductive reactance at the feedpoint and the need for sizable reflector loading. Model 6 lengthened

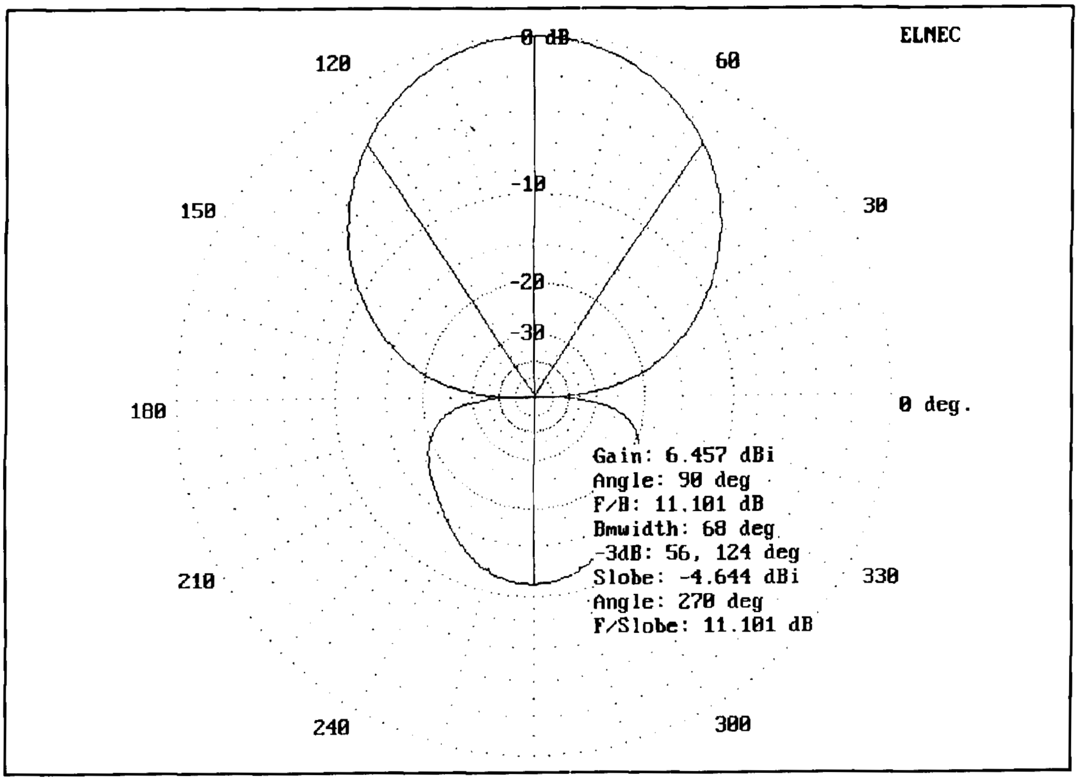


Figure 8. Free space azimuth pattern of a reference 2-element Yagi.

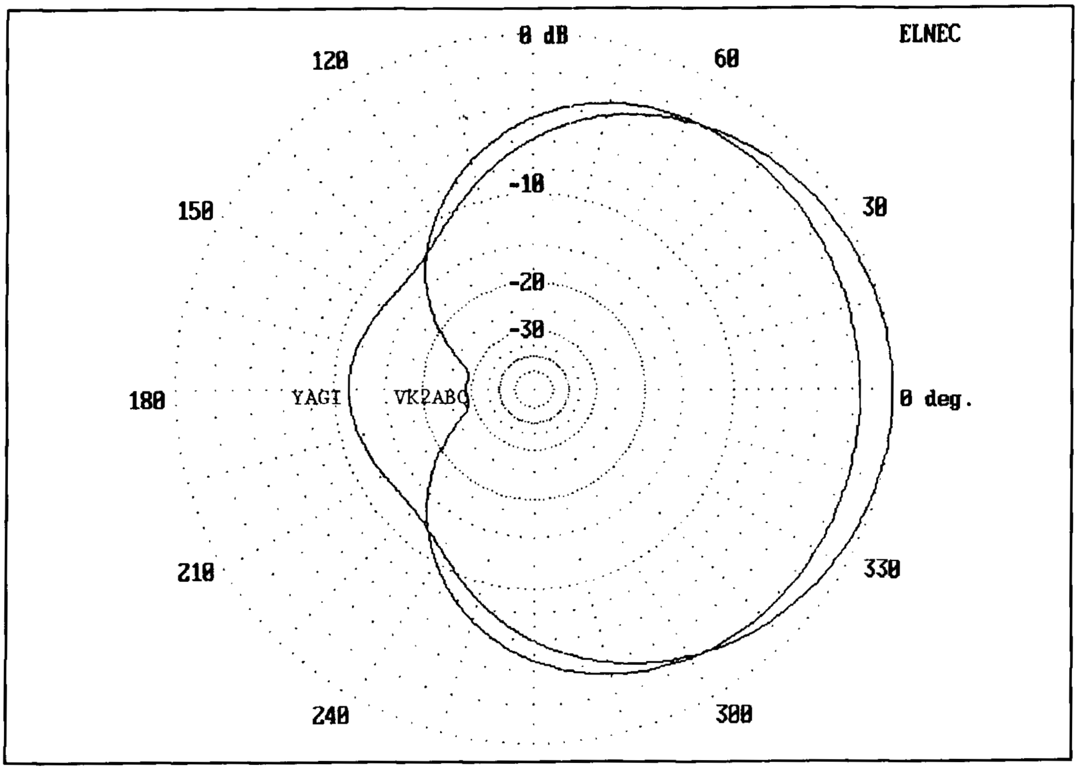


Figure 9. Free space elevation patterns of the Yagi in Figure 8 and the VK2ABQ square in Figure 3.

the element to bring down the feedpoint reactance successfully. However, it widened the gap between element ends beyond optimum and still required reflector loading.

I ceased modeling at this point due to several factors. First, the forward gain of the beam wasn't improving significantly. The best VK2ABQ, while providing exceptional front-

A Performance Comparison Among trhe VK2ABQ, the Moxon, and Some Reference Antennas

Antenna	Conditions	Refl. Load (±X ohms)	Gain (dBi)	Front-to-Back (dB)	Source-Z (R ± X)
VK2ABQ #6 (Table 2)	Free Space	+47	4.7	26.6	88 – 8
	25' Ave Gnd*	+47	10.3	30.8	98 – 13
Moxon #6 (Table 3)	Free Space	+5	5.5	33.6	80 – 3
		0	5.6	24.1	76 + 1
	20' Ave Gnd	–5	11.1	20.4	81 – 6
		0	11.0	18.9	85 – 10
	35' Ave Gnd	+5	11.0	25.5	88 – 3
		0	11.1	21.9	83 + 1
2-element Yagi	Free Space	--	6.3	11.2	32 + 1
(DE + Refl.)	35' Ave Gnd	--	11.7	13.5	35 ± 0
(16.0'/17.5'/4.25' space)					
Single loop quad,	Free Space	--	3.2	--	127 + 4
#18 copper wire	35' Ave Gnd	--	8.5	--	125 – 6
(L=1040/f(MHz) or					
9.12' per side)					
Wire dipole,	Free Space	--	2.1	--	72 ± 0
#18 copper wire	35' Ave Gnd	--	7.7	--	86 – 8
(L=468/f(MHz) or					
16.42'					

* Average ground or earth: dielectric constant = 13, conductivity 5 mS/m

Note: Compare free space figures only to other free space figures and over-ground figures only to other over-ground figures.

Table 4. A performance comparison among the VK2ABQ, the Moxon, and some reference antennas.

to-back ratio, produced a forward gain only a bit higher than that of a single quad loop mounted in the normal plane. Second, the model was departing from square to a degree that made the Moxon rectangle *the next logical* step in my work.

However, before departing the VK2ABQ, notice the general pattern in **Figure 3** once more. Unlike the X-Beam (**Figure 2**), the VK2ABQ puts all its power in the forward lobe, with a beam width that settles in around 88 to 90 degrees between –3 dB points. The main lobe extends around to the sides, so direct side rejection is only half the front-to-back ratio. In comparison, the X-Beam has good front-to-side ratio (at the expense of the rearward lobes), and the dipole, single quad loop, and 2-element Yagi antennas have excellent front-to-side ratios. *None of these antennas, however, can even* approximate the VK2ABQ for the clean and empty wide rear quadrants. This feature may be useful in more than one application.

The Moxon rectangle

To achieve better performance, Moxon *lengthened the front and rear elements and* shortened the side tails. The resulting rectangle requires very little additional turning radius than the square, but improves the gain of the antenna considerably. Modeling Moxon's beam required some initial guesses at the actual 10-meter dimensions, because the builder created u-shaped insets at the corners to handle excess wire needed to make up the perimeter.[5] Nevertheless, only two steps yielded a pretty good Moxon beam model. **Figure 4** shows the general outline of the Moxon rectangle, while **Table 3** shows the progression of models and their results.

The initial models preserved the VK2ABQ's close end spacing (although Moxon widened the gap). Model 2 is especially interesting, because it shows excessive driven element length in the

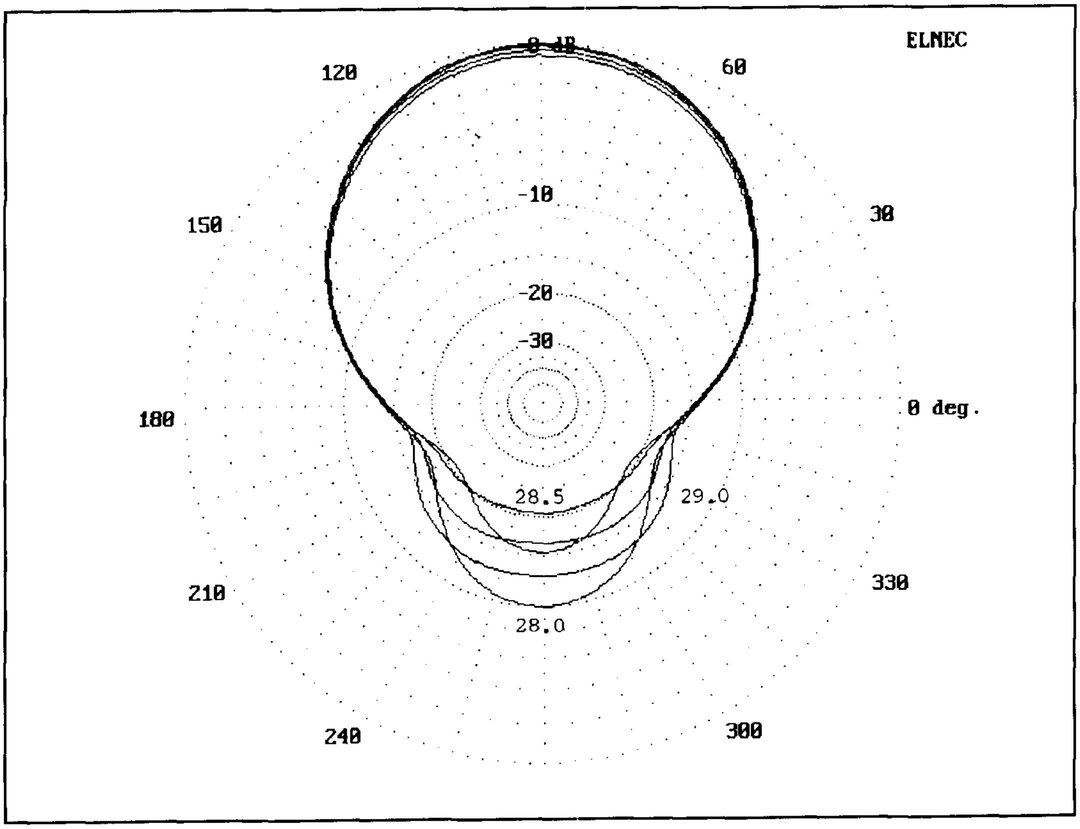


Figure 10. Pattern bandwidth of the Moxon rectangle at 35 feet using composite azimuth patterns at a 24-degree take-off angle.

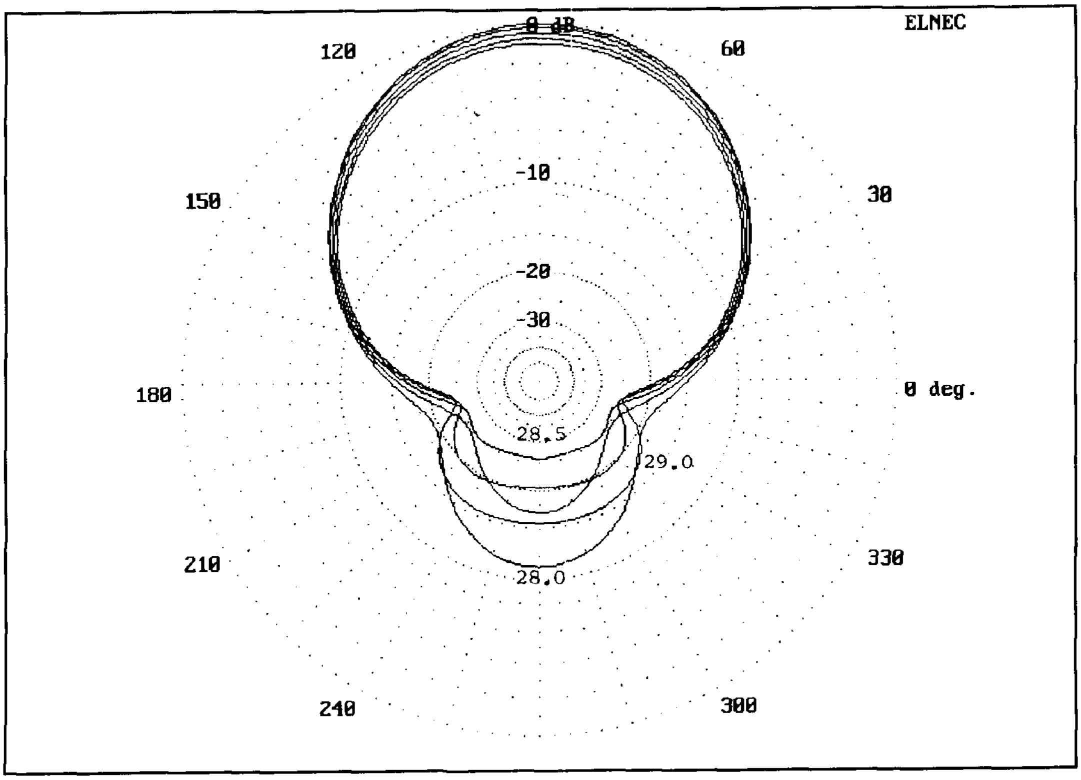


Figure 11. Pattern bandwidth of the Moxon rectangle at 35 feet using composite azimuth patterns at a 24-degree take-off angle.

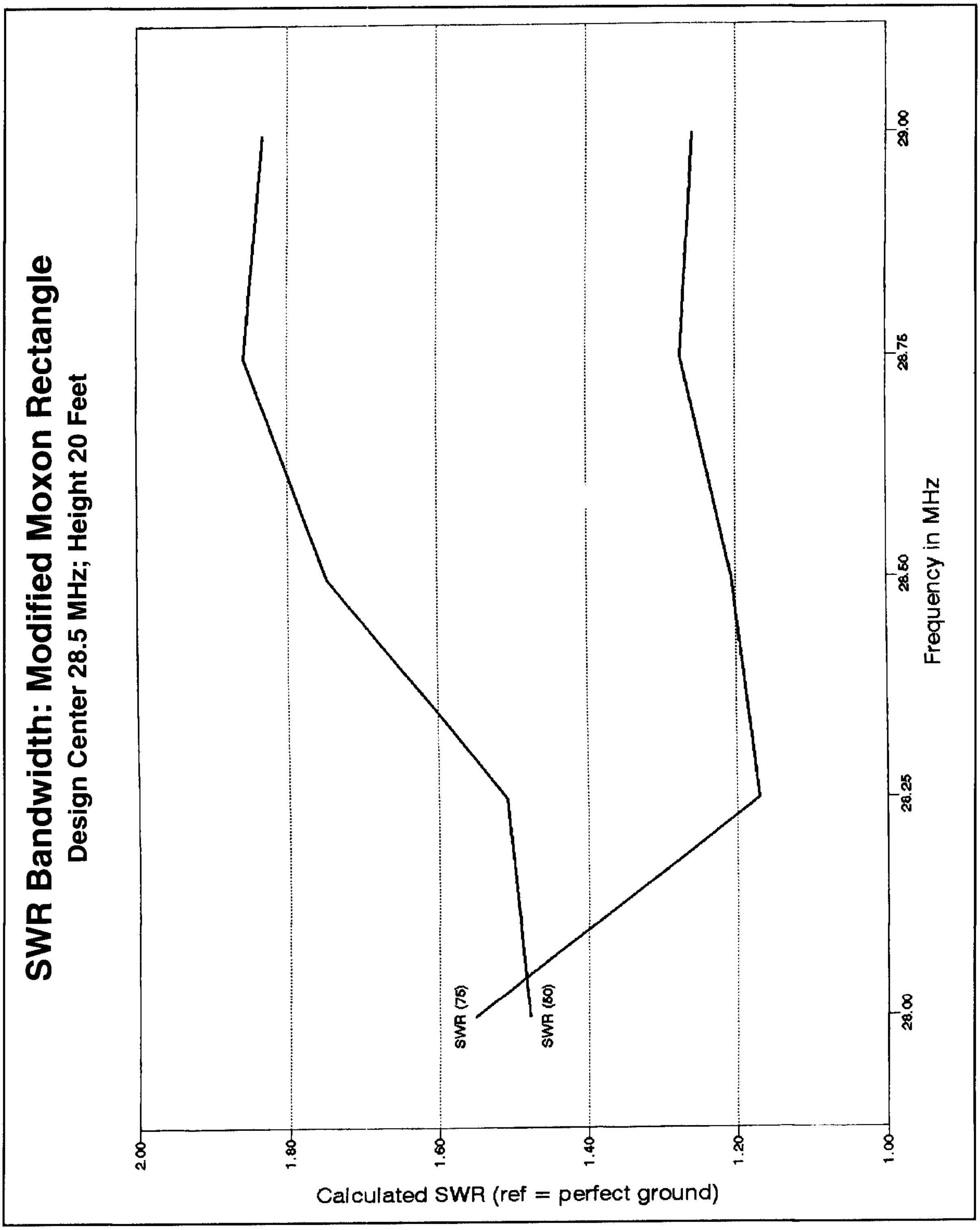


Figure 12. SWR bandwidth of the Moxon rectangle at 20 feet for 50 and 75-ohm cables.

inductively reactive source impedance. The reflector is about right for this configuration; but, the front-to-back ratio isn't up to VK2ABQ standards. My next moves were a simultaneous increase of the gap between ends and an unbalancing of the forward and rear elements. Moxon prefers matched elements, tuning each of them to optimum performance remotely. That way, he can reverse the beam and do away with expensive and maintenance-intensive rotators. However, rotators are a way of life in the United States (a TV rotator will likely handle a 3-band Moxon beam), and there are many uses for portable beams that are hand-rotated or fixed in

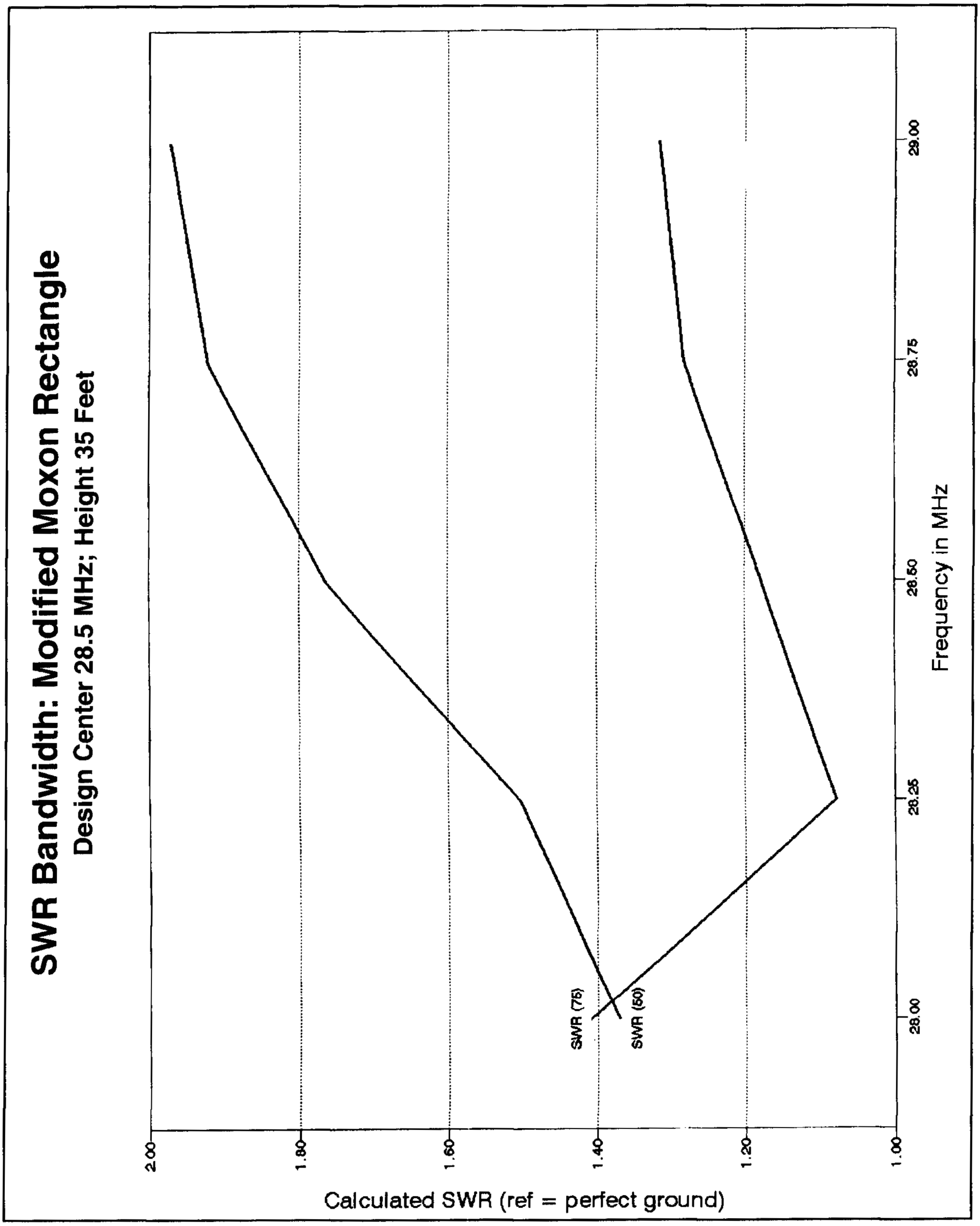


Figure 13. SWR bandwidth of the Moxon rectangle at 35 feet for 50 and 75-ohm cables.

the field. Thus, I decided to continue the exercise in unequal element lengths.

In models 3, 4, and 5, you can see the approach to a model that would have a roughly resonant feedpoint and require no loading of the reflector. I consider the last model, number 6, optimum for these reasons. **Figure 5** provides a free space azimuth pattern for comparison to other antennas. The modified Moxon rectangle is a close match to RG-11 or RG-59 coax for direct feed. The differentials of front-to-back ratio in models 4, 5, and 6 make little difference in practice, and the forward gains of the three models are the same.

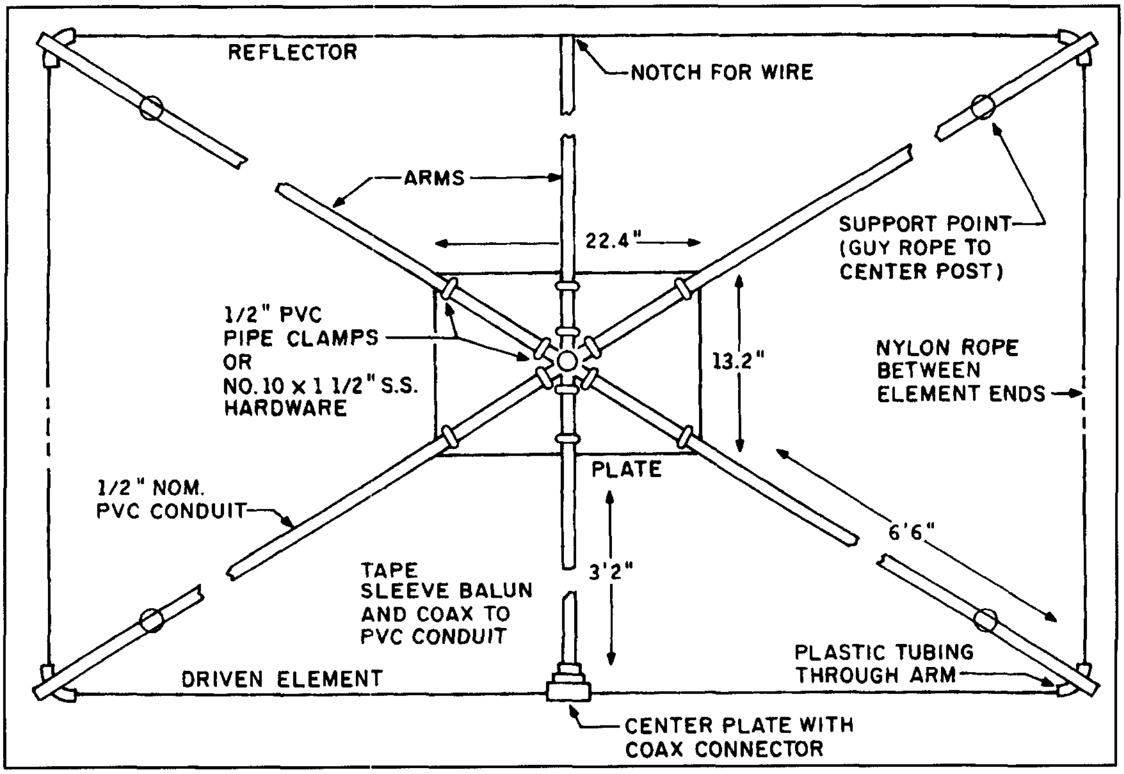


Figure 14. Construction sketch of the 10-meter test Moxon rectangle.

Free space isn't a fully adequate indicator of these quasi-loop beams over real ground. The potential for needing reflector loading was too great simply to build the free space model and hope it would work. **Table 4** presents some comparative figures. Without any reflector load at all, the Moxon 6 model promised adequate performance at both 20 feet (a typical portable height) and 35 feet (a typical home-installation height) above medium earth. The 20-foot Moxon exhibits a small wide swell in rear coverage (**Figure 6**), while the 35-foot Moxon demonstrates a more stepped appearance (**Figure 7**). Both front-to-back ratios are reasonable for the heights, although neither reaches the level of the tiny free space rear lobes.

The Moxon beam shows a gain midway between the VK2ABQ and the typical 2-element Yagi. **Figure 8** provides a free space azimuth pattern for a typical 2-element Yagi as a reference standard against which to compare the Moxon rectangle. The fact that the Moxon rectangle's gain is less than that of a linear 2-element Yagi, despite the absence of power in the rear lobe, may raise some questions. However, such questions reveal 2-dimensional thinking. Antennas are three dimensional devices. Besides forward and back, power may radiate up and down and anywhere between. Both the VK2ABQ and the Moxon rectangle radiate considerably more power to the sides and at high radiation angles relative to the horizontal than 2-element Yagis. **Figure 9** demonstrates the difference in free space high angle radiation between the VK2ABQ and the Yagi, while a comparison of **Figure 3** and **Figure 8** reveals the 18-degree beamwidth difference. Although these properties hold down forward gain, they may prove useful in other applications.

Bandwidth considerations for both the pattern and the feedpoint impedance are of concern to every small beam builder. **Figures 10** and **11** display the pattern bandwidth in sets of azimuth patterns taken at five points between 28 and 29 MHz. At 28 MHz and a 20-foot height, the front-to-back ratio of the rectangle drops to about 11 dB. At 29 MHz, the figure is also about 11 dB. These figures approximate a 2-element Yagi, but the Moxon exceeds the Yagi between 28.25 and 28.75. A similar pattern of reduced front-to-back ratio at band edges appears with the antenna at 35 feet, but the effect is smaller. Except for the lowest edge of the 10-meter band, the front-to-back ratio remains above 15 dB and above 25 dB at design center. At both heights, the forward gain, while less than that of a 2-element Yagi, remains fairly constant across the band.

With respect to feedpoint impedance, the Moxon rectangle is well-behaved across the entire first megahertz of 10 meters. Because the design center frequency impedance is about 80 ohms at all heights, 75-ohm coax provides the best match, as shown in **Figures 12** and **13**. However, the SWR relative to a 50-ohm transmitter output and cable never exceeds 2:1 from

28 to 29 MHz, simplifying matching requirements. As the test model verified, these anticipated values are close to reality, despite the limitation of MININEC in calculating impedance and SWR for perfect grounds only.

The Moxon rectangle's 3 dB gain over a dipole at the same elevation is useful, but the most significant Moxon feature is the reduction in all rear directions of potential QRM. At 6 dB per S-unit, the Moxon beam promises (at least in model form) to reduce QRM by more than a full S-unit and perhaps as much as 2 S-units compared to a 2-element Yagi. Whether the beam could deliver on its model's promise required an exercise in building.

Building a Moxon rectangle

Because the diversity of VK2ABQ dimensions in the literature suggests a sensitivity to the conductivity of the antenna structure, the portable Moxon beam requires a minimum of metal to test the model dimensions. Therefore, the beam I built was an exercise in plywood, PVC, and nylon cord (see **Figure 14** and **Photo A**). A center platform of well-varnished or fiber-glassed 3/8-inch plywood measured 22.4 by 13.2 inches. These dimensions ensured that the rectangular X-frame would have the proper angles. A pair of no. 10 1 1/2-inch stainless steel bolts (with washers and nuts) secures each of the four half-inch nominal thin-wall PVC arms. In place of the bolts nearest the corners of the platform, you may use 1/2-inch nominal PVC conduit clamps with no. 8 stainless steel hardware. Fifth and sixth arms project from the platform to the center of the driven element to support the feedline and to the center of the reflector element.

The platform has a center hole to pass a 3-foot length of 1-inch nominal schedule 40 PVC pipe. Two 2-inch corner brackets secure the platform to the pipe 18 inches down from the top. The brackets use bolts that pass through a bracket, the pipe, and the opposing bracket. Short no. 10 stainless steel hardware secures the brackets to the platform. Note that the brackets are located above the platform, as it will rest on the 1 1/4-inch nominal PVC mast pipe, with a pair of bolts through the nested pipes to lock them together.

At the upper end of the platform pipe, an X-cut—enlarged and smoothed—provides a channel for eighth-inch nylon support cord. The cord ends pass through holes in opposing arms about two thirds of the way out to the corner. Several wrappings of the cord before knotting reduce stress on this light guy. **Figure 15** provides guidance for setting up the support guys.

Each arm is 6 feet, 6 inches long. Mounted on the plate about 1 inch from the center point (to allow room for the pipe hole), the arms extend about an inch beyond the precise corner points. Quarter-inch holes through the arm in the plane of the wire permit the insertion of plastic tubing to reduce stress on the element wires that pass through them.

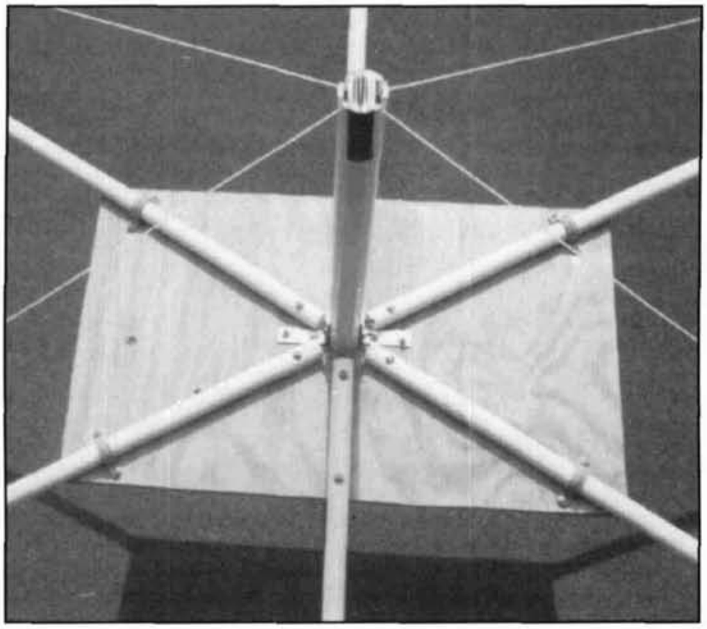


Photo A. Center plate (before fiber glassing) and guy support of the modified Moxox rectangle.

To build, measure each element with some excess. Thread each element through the plastic corner tubes. To the ends of each element, attach about a foot of nylon cord to tie the element ends together and maintain spacing between them. Add the guys running across the X-cut in the vertical pipe. The result will be a well-braced Moxon rectangle for use in up to moderate winds.

Use part of the driven element's excess wire to provide whatever is needed to attach a simple dipole center insulator and coax fitting. When you're satisfied that the dimensions are close enough for initial testing, snug up all the tie-off points. Don't solder the element end's wires yet, as some length adjustment may be needed to put the beam on target. (In fact, after completing all length adjustments, remove the cord from the element end. Solder the wrapped wire to secure it and make a loop. After cooling, reinsert the cords and resnug the assembly. This caution is needed, because nylon cord melts well before solder does.) Attach 75-ohm coax to the dipole center insulator, taping it to the extra PVC arm. You can also insert a choke or sleeve balun here to reduce chances of RF traveling down the outside of the coax braid. Alternatively, you can insert a 75-to-50 ohm balun or unun and use 50-ohm coax to the rig.

It's not necessary to make any of the initial

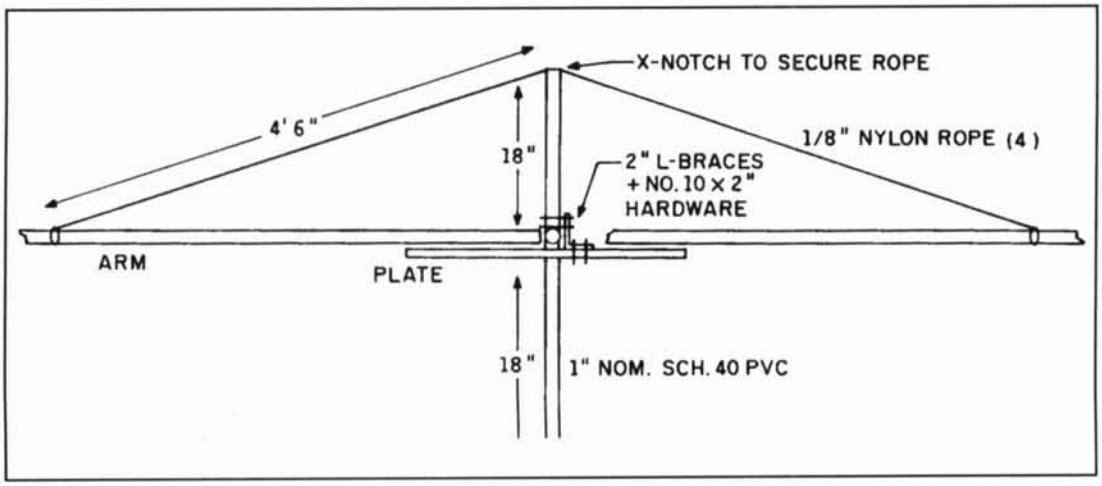


Figure 15. Sketch of the support guy system used with the test Moxon rectangle.

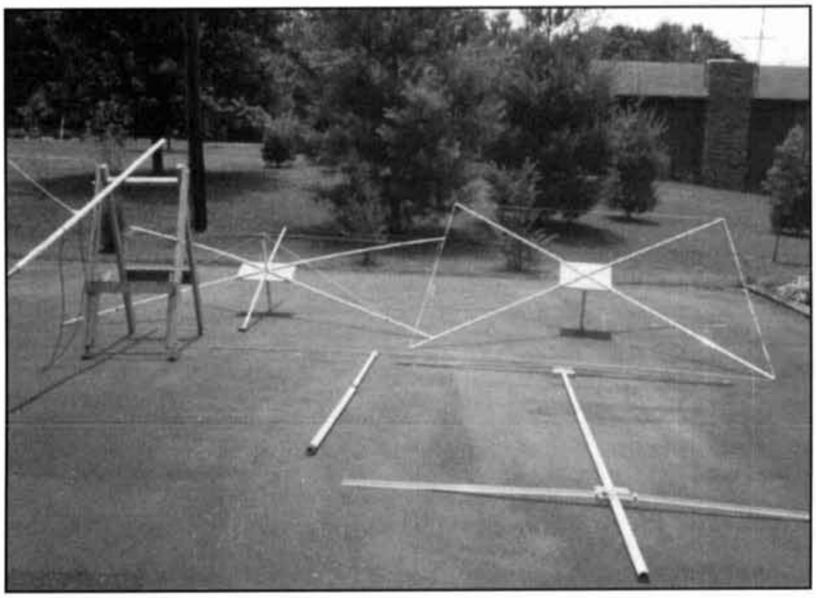


Photo B.The "test range" at W4RNL includes a mast, antenna prop, and some homebrew antennas: Moxon, X-Beam, quad loop, and dipole (clockwise from upper left).

adjustments and tests with the beam in the air. Lay the beam over a wooden prop so the reflector is a few feet off the ground and the driven element points to the sky. Using a low-power signal, adjust the driven element lengths for the lowest SWR at the frequency of choice. Now erect the antenna in the normal plane at least 15 feet high. With a small signal source and a receiver, adjust the reflector for minimum signal off the rear. Try to keep the element ends about 9 to 10 inches apart. The SWR of the driven element should not be adversely affected. However, you may wish to lower the antenna and redo the driven element length one more time to finish the adjustment task. Only the most finicky operator should need to make further adjustments at height.

With minimal metallic mass in the mounting, the Moxon rectangle adjusts quite closely to the model dimensions. Although my test set-up doesn't permit test range figures (see **Photo B**), the antenna performs to expectations at a height of 20 feet. For signal strength, it doesn't quite match my 2-element beam at 35 feet; but the front-to-back ratio is much better, despite the height disadvantage. If you feed the antenna with 50-ohm coax cable, expect an SWR that varies from 1.5:1 to 1.9:1 in a rippling fashion across the first megahertz of 10-meters. The normal dip in the resonance curve only appears with 75-ohm cable.

Point-to-point tests with local operators located 10 to 15 miles from my station confirmed the modeling exercises quite well. Using both received signals and reports of transmitted signals, the front-to-back ratio of the antenna averaged better than 4 S-units on a variety of transceivers, compared to a little over 2 S-units for my HF5B at 35 feet. The front-to-side ratio averaged a between 1 and 2 S-units, but signals fell off rapidly as the beam was rotated past the side point to the rear. These results can't be translated into the 20-foot azimuth pattern figures (**Figure 6**), because that pattern is taken at an elevation angle of greater than 20 degrees and assumes no ground clutter. Moreover, the relationship of S-units on a transceiver meter to dB of front-to-back ratio is too uncertain for quantitative comparison. However, for practical operation, the basic characteristics of the Moxon rectangle appear satisfactorily confirmed. Nonetheless, other construction methods using a greater metal mass in the support structure may require more extensive adjustment.

The wood-wire-PVC model of the modified Moxon rectangle has withstood stormy wind gusts of about 45 m.p.h.—far above the design goal for the portable antenna. However, after continuous use, the wood platform is bound to age, and the thin nylon rope will fray. For per-

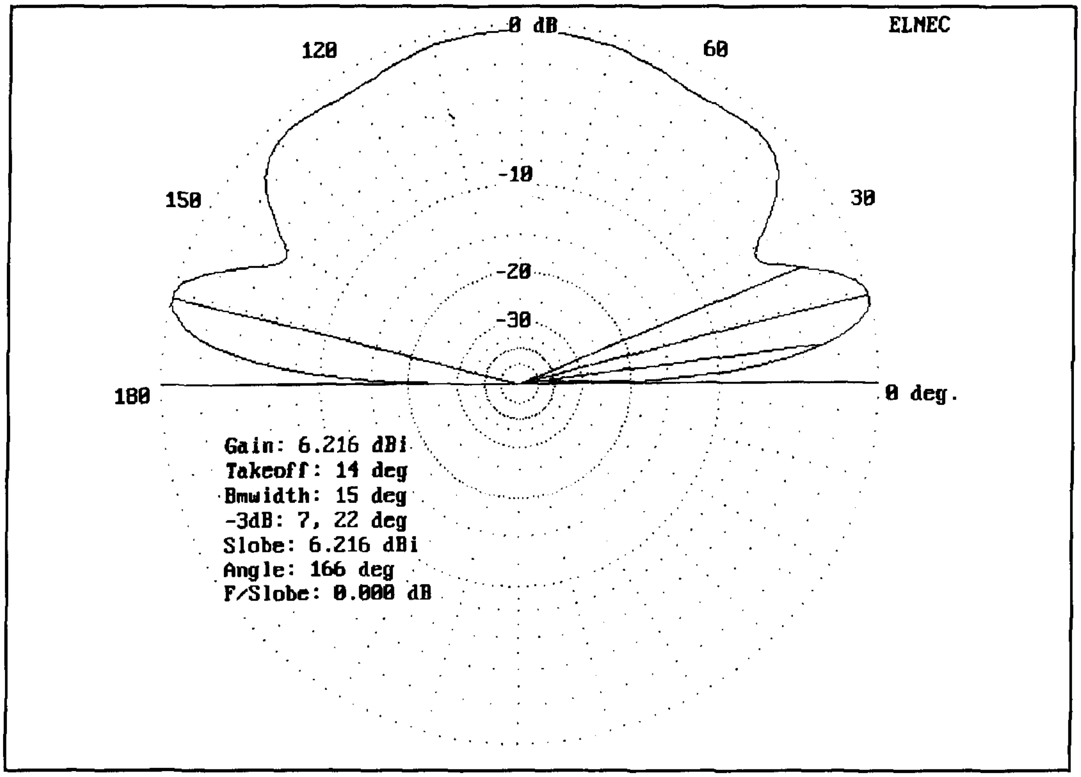


Figure 16. Elevation pattern of a vertically oriented Moxon rectangle beam (number 6) off the plat plane of the antenna.

manent installations, a more robust construction method may be in order. Models of the rectangle using 3/4-inch aluminum tubing suggest that only the driven element needs adjustment to compensate for the fatter element diameter. Shortening the driven element tails by about 0.2 feet each, while maintaining the spacing from the ends of the reflector tails, brings the beam's operating characteristics into line with the wire model.

Some applications of the Moxon rectangle

The Moxon rectangle offers the ham with limited space the chance for a compact directional beam. The concentric addition of elements for other bands is possible. Moxon reported interaction between elements on 15 and 10 meters and offers some hints on curing the problem. Of course, the multiband builder will have to experiment with element lengths for peak performance, as will the builder who uses more metal to support the arms.

If you don't make Gordian knots in the nylon guys and stays, the beam should disassemble in 15 minutes for transportation. The broad main lobe of the Moxon rectangle may serve Field Day and other operations well. It rivals W7EL's Field Day Special, but may be erected where there are no trees for end supports.[6] On either coast, a single fixed position would cover most of the United States, while inland, a TV rotator or an "Armstrong" assistant will rotate the beam with ease. For many contests and other applications, front-to-back ratio may serve the operation better than raw gain.

The antenna offers a further potential. Given the wide beam angle both horizontally and vertically, plus the exceptional front-to-back ratio, the Moxon rectangle provides a very smooth curve in both X and Y planes when pointed straight up (see **Figures 14** and **17**). Off the flat of the reoriented beam, models show almost horizon to horizon coverage with minimal dips in the pattern at a wavelength height. Side-to-side, the coverage is very smooth, although it may require a pair of rectangles, each tipped 30 degrees or more to extend coverage to near the horizon. The patterns exhibit none of the vertical holes of vertical dipoles nor any of the pattern irregularities of simple horizontal antennas. Because satellite operations have reached the point for many birds of not requiring steerable arrays, the Moxon rectangle may be serviceable as a simple fixed antenna. Hybrid construction using aluminum tubes or rods for what are now the horizontal elements, with wire and cord for the ends, may simplify the building process, but preconstruction modeling is recommended to check the effects of larger element diameters.

Modeling the modified Moxon rectangle at

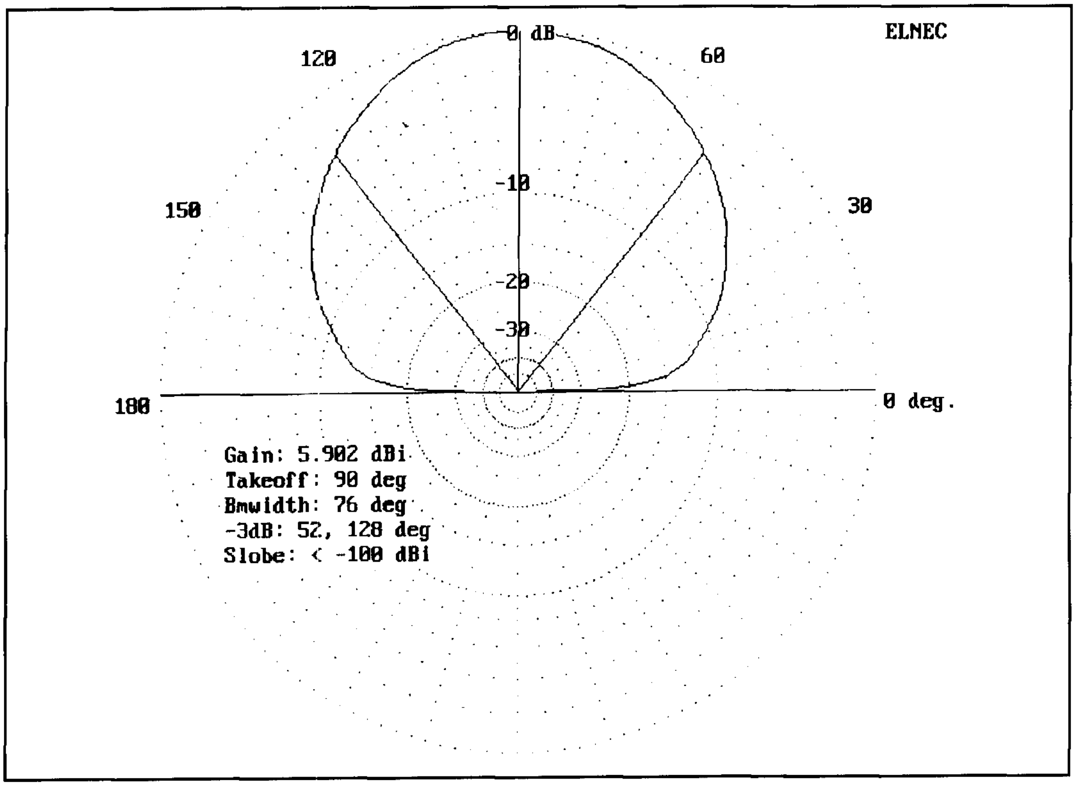


Figure 17. Elevation pattern of a vertically oriented Moxon rectangle beam (number 6) off the edge plane of the antenna.

144.5 MHz with no. 14 copper wire for the elements produced the following dimensions: a rectangle 2.36 feet long by 1.32 feet wide, with a driven element 3.40 feet total length and a reflector 3.62 feet total length. These lengths translate into 0.52-foot end pieces for the driven element and 0.63-foot end pieces for the reflector, with a 0.17 foot space separating the end pieces. The 2-meter model showed all the properties of the 10-meter version at 1 wavelength above ground or ground plane. Elevated to several wavelengths above ground and pointed straight up, the patterns develop deep nulls between adjacent lobes; lobes that multiply with height. Therefore, VHF and UHF scalings of the rectangle might use an artificial ground plane (a wire screen) below the reflector to tailor the pattern even further.[7] The driven element impedance drops to about 65 ohms due to the larger element diameter relative to the wavelength of the signal. This suggests that tubing models might approach a good match to 50-ohm coax. (A 10-meter model using 0.75-inch aluminum tubing produced a calculated 72-ohm source impedance, a 9 percent reduction relative to the no. 14 wire version.)

Overall evaluation

In our quest for gain, we may have overlooked the important "good ears" principle of effective amateur operations. The modified Moxon rectangle presented here, as an improvement of the VK2ABQ square, offers exceptional front-to-back ratio with only two elements. Moreover, its pattern offers other potentials usable by field operators and possibly even by satellite operators. The beam lends itself to home construction with components easily accessed from hardware and home-improvement outlets. As the "loose ends" in this report suggest, the modified Moxon rectangle offers a fertile field for experimentation with other materials. All in all, it's an antenna worth further study; even more, it's an antenna worth further use.

If the wire elements of the Moxon appeal to you more than aluminum tubing, then still another sort of array may be to your liking. EXTENDED DOUBLE ZEPPS lend themselves to high-gain fixed arrays of both phased and parasitic types. More on the EDZ family next time.

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UNDERSTANDING ELEVATED VERTICAL ANTENNAS

Useful information about a popular antenna type

I live on a small lot that limits my options for antennas. I'm also an avid DXer who *needs* the lowest possible radiation angle. A vertical antenna was an obvious choice to satisfy my needs. After working and listening to many DX stations who were using a vertical or GP (ground plane) antenna, mostly Europeans, I considered three possible configurations:

1) ground mounted quarter wave
2) elevated quarter wave or ground plane
3) half wave (including the popular Cushcraft "R" series)

I consulted antenna books by Kraus,[1] Orr,[2] Moxon,[3] and the ARRL,[4] and used MININEC[5] to compute the relative performance of various designs. I chose a conductivity of 4 mS/meter and a dielectric constant of 13 for all the calculations in this article. Vertical antenna performance varies greatly with ground characteristics, so the data presented here should only be used for comparison purposes. The MININIC-computed impedances and gains aren't accurate because the effect of ground on the antenna currents isn't taken into account; however, the data are adequate for comparison purposes. The elevation plots presented for quarter-wave verticals with two elevated radials were computed with 0 degrees perpendicular to the plane of the antenna and radials.

A ground-mounted vertical with 30 or more radials would be a great choice for all around operating, as illustrated in **Figure 1**. Unfortunately, I have a small yard, blockage from our two story stucco house would be excessive, and I'd have to put a fence around the antenna to protect the kids and dog—so I ruled out the ground-mounted vertical design. This narrowed the field to an elevated quarter or half-wave vertical. **Figure 1** shows the relative performance of a quarter-wave vertical 8 feet above ground and a half-wave vertical with its center 20 feet high. The remainder of this article summarizes what I learned as a result of my personal experience and by using MININEC/NEC analysis on both these antenna types.

I couldn't find an aesthetically pleasing arrangement for radials on my roof, so I purchased a Cushcraft R4—which is a half-wave design using traps for 20, 15, 12, and 10 meters. It has a built-in counterpoise consisting of a series inductor and 4 short stainless steel radials at the base. The R4 was a big improvement over my dipole for DXing on 20 meters. I computed the performance of the R4 on my roof by simulating it as a vertical dipole with it's center 30 feet off ground. The results shown in **Figure 2** are very interesting. The antenna has a fairly broad second lobe, which can be viewed as a plus because it increases the angular coverage of the antenna, or a minus because the higher angle lobes may increase the QRM from local stations. Chapter 3, Figure 15 of *The ARRL Antenna Book*, 16th edition, shows the effect of height on a ground plane

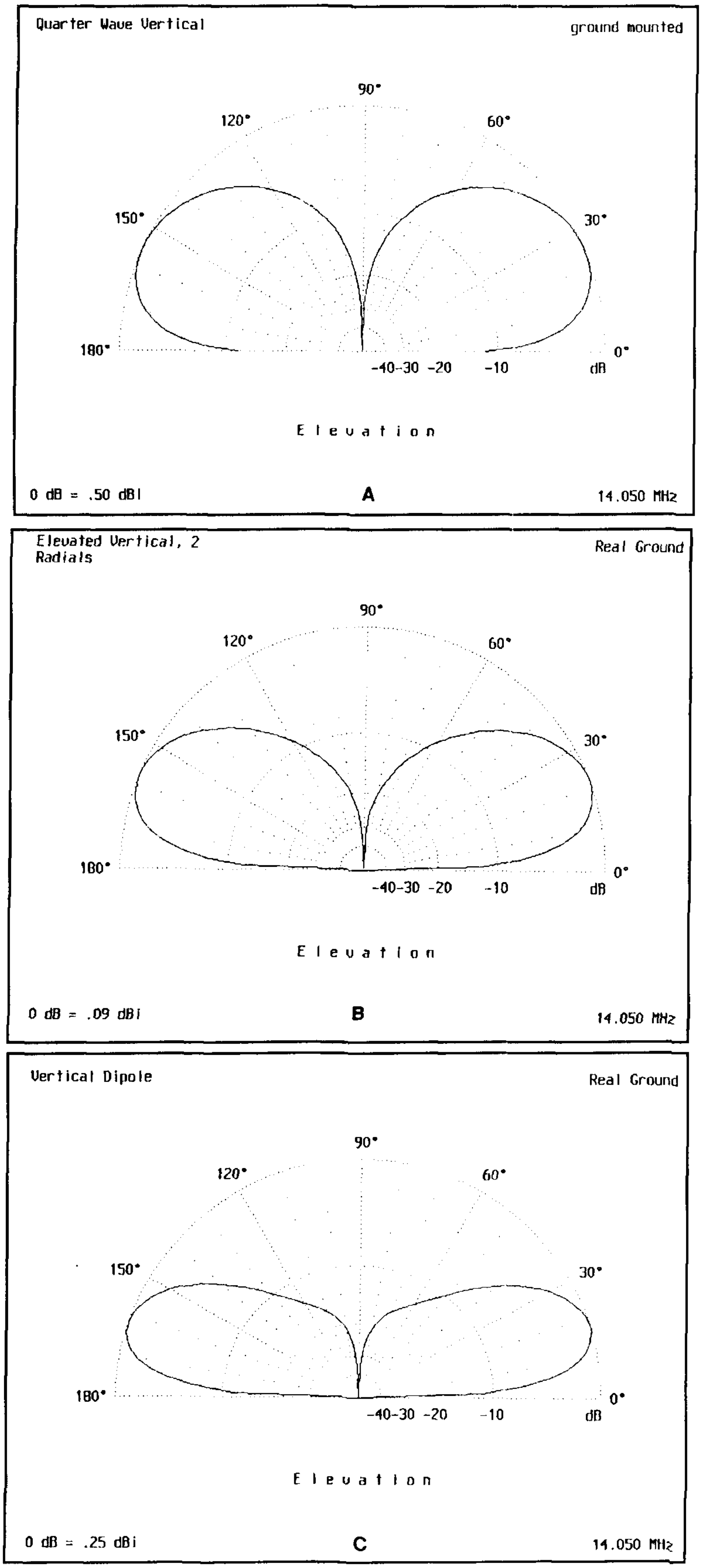

Figure 1. Relative performance of (A) ground-mounted quarter wave, (B) elevated quarter wave (or ground plane), and (C) half-wave vertical antennas.

antenna. This is very close to the same results for the vertical dipole. If your goal is strictly DXing, you need not mount the antenna with its center higher than 1/4 wavelength above ground. For this half-wave equivalent antenna, that means the base will be close to the ground.

Al Christman, KB8I, published an interesting article in *QST* on elevated vertical antennas.[6] He showed that good performance could be obtained with only 2 radials. A comparison of a vertical mounted 20 feet high with 2 and 4 radials is shown in **Figure 3**. The antenna with 2 radials has an azimuthal asymmetry of only 0.25 dB—hardly worth worrying about. I used NEC[7] to analyze the performance of verticals with 2 and 4 radials at lower height. NEC computed the effects of ground on the antenna currents and produced accurate impedance and gain results. These results are shown in **Figure 4**; again, no appreciable difference can be seen. I was pleasantly surprised, but subsequent investigation turned up a potential problem with the 2-radial design that I couldn't ignore.

Les Moxon, G6XN, included an interesting discussion on short, coil-loaded radials in his excellent book *HF Antennas for All Locations*. He mentions the effect of radial imbalance on vertical antenna performance. Radial imbalance may be caused by wire length differences or as a result of unequal loading due to nearby objects like a house, wiring, plumbing, or antennas. The effect created when 1 radial is 6 inches long and the other 6 inches short is shown in **Figure 5**; this is only ±2.7 degrees on 20 meters. The resulting pattern with its high angle lobe may not be suspected by the operator in his shack because the SWR is not always sensitive to these imbalances and is generally tuned during antenna installation. This effect is not observed at very low heights, like 2 feet. Another example, with which I have personal operating experience, is a 40-meter elevated vertical (up 20 feet) with 2 radials spread out on the roof. I was never happy with the performance of this antenna, which was worse for DX than my dipole up only 40 feet. The analysis shown in **Figure 6** clearly shows a significant low angle gain degradation (3 dB or more at 10 degrees) for the same small radial imbalance. Quarter-wave wire radials run close to a house roof are good candidates for coupling or loading-induced imbalances.

Moxon's solution to this problem is to use short, coil-loaded radials. A MININEC analysis confirmed his design. Vertical antenna performance with radial lengths of 60 degrees or less was insensitive to radial imbalances. I read of a low-band station that used coax radials with good luck.[8] A quarter-wave length of coax with a velocity factor of 0.66 is 60 degrees long on the outside of the shield. A quarter-wave open circuit stub looks like a short at the feed end and, because it is less than 60 degrees long on the outside, it won't cause pattern distortion if the radial pair is imbalanced. I trimmed a pair of RG-213 radials for 30 meters using a dip meter and installed them on a roof-mounted WARC-band vertical. I simply connected the center conductor of the coax radial to the feedline coax ground and left the shield open. I could have connected the radial shields together, but saw no reason to do so. The results were as expected and the antenna tuned the same as it had with 2 wire radials. I then cut pairs of coax radials for my roof-mounted 40/80/160 meter multiband vertical and replaced the wire radials. Again, the antenna tuned as before and even seemed to work better. I dressed the coax neatly around the edges of the roof. This made my wife happy, and I no longer have to worry about tripping over the wire radials I have running every which way on the roof!

I've been doing some 80-meter antenna comparisons over the past few months. My inverted vee is only 40 feet up at the apex, but it outperforms my vertical on most DX stations. I believe part of the reason for this is the enhanced signal-to-noise radio provided by the inverted vee, but even strong DX signals were often weaker on the vertical. The performance improved significantly after I added 2 additional coax radials to the vertical for 80 meters. I think the pattern may have been skewed because the radials weren't in a straight line and didn't provide good field cancellation, but I'm not certain. All I know is 4 radials work better than 2 in this situation.

The radiation resistance of an elevated vertical depends on the height above ground. Close to the ground, the quarter-wave design has about one half the resistance of a dipole as expected (i.e., $\cong$ 36 ohms). As the antenna is elevated, the radiation resistance drops and becomes 18 ohms when far from ground. Moxon gives an excellent explanation of this effect.[9] His article "Ground Planes, Radial Systems, and Asymmetric Dipoles," is must reading for anyone seriously considering an elevated vertical antenna. My NEC radiation resistance calculations (shown in **Figure 7**) agree very closely with those presented in Moxon's article. These results show that even for a vertical with 2 radials mounted 1 foot above ground, the loss resistance is less than 3 ohms. This corresponds to an efficiency of 92 percent, which is better than all but the most extensive ground-mounted systems.

Elevated vertical antennas are good performers when properly installed. The feedpoint impedance can be raised to 50 ohms using the old "ground plane" technique of sloping the radials down toward the ground. A better way to

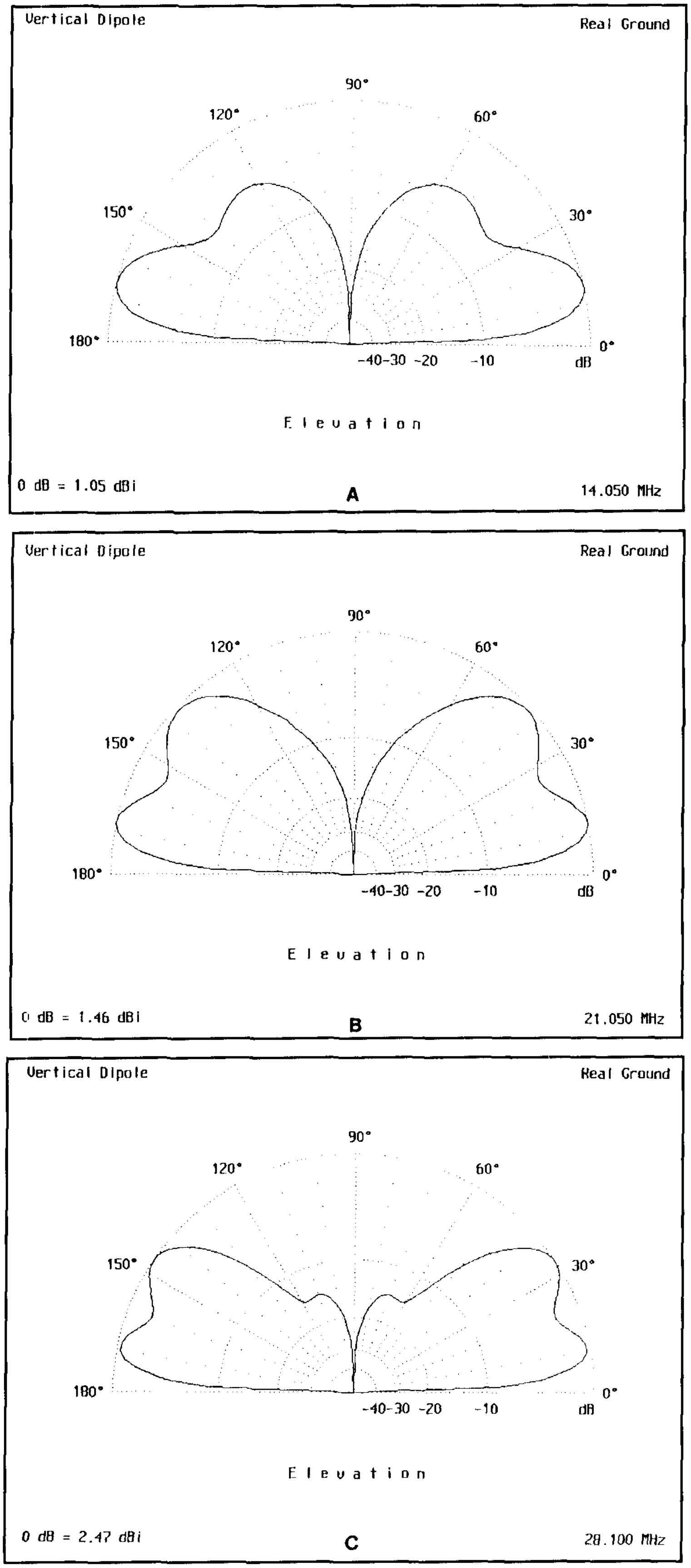

Figure 2. Performance of a vertical dipole with its center up 30 feet on (A) 20, (B) 15, and (C) 10 meters.

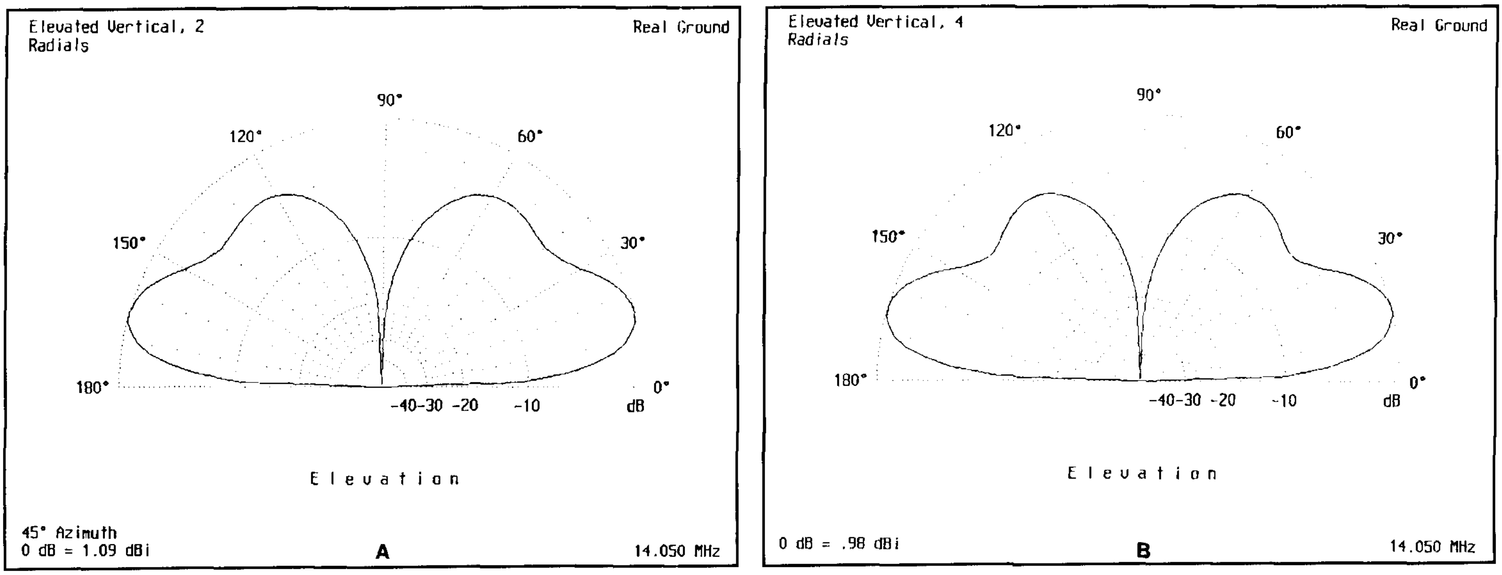

Figure 3. Comparison of elevated quarter-wave verticals with (A) 2 radials and (B) 4 radials.

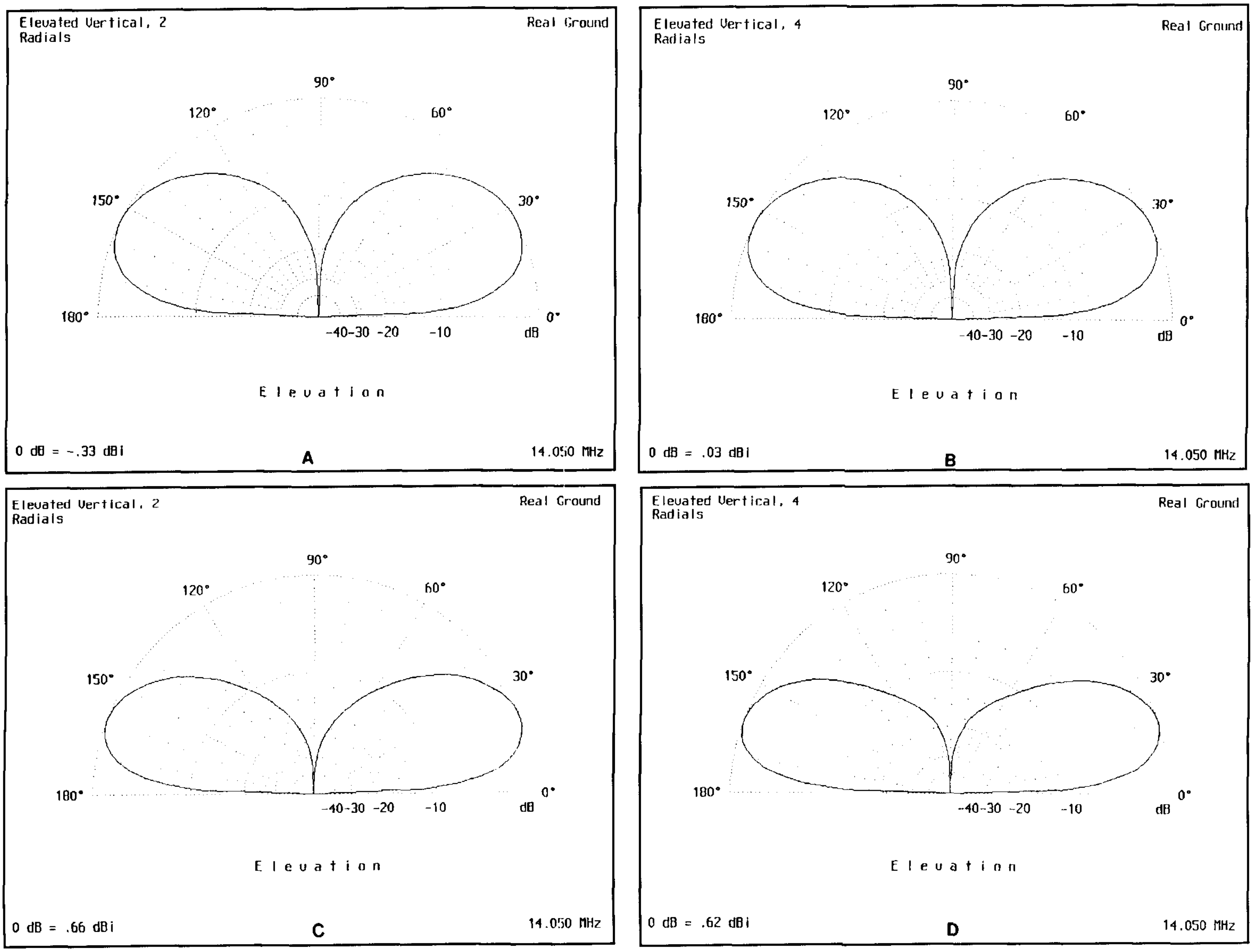

Figure 4. Performance comparison of elevated vertical antennas at low height (A) up 2 feet, 2 radials, (B) up 2 feet, 4 radials, (C) up 10 feet, 2 radials, and (D) up 10 feet, 4 radials.

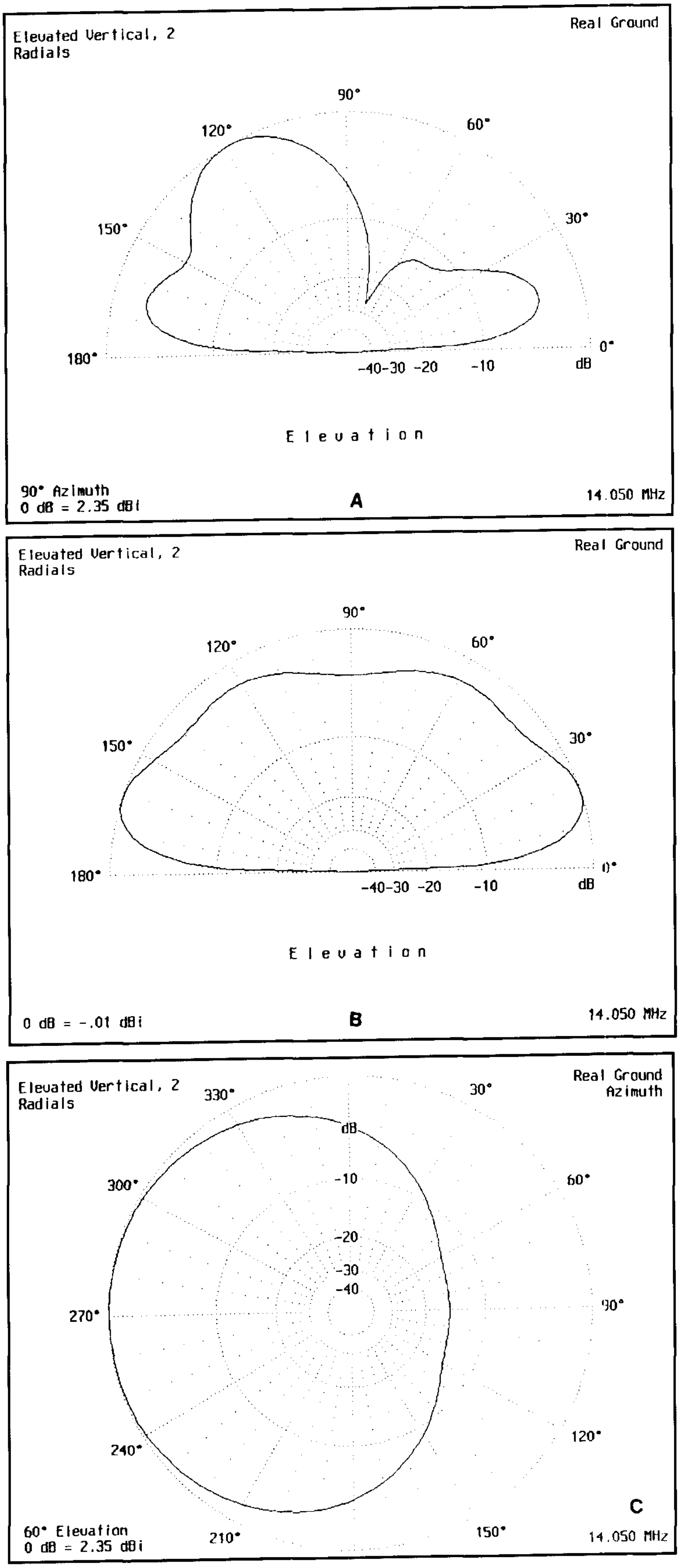

Figure 5. Twenty-meter vertical elevated 20 feet with 2 radials imbalanced ±2.7 degrees. (A) Worst case elevation pattern at 90 degrees azimuth, (B) elevation pattern at 0 degrees azimuth, and (C) azimuth pattern at 60 degrees elevation.

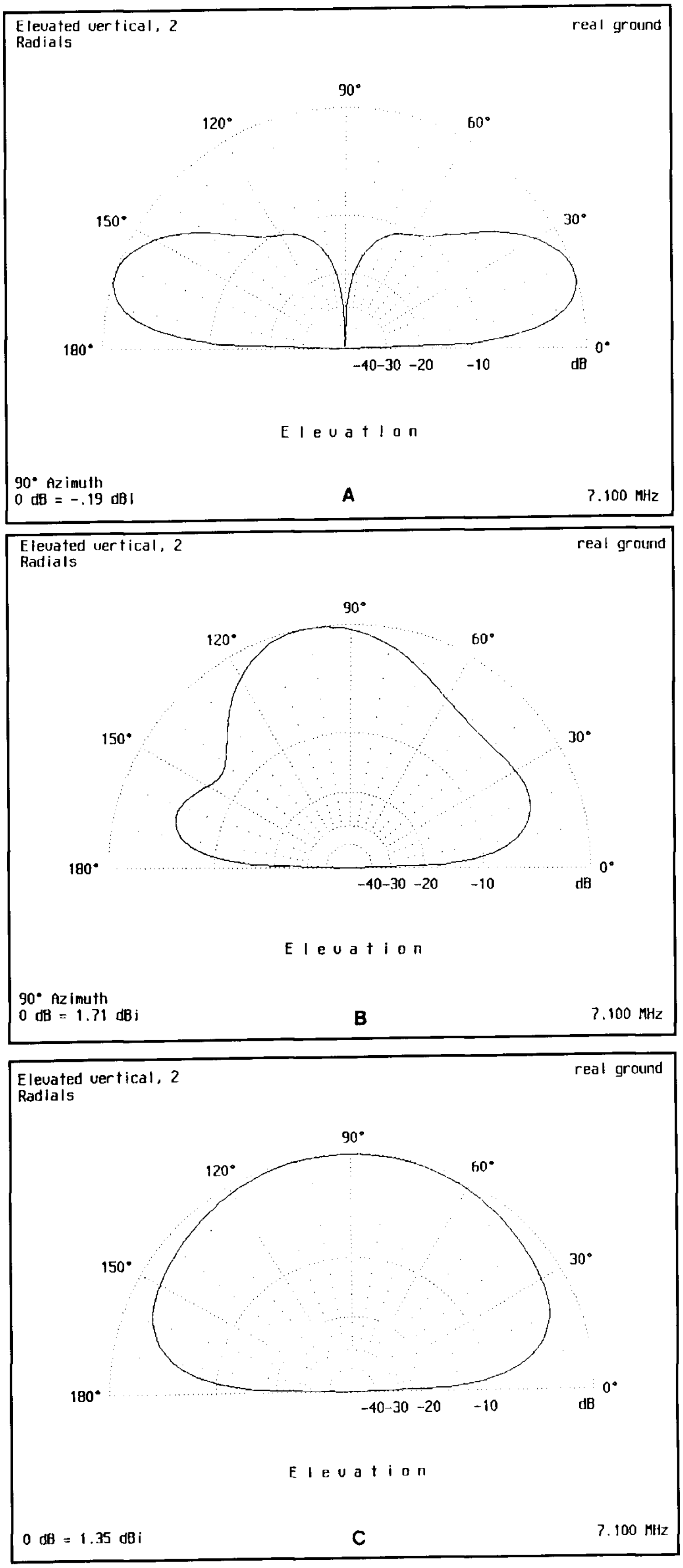

Figure 6. Forty-meter vertical elevated 20 feet with (A) 2 balanced radials, (B) 2 unbalanced radials, and (C) 2 unbalanced radials for azimuths of 90 degrees and 0 degrees, respectively.

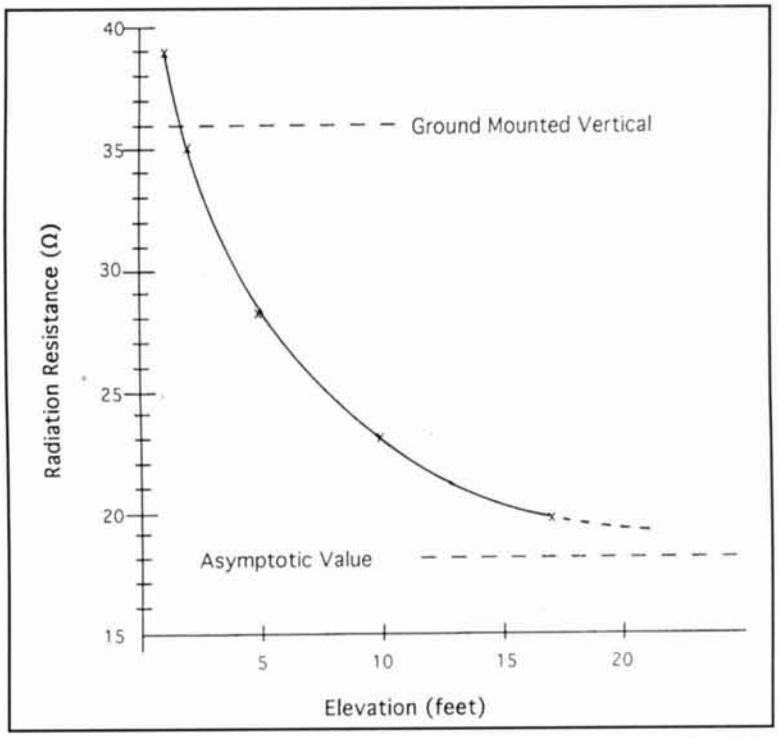

Figure 7. Radiation resistance versus height above ground for a 20-meter, 2-radial vertical.

obtain a 50-ohm match is to use a transmission line transformer. Jerry Sevick, W2FMI, has published many low-impedance designs in the past few years.[10] Sevick's transformers are available commercially from Amidon Associates.* I hope this article has provided some useful data for elevated vertical antenna users.

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*Amidon Associates, Inc., 2216 East Gladwick Street, Dominguez Hills, California 90220.

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PRODUCT INFORMATION

New Analog Devices Brochure

Analog Devices offers a 24-page brochure that describes their latest fixed- and floating-point DSPs (digital signal processors), and 16-bit codecs, as well as chipset solutions for sound, fax/modem and combination sound/modem designs. An overview of DSP architectures includes the new SHARC (Super Harvard ARchitecture Computer) DSP with a 4-megabit on-chip SRAM and "glueless" interface for multi-processor applications. A second member of the SHARC family offers 2-megabits of memory, and future memory variants are on the way. Also included is an overview of the company's software and hardware tools for application development; tools include GNU C Compilers and C Debuggers. FFT benchmarks are provided to indicate performance for routine DSP functions. Mixed-Signal Processors are also discussed for use in high-volume, cost-sensitive applications where the DSP, codec, and all data and program memory are included on a single tightly integrated chip.

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INSTRUMENTS FOR ANTENNA DEVELOPMENT AND MAINTENANCE

Part 1: Voltage and current measurements

The work of developing and testing a new antenna is reduced significantly if the proper tools are available. This includes the tools for measuring the performance of the antenna at each stage of its development. Even if you are just assembling a store-bought antenna, its best to do some testing before the antenna is at the top of the tower. As for that used bargain beam from the hamfest, measurements can tell you if it's really a bargain, or just a source of aluminum.

This article begins a series that's partly a review of antenna measuring techniques and instruments, and partly a compilation of useful methods and tricks. These methods include some suggestions for modification of standard devices for better use in antenna work. Let's start with some very old-fashioned items that I haven't seen used in years.

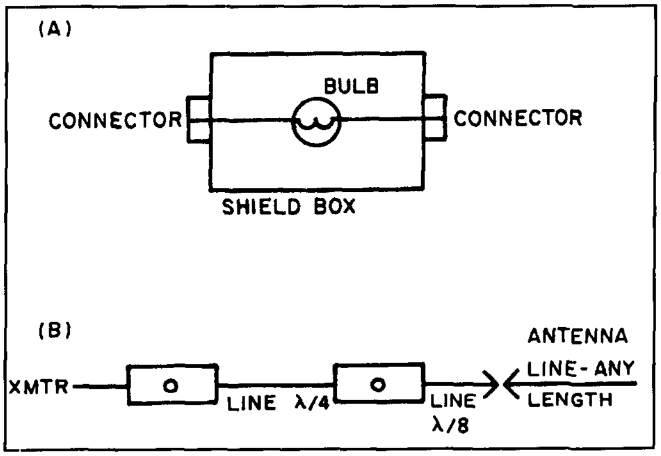

Figure 1. Use of lamp bulbs as ammeters. (A) Use as a wide-band RF ammeter. Estimate current by brightness. Or, place a second bulb with known current from a battery, rheostat and ammeter as close as possible, adjusting current for equal brightness. The RMS RF current is the same as the ammeter reading. (B) Two bulbs separated by 1/4 wavelength make a SWR indicator. Equal brightness is 1:1 SWR unless line length is accidentally such as to give a false equality. If the relative brightness changes on moving the 1/8-wave section to the transmitter end, the new relative brightness is the correct indication.

Simple voltage and current measurement using light bulbs and neon tubes

Two useful tools for the antenna developer are a light bulb and a neon tube. Or more properly, a handful of bulbs of various ratings. The filament bulbs will be used as current indicators, and each rating is good for only a 10:1 range of current, or so. Two types of neon bulbs are useful: the small 1/10-watt ones with rod electrodes, and the larger 2-watt ones with two D-shaped electrodes.

Low-voltage dial-lite bulbs are readily available in current ratings from 60 mA to several amperes. Some power is needed to operate them. In a 50-ohm line one ampere is 50 watts, and 100 mA is one-half watt. These levels are

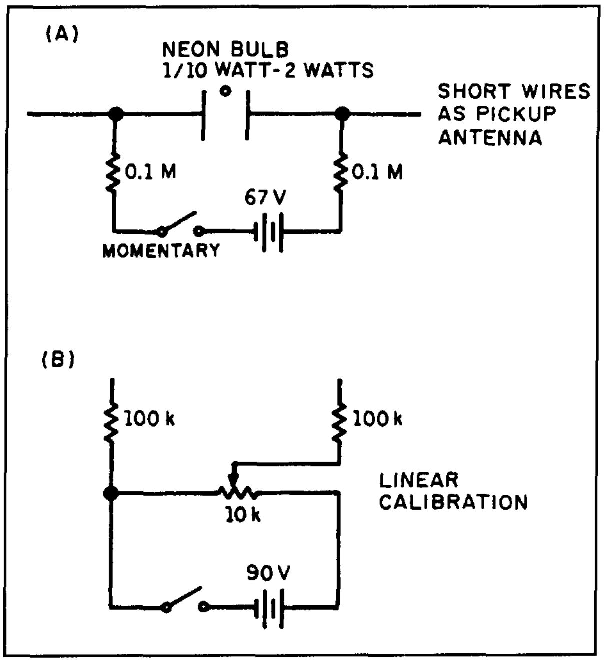

Figure 2. Neon bulb indicators. A small neon bulb is a useful indicator of the presence of RF. Sensitivity can be increased by forming the leads into dipole form. Or: (A) Bias the bulb with a small DC current from a battery, to just above the striking voltage. (B)Use a higher adjustable voltage to measure the difference between the striking voltage with RF present and absent. This is equal to the peak RF voltage across the terminals.

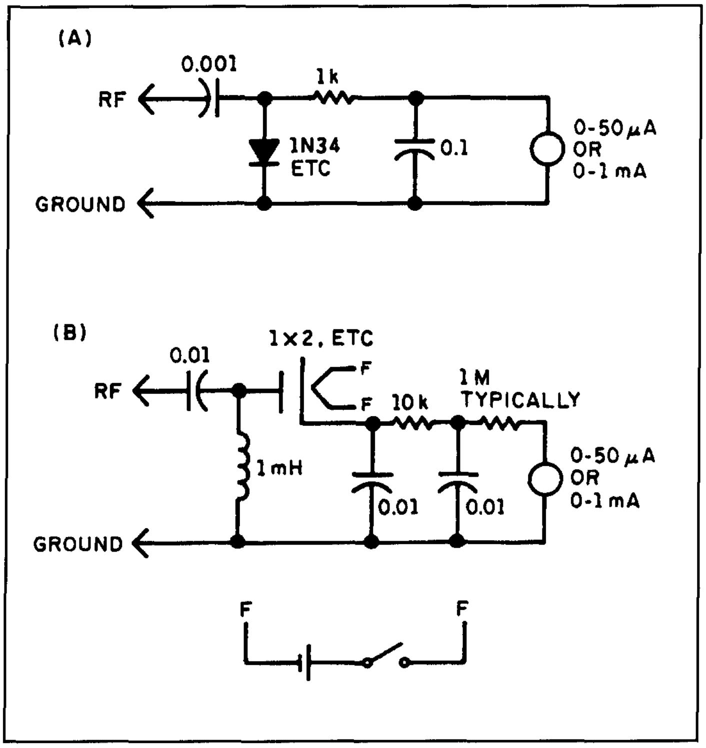

Figure 3. Diode voltmeters. (A) Germanium diode RF voltmeter for low voltage measurements. A 1N914 silicon diode will withstand higher voltages, with a small loss in sensitivity. (B) A vacuum tube diode voltmeter for high voltage RF measurements. Also useful in transmitter development. Use appropriate safety precautions.

transmitter levels rather than signal generator levels, but as will be discussed later, the transmitter is a common test instrument.

Use the filament bulbs whenever a current indicator is needed. It's helpful to have a pair of small boxes, each with two RF connectors joined by a lamp socket as in **Figure 1A**. One unit makes a useful telltale indicator that current is flowing. With two connected in series by a quarter-wave length of transmission line, as in **Figure 1B**, they become a visual SWR indicator. When the bulbs are equally bright, the SWR is 1:1. This technique is especially handy when adjusting the base tuning elements of a low frequency vertical. Of course, a SWR meter is more accurate; but, do you really want to expose your Bird™ Wattmeter to the rain? Or keep a spare in your emergency kit? I'll show you a better lamp-type SWR indicator later on.

A neon bulb is useful as a voltage indicator. As for the filament bulb, it's a wide-band device. To perform a quick check of antenna performance, bring a neon bulb close to the ends of antenna elements. Touch the elements themselves if you're using low power. The effectiveness of Yagi elements is shown by their differing brightnesses. Unbalance between the two element ends can be detected the same way. Don't forget the old test of a transmitter: If the bulb glow is rose rather than orange, suspect the presence of a VHF parasitic. *Be careful to mount the bulb at the end of a dowel or insulated rod to keep hands away from high DC and RF potentials.*

The sensitivity of a neon bulb can be increased by a passing a small DC current through the bulb. This is just enough current to produce a tiny glow. A circuit which will enable you to do this is shown in **Figure 2A**. If the glow starts when the switch is closed and continues with the switch open, the RF voltage is between the striking and extinction voltages—typically between 50 and 67 volts. Adding a calibrated potentiometer as in **Figure 2B** converts the indicator to a measuring instrument. The RF voltage is equal to the striking voltage of the neon bulb minus the DC voltage from the potentiometer. Adding a short dipole at the bulb-choke terminals creates a crude field voltage indicator.

A 4-foot fluorescent bulb makes a good indicator of antenna performance during the final full-power check of a new antenna. It also impresses the neighbors.

Better voltage and current measurements

While the above are useful indicators, for precision antenna work you should be able to make numerical measurements. This means, at least, that you must obtain an indicator with a calibrated scale. Professionals now use digital instruments, but most are too expensive for amateur use. However, don't forget to watch the swap and surplus sales. Sometimes you can get a good deal.

RF voltmeters

RF voltmeters are invariably rectifier-DC voltmeter combinations. **Figure 3A** pictures a solid-state type. A germanium diode is shown; it provides good response at low voltages. Such a unit is good to about 50 watts at 50 ohms. For higher voltages, silicon rectifiers or the vacuum tube rectifier of **Figure 3B** can be used. You can calibrate these devices by comparing them to an already calibrated unit. It is also possible for you to use a thermocouple ammeter as a standard, measuring the voltage across a known load, or shunting the coupling capacitor with a larger one, using a low frequency AC voltmeter as the standard.

These RF voltmeters are so useful and inexpensive that they are usually built into other pieces of equipment, like the transformer ammeter. One or two separate units are often useful. For example, they can be used instead of the bulbs in **Figure 1B**.

Hot-wire ammeter

The oldest method of RF current measurement called for a hot-wire ammeter. As pictured in **Figure 4A**, a piece of resistance wire expanded from passed current. The expansion was converted to rotary motion by a drum, with a needle on a calibrated scale indicator tracing the measurement. You'll probably have to visit a museum to see one.

The next method, **Figure 4B**, used a thermocouple connected to the hot wire, feeding a standard DC meter. These were a standard part of military equipment during WWII, and can still be found in junkboxes, on swap tables, and in surplus. The small antenna connector box of the "Command Sets" used a separate thermocouple-meter system good for the power range of 10 to 100 watts. The DC meter isn't calibrated in amperes, but on an arbitrary linear scale. Its poles are shaped to give an approximately linear reading with power. Meters with internal thermocouples can be found, with nonlinear scales calibrated in amperes.

A major advantage of these units is that they are nearly insensitive to frequency. They can be calibrated on DC. For greater accuracy, they should be checked on several frequencies, using a known load and an RF voltmeter to determine the current. The major disadvantage of these units lies in their fragility and susceptibility to mechanical shock damage and burnout on overload.

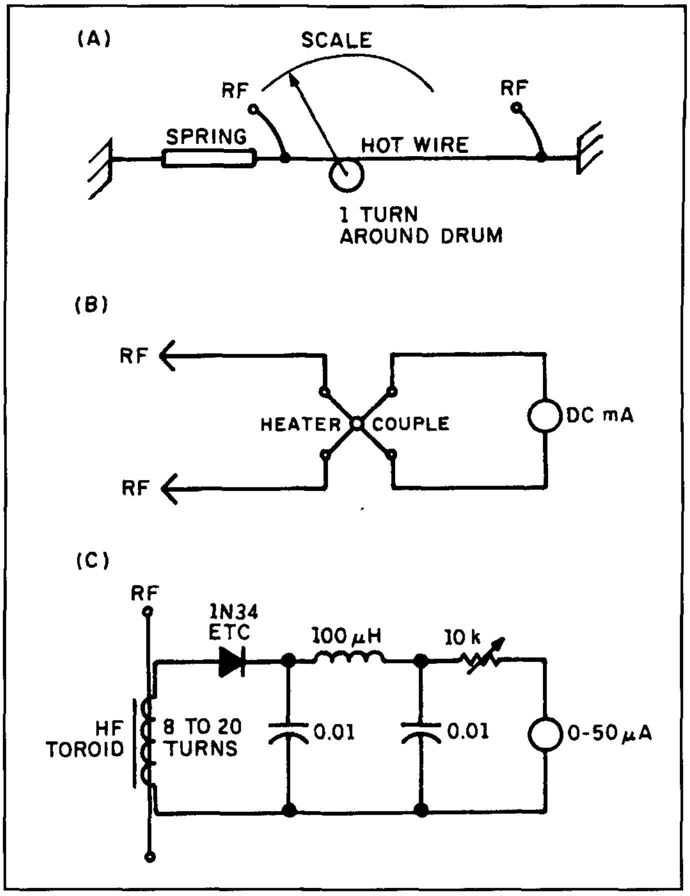

Figure 4. RF ammeters. (A) Hot-wire ammeter, measuring the current by amount of elongation of a wire heated by the current. Liable to damage by shock, or by too high current. (B) Thermocouple ammeter, which produces a small DC current by measuring the temperature of a wire heated by RF with a miniature two-metal thermocouple. Liable to damage from excessive current. Very good as a calibration standard. (C) Transformer ammeter, measuring the voltage induced in the secondary by the current in the one-turn primary winding. Now the most popular RF ammeter.

RF transformer/RF voltmeter combinations

Today, it's almost certain that current measurements are made with an RF transformer/RF voltmeter combination, as in **Figure 4C**. The voltage across the resistor is proportional to current. The scale will be nonlinear for small currents due to the square-law action of the diode rectifier. The suggested technique is to use a thermocouple type for calibration, plus one or two transformer types for routine work.

RF ammeters can be used much more frequently than they are. These ammeters are naturals for making measurements of base-fed verticals on the lower bands. They are also useful where balanced feed is used, as in rhombics, the Zepp, and even quad loops fed by parallel coax or twin-line. *The ARRL Handbook* provides construction details of a specialized form especially useful for measuring current on guy wires, towers and other conductors.

To give you the complete picture, another RF voltmeter should be mentioned. This is a receiver with a meter type of S-meter. The LED bar-graph type is too coarse for most work. The best procedure is to calibrate the S-meter with a steady signal fed through an attenuator box, as described in the ARRL and other handbooks. The meter reading on noise can be used as the reference, as can the level of the generator if it is so calibrated. One of the common uses is to measure the antenna pattern of a friend's antenna. (Most hams can't get enough separation between their own pair of antennas to do proper measurements. More on this in future articles.)

Coming in Part 2

In this installment of "Instruments for Antenna Development and Maintenance," we discussed methods and equipment for making voltage and current measurements. Part 2 will discuss signal generators. ■

PRODUCT INFORMATION

AEA FAX III

Advanced Electronic Applications, Inc. has announced the availability of the new AEA FAX III. The AEA FAX III allows amateur operators to colorize received weather fax images. This "pseudo-color" feature lets users choose from 256 colors to clarify images or make them more appealing. Export images to GIF or PCX files for manipulation in other graphics programs, then include the images in newsletters, letters, or other publications.

This IBM-compatible software receives satellite maps and WeFax images in 16 levels of gray. Maps and images can be displayed in 16 levels of gray or in color using a VGA monitor. AEA FAX III also works with EGA and CGA monitors. AEA FAX III also receives and decodes CW, RTTY, and NAVTEX transmissions. The demodulator plugs into the back of the computer and plugs into the external speaker jack of your HF SSB receiver. AEA FAX III works with or without a mouse, is menu driven, and offers support for COM1-COM4.

For more information, contact Advanced Electronic Applications, Inc., P.O. Box C2160, Lynnwood, WA 98036 (phone: 206-774-5554; Fax: 206-775-2340).

New Hameg HM8042 Curve Tracer

Hameg Instruments, Inc. has introduced the HM8042 Curve Tracer. This is a module that plugs into Hameg's HM8001-2 Mainframe Power Supply and is used in conjunction with any oscilloscope that has X-Y display capabilities. It can test diodes, transistors, FETs and thyristors. The instrument is microprocessor based, and measures and displays characteristic curves of semiconductor devices. Digitized data is used to generate a 5-curve, flicker-free X-Y oscilloscope display. A 4-digit LED numeric readout indicates parametric data.

For additional information, call Hameg toll-free at 800-247-1241.

AEA's PC PakRatt for Windows 2.0

Advanced Electronic Applications, Inc. is now offering version 2.0 of their PC PakRatt for Windows computer program. PC PakRatt for Windows 2.0 is a full-blown Windows application for controlling the entire AEA family of data controllers, including the PK-900, DSP-1232, and DSP-2232. This new version now supports both the PK-96 1200/9600 bps Packet controller and the PK-12 1200 bps Packet controller.

PC PakRatt for Windows 2.0 can run two AEA data controllers simultaneously. Run HF or VHF Packet, AMTOR, BAUDOT, Morse code, ASCII, Signal Analysis, NAVTEX, PACTOR, or Dumb Terminal modes all through PC PakRatt for Windows. All options are a mouse-click away. PC PakRatt for Windows 2.0 is now fully compatible with Log Windows 2.0.

For more information, contact Advanced Electronic Applications, Inc., P.O. Box C2160, Lynnwood, WA 98036 (Phone: 206-774-5554; Fax: 206-775-2340).

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THE SOLAR SPECTRUM

A peek into the past

As most of you know, we usually concentrate on current solar astronomy and technology in this column. Once in awhile, however, it's fun to take a look back at the role the Sun played in the lives of our early ancestors. This issue we're going to take a peek at two ancient sites known to be associated with solar observations, and also profile a fascinating similarity that occurred thousands of years later in the American Southwest.

In the cool pre-dawn darkness more than 1000 years ago, the old Zuni Sun-priest hurried along the trail to his vantage point high on the mesa. He sang and prayed as he did each morning, awaiting his first glimpse of the Sun. Finally, as the leading rays of light burst above a distant mountain peak, the priest plotted the position of the rising Sun against the desert landscape and carefully carved a mark into a crude soft-pine calendar. Today he would announce to his people that the Sun was nearing its winter home. The winter solstice was nearly at hand.

For ancient cultures, the days marking the solstices (points in the Earth's orbit where the Sun reaches its greatest northern and southern declination, marking the beginning of summer and winter) and equinoxes (points midway between the solstices when day and night are of equal length) were important ways to measure the passage of time, and therefore spawned elaborate rituals. Moreover, these special moments in time were often depicted in ancient art forms and reflected in the design of prehistoric monuments and other structures. The New Mexican site known as Fajada Butte is a case in

Photo A. The Stonehenge site near Wiltshire, England at the summer solstice. The "Heel Stone" can be seen just beneath the rising Sun, framed by three gigantic stones. Photo courtesy of L.C. Smith, retired custodian of the Stonehenge Monument.

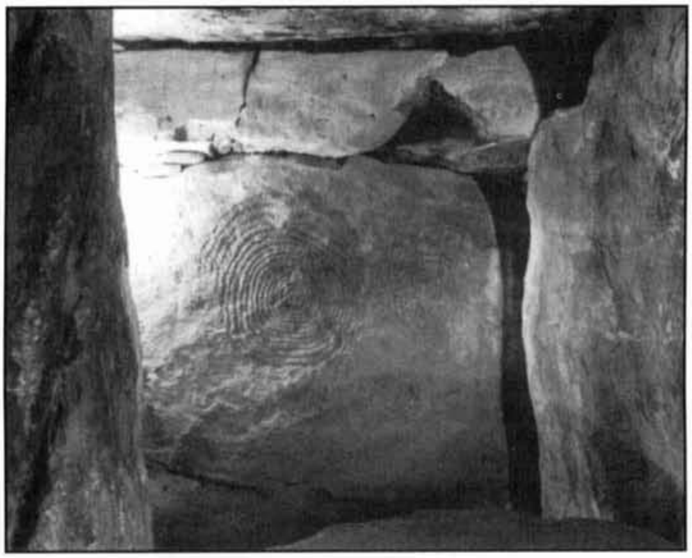

Photo B. The Newgrange Tomb, located near Dublin, Ireland, is the oldest known structure with an astronomical function. The tomb is thought to have been build over 5150 years ago, thus predating Stonehenge and the Great Pyramid. Note the similarity between these spiral etchings and those featured in petroglyphs produced thousands of years later by Indians in the American Southwest (Photo C). Photograph courtesy of the Irish Tourist Bureau.

point. Many hundreds of years ago, primitive Indians placed three sandstone slabs high on a rock ledge. One of the rock panels was carefully inscribed with a pair of strategically located spirals so that at the summer solstice the Sun shone between the remaining slabs and threw a bright sliver of light onto the center of the larger spiral, dramatically announcing the arrival of the summer season.

We will return to the American Southwest, but first let's take a brief look at a couple of astronomical monuments that were erected half a world away more than 3000 years earlier. The first was constructed by ancient Britons and is probably the most famous of these early sites; a circular "menhir" (a prehistoric monument consisting of a single tall, rough stone standing alone or with others) with huge stones precisely aligned at sunrise on the day of the summer solstice. When the Sun appeared* framed by a "window" formed by several of the stones, and was directly above a single tall stone known as the "Heel (or Hele) Stone," summer was at hand. Of course we're talking about the extraordinary "Stonehenge Monument," built on the Salisbury Plain near Wiltshire, England (**Photo A**).

Stonehenge was constructed in stages between 2800 and 1100 B.C., a period that extends from the late Stone Age into the Bronze Age. Unfortunately, although much has been written about unraveling the mysteries of Stonehenge, its builders left no records and very little is known for certain.

There is no shortage of legends, however. One of the more interesting is told by L.C. Smith—now retired, but formerly the custodian of the Stonehenge Monument. This particular fable deals with the way the huge stones reached the Salisbury Plain, and with the origin of the Heel Stone.

It seems that the devil decided to undertake a project that would baffle and amaze all future generations. While traveling up and down the Earth, he had noticed some huge stones in the yard of an old woman in Ireland, and decided to transport them to the stoneless Salisbury Plain. At first the woman refused his request for the stones, but she eventually agreed when the devil promised to give her as much money as she could count during the time it took for him to remove the stones. Whereupon, he handed her a fistful of coins.

However the devil knew the woman had little knowledge of arithmetic, and she had barely counted the first few coins when he called on her to stop. The devil had collected all the stones and bound them together in a giant bundle tied with a wide band slung over his shoulder. The disappointed woman reluctantly returned the leftover coins, and away flew the devil towards the Plain. But as he neared his destination the stones proved too heavy, and with a shudder, the lion's share of the stones fell down into the Avon Valley and into the river at Bulford, where they remain today.

When the devil reached the Plain with the remaining stones, he immediately set about arranging them. He was soon delighted with his progress, and cried out in glee, "Now I'll puzzle all men, for no one knows, or ever will know, how these stones have come here!" But unfortunately for the devil a passing friar overhead his boast, and shouted out, "That's more than thee can tell!" Then, realizing who the builder was, the friar turned and ran for his life.

The devil was enraged that he had been discovered, and taking a stone that he had just rested upon two upright stones, he flung it at the holy man, striking him on the foot as he ran. The friar's sanctity was apparently greater than his courage, however, and the stone suffered the most damage; and even today the impression of the friar's heel can be seen upon it, which is said to demonstrate the truth of this legend. (More seriously, the word "hele" may be derived from the Anglo-Saxon verb "helan"—to conceal—and applied to the stone because it hides the first light of the rising Sun on the day of the summer solstice. The Greek word "helios" is another possibility.)

Turning from fancy to fact . . . which site is

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* The use of the past tense in these descriptions is due to changes in geometry dictated by the precession of the Earth's axis. Thus, historical analyses of such sites must be based on the location of the rising Sun thousands of years ago, which was not the same as today.

Have You Heard Signals from "Red Sprites" or "Blue Jets"?

Our friend, Otha Vaughan, an engineer researching atmospheric electricity at Marshall Space Flight Center in Huntsville, Alabama, is seeking information on the following phenomena. Otha:

"During the period between 29 June and 13 July, 1994, Dr. David Sentman and his colleagues at the University of Alaska conducted an observational program of high-altitude flights near thunderstorms above the Texas panhandle, Arkansas, and other U.S. sites.

"The group was able to obtain a number of video images of atmospheric phenomena which appear above thunderstorms and are believed to be related to the lightning flashes that occur in the top of the storm. Sentman called these events 'Red Sprites' because they were reminiscent of the mythical fairy-like creatures that appear briefly out of the corner of one's eye. They also observed a second atmospheric phenomenon that they named 'Blue Jets.' The sprites were red in color and resembled large jellyfish with trailing tendrils. They materialize after lightning flashes which occur in the cloud top, reaching upward to around 95 km and down to about 65 km. Since they extend to an altitude of 95 km, they are primarily mesospheric/D-Region phenomena.

"Blue Jets seem to move outward from the cloud top after there has been a considerable amount of lightning. They proceed upward for at least 33 km, where they terminate, sometimes spreading out or sometimes remaining jet-like. Blue Jets appear to move at a rate near 95 km/sec.

"During the experimental aircraft flights, Dr. Sentman and his co-researchers set up VLF radio receivers near Oklahoma City—about 150 miles from the storms they planned to observe—in an attempt to record sferic information related to the events. They used search-coil type hardware and DAT recorders. One receiver was tuned to operate in the frequency range of 1-13 kHz, while a second monitored the band between 20 kHz and 20 MHz. Data recorded by the first receiver showed two distinct 'pops' and other RF energy when the tapes were played back using an audio recorder, and the sprite image appeared to be time-coordinated with the pops. No RF pulses were observed from the jets.

"During our thunderstorm observations from the space shuttle using the payload bay cameras, we have also seen the sprites and jets. Since many radio amateurs record stable VLF and/or ELF radio signals while searching for ionospheric disturbances, etc. and have conducted sporadic E communications operations, we here at NASA/MSFC are very interested in obtaining information in either of the two bands that Sentman used, or at other frequencies when thunderstorms are in close proximity to the monitoring site. The best observational periods occur during the nighttime and when moonlight is low, so that the sprites have a higher contrast ratio. The most favorable time of year to observe these phenomena is spring through fall, when large thunderstorms have a tendency to develop.

Image of a 'Red Sprite,' obtained with a low-light level TV camera aboard a high-altitude aircraft. The top of the sprite is at an altitude of about 95 km, and the tendrils extend downward to around 65 km. The bright area over the top of the storm cell is lightning. This thunderstorm occurred in the Texas Panhandle on the night of 3 July, 1994. Photo courtesy of the Geophysical Institute of the University of Alaska, Fairbanks (D. Sentman).

"If you have suitable equipment and would like to participate in this project, please let me know so that I can communicate with you. My voice mail number here at MSFC is (205) 992-5893, my fax number is (205) 992-5723, or e-mail skeet@sferic.msfc.nasa.gov. If you have access to the Internet and Mosaic or similar software, we have a home page that you can access to see what the sprites and jets look like.

The URL is:
http://rimeice.msfc.nasa.gov:/5678.

Once you are on the page, click on 'Shuttle Lightning, Videos and Movies.' Browse and enjoy!"

Otha H. "Skeet" Vaughan, Jr.
P.I., Mesoscale Lightning Experiment

Photo C. This spiral petroglyph—symbolizing the Sun—was etched into a rock cliff by the Sinagua Indians, a prehistoric tribe who inhabited Arizona's Verde Valley. Such petroglyphs are difficult to date, but the Sinagua (or their ancestors) are known to have inhabited the American Southwest from about 8000 B.C. until A.D. 1400. Photograph courtesy of the *Clear Skies* newsletter.[1]

likely to be the most ancient of all structures with a proved astronomical function? The answer might surprise you. Recent research indicates that the Newgrange Tomb build north of Dublin, Ireland around 5,150 years ago—shortly after the invention of cuneiform writing by the Sumerians—is the oldest known monument firmly linked to observations of the Sun's celestial movements.

The tomb itself is contained within a mound of loose stones about 90 meters wide and 10 meters tall. Modern studies have determined that thousands of years ago, the first sunlight at the winter solstice flowed down a long, central corridor and shone on an etching (**Photo B**) composed of the circular pattern that was repeated thousands of years later in the American Southwest.

Sunlight first penetrated the tomb's entrance through a small horizontal opening some 20 centimeters high and a meter wide, creating a lighted spot on the chamber floor and illuminating a carving comprised of three distinct spirals. At daybreak on the solstice, the Sun first appeared in the lower left-hand corner of the gap, silently rose until it was centered, and eventually exited at the upper right-hand corner. The opening was carefully crafted so that when the Sun was framed within its borders it matched the Sun's width vertically, within about 1/12th of its apparent diameter; quite an accomplishment for builders over 5100 years ago.

Long before our Zuni-priest tracked the Sun and compiled his forecasts, other pre-historic North American tribes faithfully followed the Sun's movement through the daytime sky. (Such priests among the Western Pueblos—Hopis in northeastern Arizona and Zunis in northwestern New Mexico—and the culturally affiliated Eastern Pueblos of the Rio Grande Valley, continue to treat sky-watching as a solemn religious duty. Even today, they stand on mesa tops at dawn carefully marking the location of the rising Sun and use the information to predict the change in seasons.)

While we don't know the exact motivation for their ancestral observations, we do know that the Sun was important enough to these early tribes that they spent an extraordinary amount of time recreating its presence in petroglyphs . . . artistic symbols created by tediously chipping layers of "desert varnish" from the rocks along canyon walls with a sharpened stone, or by striking a chisel-like object with another stone. "Rock art" such as this is typified by the Fajada Butte carvings. It is frequently composed of spirals or concentric circles generally thought to be symbolic of the Sun, and is fairly commonplace throughout the American Southwest. (When the nomadic tribes who crossed the Bering Strait land bridge into North America moved through the southwest and into the midwest following the retreating Ice Age glaciers, they created petroglyphs all the way into what is now Wisconsin. It is thought that such engravings served both a religious and secular purpose.)

The spiral petroglyph shown in **Photo C** was discovered in an area inhabited by the Southern Sinagua Indians, who lived in Arizona's Verde Valley. The first definite human presence in the valley is believed to date from around 8000 B.C., although according to N.L. Hendrickson who took the photograph, this example is thought to be around 1000 years old. The similarity between such artistry and that contained in the Newgrange Tomb is striking, and thus far has not been explained to me. Perhaps one of you can provide the connection, if one has been uncovered and verified.

If we can learn anything from such illustrations, it is that the Sun has dominated the hearts and lives of our predecessors for untold centuries. As we do today, human beings have continually sought ways to understand the nature of the Sun and predict its behavior. If we consider only the impact of seasonal change on their daily lives, it is easy to understand why such a detailed knowledge of the solstices and other features of the Sun's annual path in the sky were so important to generation after generation of our forbearers. But regardless of the source of their curiosity, we have come to realize that by undertaking the first observations of the Sun, our ancestors also became the first true solar astronomers.

REFERENCE

1. The *Clear Skies* newsletter—a quarterly publication dedicated to the active amateur astronomer—is available from Sky Bear Publishing, 10464 Clairemont Mesa Boulevard, San Diego, California 92124. (Telephone 800-501-3003, or fax 619-280-0632 for a brochure.)

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BUILDING A WIDE RANGE RF PREAMPLIFIER

High dynamic range for VLF, LF, AM, BCB, and HF receivers

There are many situations that call for a broadband RF amplifier. Typical applications include: boosting the output of RF signal generators (which normally tend to be quite low level, so they can be used on receivers), antenna preamplification, as loop antenna amplifiers, and in receiver front ends. There are a number of different published circuits, but one failing that I've noted in most of them is that they usually lack response at the low end of the radio frequency range. Many designs offer –3 dB frequency response limits of 3 to 30 MHz or 1 to 30 MHz, but rarely are the VLF, LF, or even the entire AM broadcast band (540 to 1700 kHz)* covered. What's needed is a circuit that can be used over a wide range of frequencies.

One of the problems seen in the lower frequency bands—especially the AM BCB—is that signal levels tend to be high, and there are lots of signals. As a result, any RF amplifier or preamplifier must have a high dynamic range, or it will be a marginal performer.

I started experimenting with high dynamic range circuits when I found I needed an amplifier to boost AM BCB DX signals. Many otherwise fine communications or entertainment grade "general coverage" receivers operate from 100 kHz to 30 MHz, or so, and initially that range sounds real good to the VLF through AM BCB DXer. However upon closer examination, it turns out that the receiver lacks sensitivity on the bands below either 2 or 3 MHz, so it fails somewhat in the lower end of the spectrum. The receiver I own has a respectable 0.15 μV sensitivity in the HF region, but the sensitivity drops to 1 μV below 1800 kHz, and from 100 to 530 kHz it's ridiculous. While most AM BCB listeners tune in to powerful local stations (here, receivers without RF amplifiers and a loopstick antenna work nicely), those who are interested in DX reception are not well served.

In addition to the receiver problem, I wanted to boost my signal generator 50-ohm output. Doing so would make it easier to develop some AM and VLF projects that I'm working on, and would also provide a preamplifier for a square loop antenna that tunes the AM BCB.

I came up with several requirements for the RF amplifier. First, it had to retain the 50-ohm input and output impedances standard in RF systems. Second, it had to have a high dynamic range and third-order intercept point to cope with the bone crunching signal levels on the AM BCB. One problem of the AM BCB is that sought-after DX stations tend to be buried under multi-kilowatt local stations on adjacent channels. That's why high dynamic range, high intercept point, and loop antennas tend to be required in these applications. I also wanted the amplifier to cover at least two octaves (4:1 frequency ratio), and in fact achieved a decade (10:1) response (250 to 2,500 kHz).

Furthermore, the amplifier circuit had to be easily modifiable to cover other frequency ranges up to 30 MHz. If possible, the amplifier should work well into the HF region without modification. This last requirement would make

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*The AM BCB upper limit was recently extended to 1700 kHz.

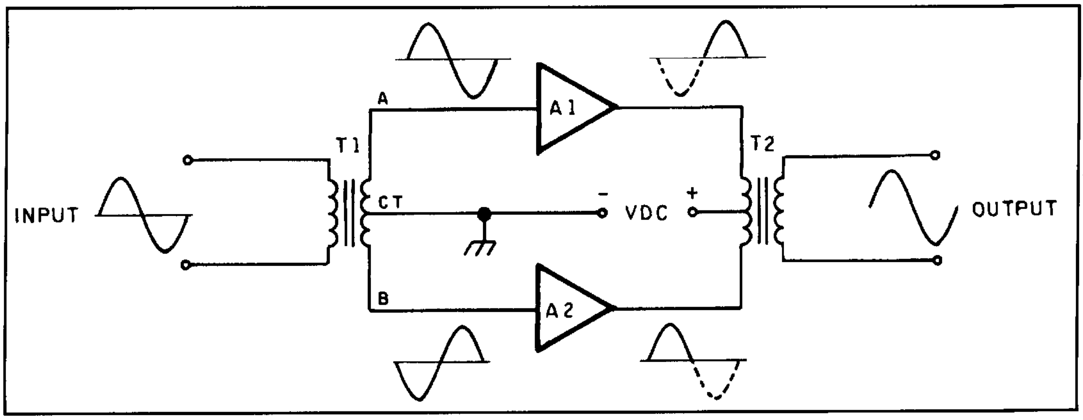

Figure 1. Block diagram of a push-pull RF amplifier.

the amplifier useful to a large number of readers, as well as extending its usefulness to me.

There are a number of factors to consider when designing an RF amplifier for the front end of a receiver. I mentioned the dynamic range and intercept point requirements above. Another factor is the amount of distortion products (related to third order intercept point) generated in the amplifier. It does no good to have a high preamplifier capability, only to overload the receiver with a lot of extraneous RF energy it can't handle—energy generated by the preamplifier and not from the stations being received. These considerations point to the use of a *push-pull RF amplifier* design.

Push-pull amplifiers

The basic concept of a push-pull amplifier is illustrated in **Figure 1**. This type of circuit consists of two identical amplifiers that each process half the input sine wave signal. In the circuit shown, this job is accomplished using a center-tapped transformer at the input to split the signal, and another at the output to recombine the signals from the two transistors. The transformer splits the signal because its center tap is grounded, and serves as the common for the signals applied to the two transistors. Due to normal transformer action, the signal polarity at end "A" will be opposite that at end "B" when the center tap ("CT") is grounded. Thus, the two amplifiers are driven 180 degrees out of phase with each other; one will be turning on while the other is turning off, and vice versa.

The push-pull amplifier circuit is balanced, and as a result it has a very interesting property: even order harmonics are canceled in the output, so the amplifier output signal will be cleaner than for a single-ended amplifier using the same active amplifier devices.*

The push-pull RF amplifier

There are two general categories of push-pull RF amplifiers: tuned and wideband. With the tuned amplifier, the inductance of the input and output transformers is resonated to some specific frequency. In some circuits the non-tapped winding may be tuned, but in others a configuration such as **Figure 2** might be used. In this circuit, both halves of the tapped side of the transformer are tuned individually to the desired resonant frequency. Where variable tuning is desired, a split-stator capacitor might be used to supply both capacitances.

The broadband circuit category is shown in **Figure 3A**. A special transformer is usually needed in this type of circuit. The transformer must be a broadband RF type—which means it must be wound on a suitable core, so the windings are bifilar or trifilar. The transformer in **Figure 3A** has three windings, of which one is much smaller than the others. These must be trifilar wound for part of the way, and bifilar the rest. All three windings are kept parallel until no more turns are required for the coupling link, then the remaining two windings are kept parallel until they are completed. **Figure 3B** shows a transformer with a ferrite or powdered iron *toroid* core.

Actual circuit details

The actual RF circuit is shown in **Figure 4**; it's derived from a circuit found in Doug DeMaw's excellent book *W1FB's QRP Notebook*.** The active amplifier devices are junction field effect transistors (JFET) intended for service from DC to VHF. You can use the ever-popular MPF-102, or its replacement equivalent from the SK, ECG, or NTE lines of devices. The 2N4416 JFET is a better device to use; it can be replaced by ECG-452, NTE-452, and other ser-

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*This is true for class C or B operation. However, push-pull transistor preamps intended for receiver front ends generally are biased well into the AB or A regions—both are active over the full RF cycle. This greatly minimizes crossover distortion, yields the best linearity, and thus, the best IMD performance. Ed.

**Available from the ARRL, 225 Main Street, Newington, Connecticut, 06111, USA.

vice devices. I chose a close cousin, the NTE-451 JFET transistor. This device offers a transconductance of 4,000 microsiemens,* a drain current of 4 to 10 mA, and a power dissipation of 310 mW, with a noise figure of 4 dB maximum. American or overseas designers can make selections from European lines of devices using these parameters.

The JFET devices are connected to a pair of similar transformers, T1 and T2. The source bias resistor (R1) for the JFETs, and its associated bypass capacitor (C1), are connected to the center tap on the secondary winding of transformer T1. Similarly, the +9 volts DC power supply voltage is applied through a limiting resistor (R2) to the center tap on the primary of transformer T2.

Take special note of those two transformers. They are known generally as wideband transmission-line transformers, and can be wound on either toroid or binocular ferrite or powdered iron cores. Because of the low frequencies involved, I selected a type BN-43-202 binocular core. The type 43 material used in this core is a good selection for the frequency range involved. The core can be obtained from either Amidon Associates (2216 East Gladwick, Dominguez Hills, CA, 90220; phone 213-763-5770, voice, or 213-763-2250, fax) or Ocean State Electronics (P.O. Box 1458, 6 Industrial Drive, Westerly, RI, 02891; phone 401-596-3080, voice, 401-596-3590, fax, or 1-800-866-6626, orders only). There are three windings on each transformer. In each case, the "B" and "C" windings are 12 turns of no. 30 AWG enameled wire wound in a bifilar manner. The coupling link in each is winding "A." The "A" winding on transformer T1 consists of four turns of no. 36 AWG enameled wire, while on T2 it consists of two turns of the same wire. The reason for the difference is that the number of turns on each transformer is determined by the impedance matching job it must perform (T1 has a 1:9 pri/sec ratio, while T2 has a 36:1 pri/sec ratio). Neither the source nor drain impedances of this circuit are 50 ohms (the system impedance), so there must be an impedance transformation function. If the two amplifiers in the circuit were of the sort that had 50-ohm input and output impedances, such as the Mini-Circuits MAR-1 through MAR-8 devices, then winding "A" in both transformers would be identical to windings "B" and "C." In that case, the impedance ratio of the transformers would be 1:1:1.

Figure 5 shows the detail for transformers T1 and T2. I elected to build a header of printed circuit perforated board for this part; the board holes are on 0.100 inch centers. The pc type of perfboard has a square or circular printed circuit soldering pad at each hole. I cut a section of perfboard with a matrix of five by nine holes, then inserted Vector Electronics push terminals from the unprinted side, and soldered them into place. These terminals serve as anchors for the wires that form the transformer windings. Two terminals are placed at one end of the header, and three at the opposite end.

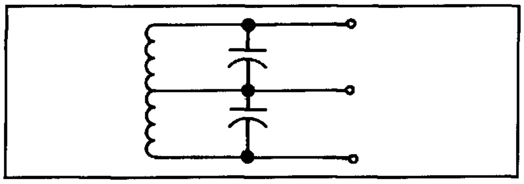

Figure 2. Tuning the push-pull input or output transformer to a single frequency.

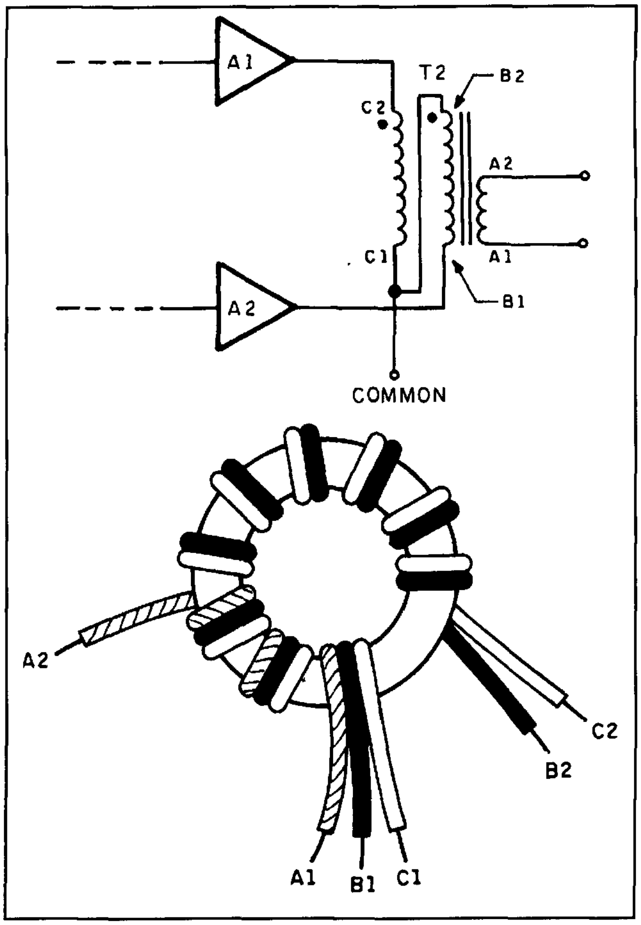

Figure 3. (A) Using a broadband transformer for the output transformer of a push-pull RF amplifier. (B) Winding the transformer on a toroid core.

The coupling winding is connected to pins 1 and 2 of the header, and is wound first on each transformer. Strip about a quarter inch of insulation from one end of a length of no. 36 AWG enameled wire. Do this by scraping the wire with a scalpel or X-acto™ knife, or by burning the insulation with the tip of a soldering pencil. Make sure the exposed end is tinned with solder, then wrap it around terminal no. 1 of the header. Pass the wire through the first hole of the binocular core, across the barrier between

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*Note units: 1 μSiemen = 1 μMhos.

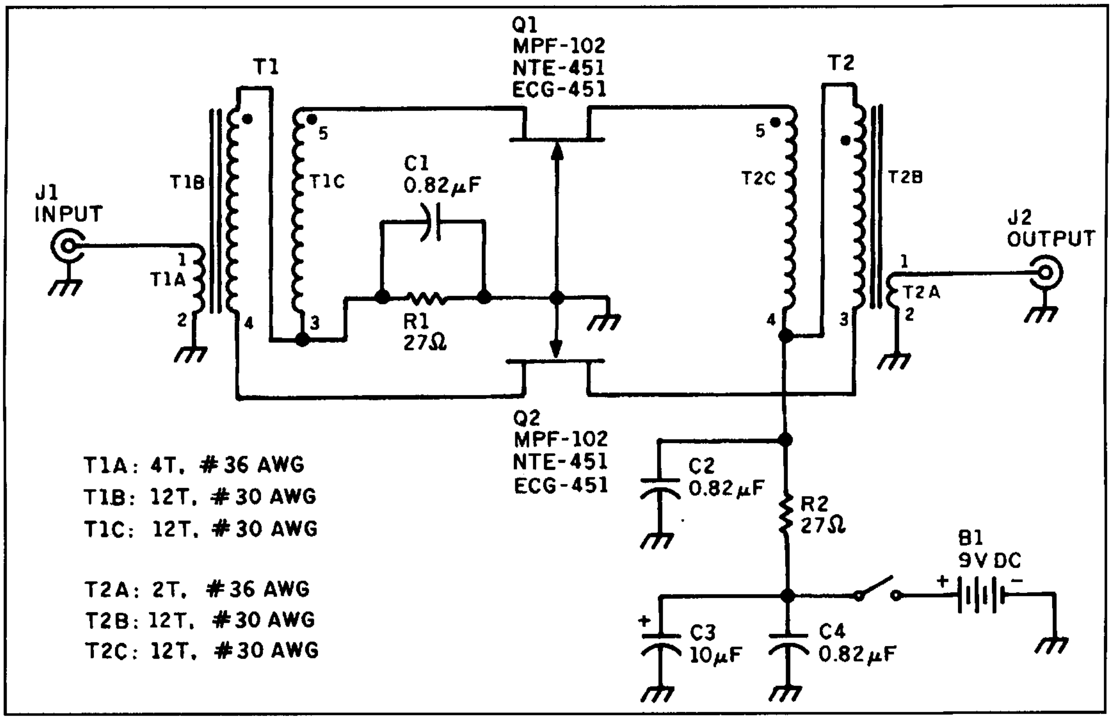

Figure 4. Circuit for the VLF-AM BCB amplifier.

the two holes, and through the second hole. This "U" shaped loop counts as one turn. To make transformer T1, pass the wire through both sets of holes three more times (to make four turns). The wire should end up at the same end of the header from which it started. Cut the wire to allow a short length to connect to pin no. 2. Clean the insulation off this free end, tin the exposed portion, wrap it around pin no. 2, and solder. This completes the primary of T1.

The two secondary windings are wound together in the bifilar manner, and consist of twelve turns each of no. 30 AWG enameled wire. The best approach seems to be to twist the two wires together. I use an electric drill. Join two pieces of wire, each 30 inches long, and chuck them up in an electric drill. Anchor the other ends of the wire (also joined together) in a bench vise, or some other holding mechanism. Back off, holding the drill in one hand, until the wire is nearly taut. The turning of the drill causes the two wires to twist together. Keep twisting them until you obtain a pitch of about eight to twelve twists per inch.

It's **very important** to use a drill that has a variable speed control, so you can make the drill chuck turn very slowly. It's also **very important** that you follow certain safety rules—especially as regards your eyesight—when making twisted pairs of wire. Be absolutely sure to wear either safety glasses or goggles while performing this operation. If the wire breaks, and this is a common problem, it will whip around as the drill chuck turns. While no. 36 wire may not seem to be very substan-

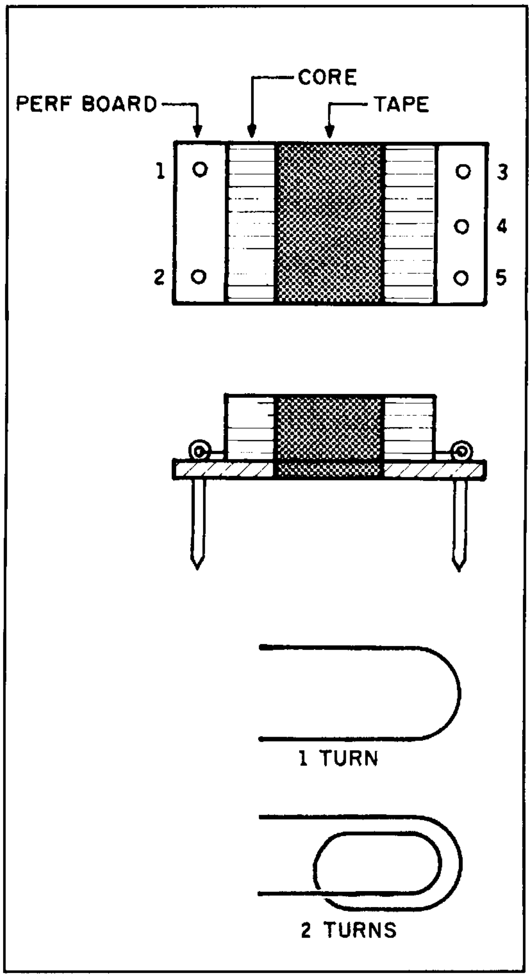

Figure 5. Detail for the construction of T1 and T2.

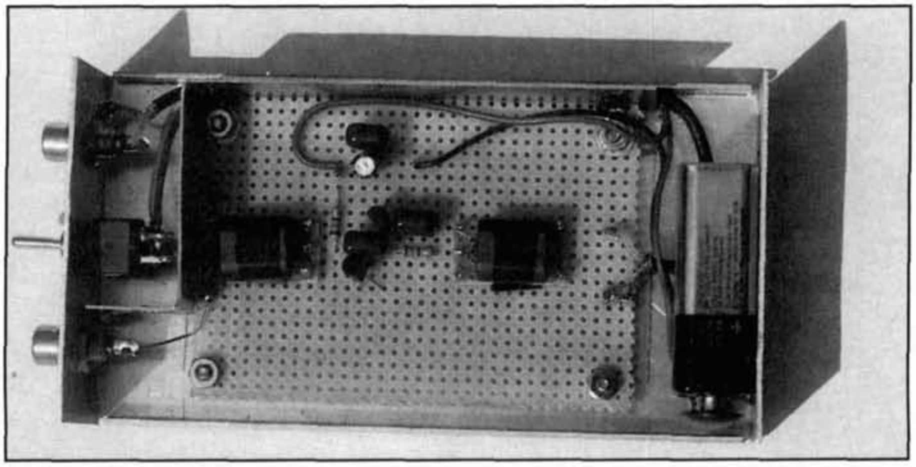

Photo A. The actual amplifier, as built.

tial, at high speed it can severely injure an eye.

To start the secondary windings, scrape all the insulation off both wires at one end of the twisted pair, and tin the exposed ends with solder. Solder one of these wires to pin no. 3 of the header, and the other to pin no. 4. Pass the wire through the hole of the core closest to pin no. 3, around the barrier, and then through the second hole, returning to the same end of the header as where you started. This constitutes one turn. Perform this operation eleven more times until all twelve turns are wound. When you've completed the twelve turns, cut the twisted pair wires off leaving about a half an inch free. Scrape and tin the ends of these wires.

It's easy to connect the free ends of the twisted wire, but you'll need an ohmmeter or continuity tester to determine which wire goes where. Identify the wire that's connected at its other end to pin no. 3 of the header, and connect this wire to pin no. 4. The wire that remains should be the one whose other end was connected to pin no. 4 earlier; connect this wire to pin no. 5 of the header.

Make transformer T2 the same way you made transformer T1, but place only two turns on the coupling winding rather than four. In this case, the coupling winding is the secondary, while the other two form two halves of the primary. Wind the two-turn secondary first, as you did with the four-turn primary on T1.

You can build the amplifier on the same sort of perforated board used to make the transformer headers. Indeed, the headers and the board can be cut from the same stock. The size of the board will depend somewhat on the box you select to mount it in. My box was a Hammond 3 x 5.5 x 1.5-inch cabinet. After allowing room for the 9 volts DC battery at one end, and the input/output jacks and power switch at the other, I was left with 2.5 x 3.5 inches of available space in which to build the circuit (**Photo A**).

I built the circuit from the output end backwards toward the input, so transformer T2 was mounted first with pins 1 and 2 towards the end of the perfboard. Next, I mounted the two JFET devices, and then soldered T1 into place. After that, I added the two resistors and capacitors to the circuit. I finished the board by connecting the elements together and providing push terminals for the input, output, DC power supply ground, and the +9 volts DC.

Because the input and output jacks were so close together, and because the DC power wire from the battery to the switch had to run the length of the box, I decided to use a shield partition to keep the input and output separated. I constructed this partition from 1-inch brass stock. This material can be purchased at almost any hobby shop that caters to model builders. The RG-174/U coaxial cable between the input jack on the front panel and the input terminals on the perfboard run on the outside of the shield partition.

Variations on the theme

Three variations on the circuit extend its usefulness for many different readers. First, there are those who will want to use the amplifier at the output of a remote-mounted loop antenna. However, it isn't easy to go up to the roof or attic to turn on the amplifier any time you wish to use the loop antenna. Therefore, it's better to install the 9 volts DC power source at the receiver end, and pass the DC power up the coaxial cable to the amplifier and antenna. This method is shown in **Figure 6**. At the receiver end, RF is isolated from the DC power source by a 10-mH RF choke (RFC2), while the DC is prevented from affecting the receiver input (which could short it to ground!) by using a blocking capacitor (C4). All these components should be mounted inside a shielded box. At

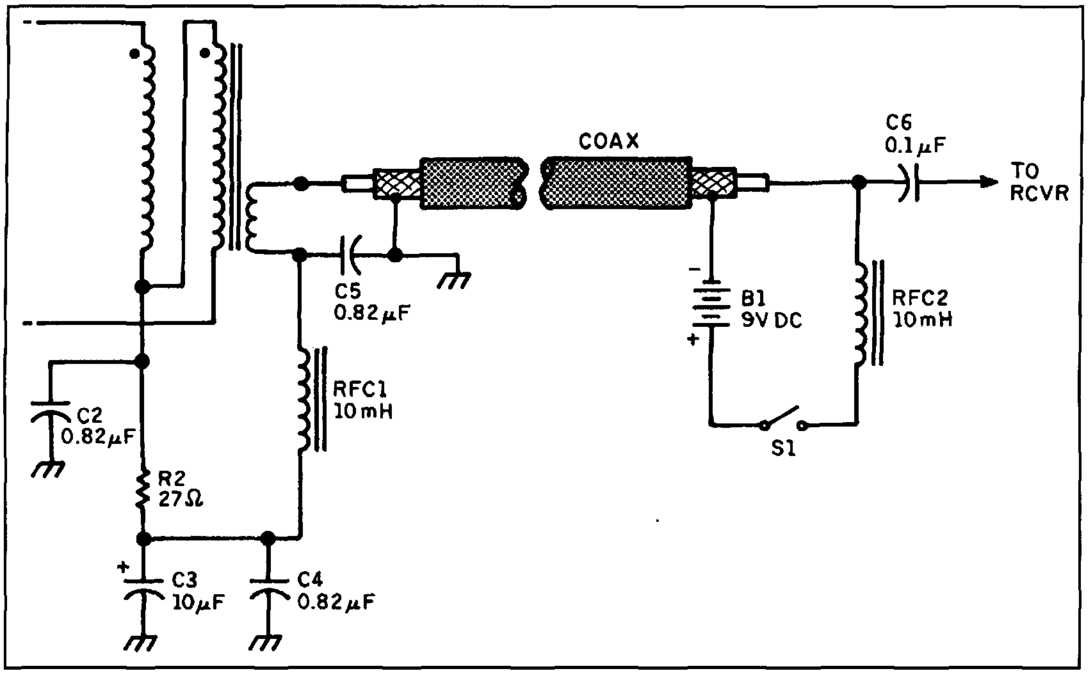

Figure 6. Remote power scheme for preamplifiers mounted at the antenna site.

the amplifier end, lift the grounded side of the T2 secondary, and connect it to RFC2, which is then connected to the +9 volts DC terminal on the perfboard. A decoupling capacitor (C3) keeps the "cold" end of the T2 secondary at ground potential for RF, while making sure it's isolated from ground for DC.

A second, easy to accomplish, variation is to build the amplifier for the shortwave bands. First, reduce all capacitors to 0.1 μF. Second, build the transformers (T1 and T2) on a toroid core rather than the binocular core. In W1FB's original design, a type TF-37-43 ferrite core was used with the same 12:12:2 and 12:12:4 turns scheme used above.

Alternatively, select a powdered iron core such as T-50-2 (RED) or T-50-6 (YEL). I suspect that about twenty turns will be needed for the large windings, four turns for the "A" winding on T2, and seven turns for the "A" winding on T1. Experiment with various cores and turns counts to optimize for the specific section of the shortwave spectrum you wish to cover.

The third variation is to make the amplifier operate on a much lower frequency; for example, well down into the VLF region. The principal changes needed are in the cores used for transformers T1 and T2, the number of turns of wire needed, and the capacitors needed. The type 43 core will work down to 10 kHz, or so, but requires a lot more turns to work efficiently in that region. Type 73 material, found in the BN-73-202 core, will provide an A_L value of 8,500, as opposed to 2,890 for the BN-43-202 device used in this article. Doubling the number of turns in each winding provides a good starting point for amplifiers below 200 kHz. The type 73 core works down to 1 kHz, so, with a reasonable number of turns, it should work in the 20 to 100 kHz range as well.

For a different approach to this circuit, replace the custom-wound binocular balun transformers with a commercial transformer that does the same job. Mini-Circuits offers a series of RF transformers, but none in the correct turns ratio to accommodate impedance matching. If your application can tolerate the higher input and output impedances, you can use a Mini-Circuits 1:1:1 or 1:1:2 transformer. Otherwise, it's possible to use a 1:1:1 Mini-Circuits transformer cascaded with their 36:1 transformer. However, you must pay close attention to the specifications of each transformer. The insertion loss of two transformers at both input and output ends of the circuit won't be too terrible in the higher frequency region, but in the lower frequency region a –3 dB per transformer loss may occur—and that loss level would be fatal to this project.

Conclusion

Push-pull RF amplifiers offer certain advantages over other forms, especially for bands fraught with bone-crunching interference. The AM BCB qualifies in this regard, as do certain ham radio bands (75 and 20 meters, for example) and the major international shortwave broadcast bands. This RF preamplifier should work well for all of these applications. ■

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QUARTERLY COMPUTING

Take a dip in the information river

In this age of the "information explosion," keeping up with new developments in amateur radio is analogous to sipping water from a fire hose—a lot goes by very quickly, and an incautious sampling may well leave you dazed and confused.

Amateur radio newsletters, magazines, and books all dip containers of varying size and permanence into the information stream and capture what they can. The CD-ROM, humanity's newest and arguably most successful information bucket, excels at storing immense amounts of data.

As a result, many PCs sold as multimedia machines now sport a basic-model CD-ROM drive, and upgrade kits for older PCs are available for under $200. If your PC isn't already so equipped, it's time to think seriously about adding CD-ROM capability. As an added incentive, note that many commercial software suppliers distribute their products on CD-ROMs, and installing from a single CD-ROM beats shuffling a pile of floppies.

In this issue, we'll examine the latest releases of a pair of popular amateur radio callbooks and file collections on CD-ROM.

The World of Ham Radio

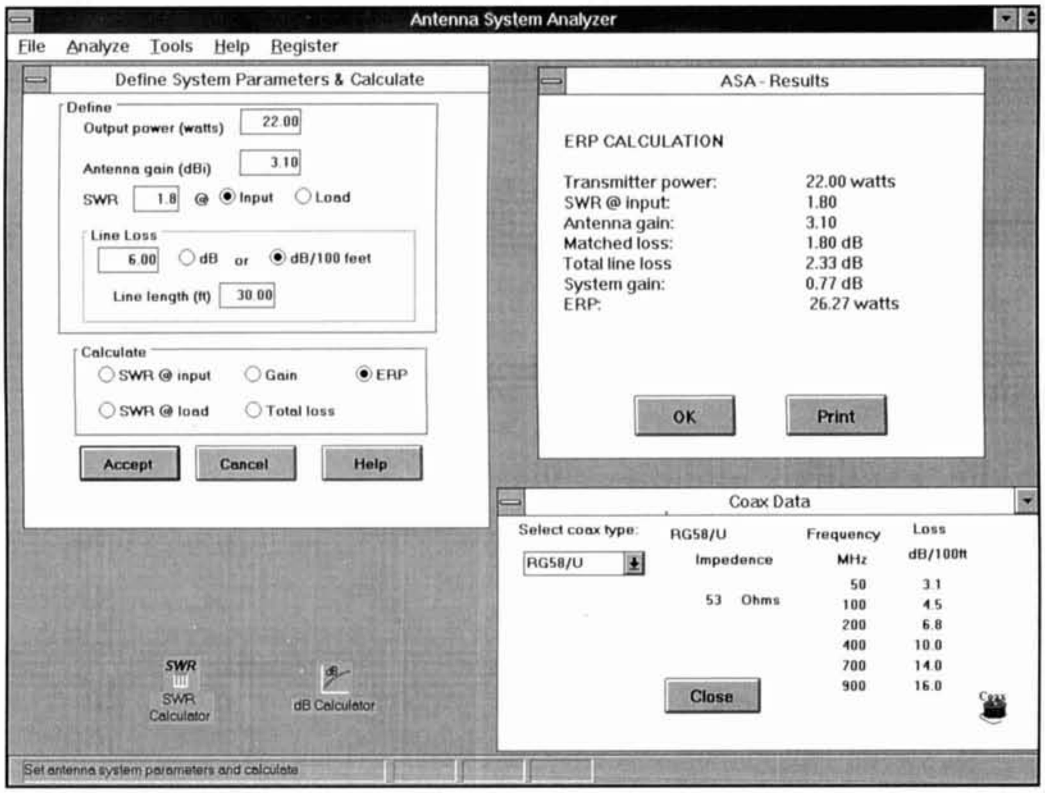
The latest release of AmSoft's CD-ROM *The World of Ham Radio* (January 1995, $39) dips into the information river and captures a sample of almost 21,000 files for IBM-compatible and Apple Macintosh PCs. A printed list of new and modified entries alone covers almost four pages. In addition to updating the United States amateur callsign database to reflect changes through December 1994, AmSoft has added DX callsigns from Canada, Taiwan, and the United Kingdom.

If you're interested in tasting the torrent of the much-publicized Internet without committing yourself to spending money on a high-speed modem, data-transfer software, and connect-time charges, you can explore two collections of files on AmSoft's CD-ROM that offer a sample of what the Internet does best.

The first assortment, filed under the \DIST_NET subdirectory, consists of a collection of shareware and freeware gathered from the Ham Distribution Net, a service that provides the files to Internet FTP (File Transfer Protocol) sites. Here, you'll find programs such as N6BV's TL.EXE. This is nifty freeware that accepts as input transmission line type (e.g., RG-58/U) or parameters (i.e., velocity factor, impedance, and attenuation), line length, and antenna impedance. TL computes line losses, peak voltage and location, SWR, and component values for a two-element matching network.

Another program, ASA11.ZIP, runs under Microsoft Windows and provides coaxial-cable loss data in tabular and graphical formats and calculates SWR and dB losses. You can also specify transmitter power, feedline length and losses, and antenna gain, and ASA will compute SWR, ERP, and more (**Figure 1**). Offered by Micro Resources, this $20 toolkit may be just what you're looking for. As with all shareware, try it, but don't forget to pay your registration fee if you plan to keep the software.

Owners of Ramsey Electronics' popular FX-146 2-meter transceiver kit will want to review N9GMW's design for a computer-controlled, parallel-port interface for the radio. A single archive file (FX146.ZIP) contains a schematic in Windows WRI format, and elementary



Define

Output power (watts) 22.00

Antenna gain (dBi) 3.10

SWR 1.8 @ ● Input ○ Load

Line Loss

6.00 ○ dB or ● dB/100 feet

Line length (ft) 30.00

Calculate

○ SWR @ input ○ Gain ● ERP

○ SWR @ load ○ Total loss

ERP CALCULATION

Transmitter power:	22.00 watts
SWR @ input:	1.80
Antenna gain:	3.10
Matched loss:	1.80 dB
Total line loss	2.33 dB
System gain:	0.77 dB
ERP:	26.27 watts

Select coax type: RG58/U

RG58/U

Impedence

53 Ohms

Frequency MHz	Loss dB/100ft
50	3.1
100	4.5
200	6.8
400	10.0
700	14.0
900	16.0

Figure 1. Antenna System Analyzer's workscreen windows are shown clockwise from left: system definitions, results and coaxial cable data for RG-58/U.

QBASIC programs to test the port and set the radio's frequency.

AmSoft's second Internet-related collection consists of over 18 MB (megabytes) of ASCII text files and their cryptic Internet routing headers— all readable with any browsing tool. Gathered over a three-month period, these files resemble an extended on-the-air roundtable or old-fashioned ragchew. Topics run the gamut from items for sale or swap, to antenna and homebrew equipment construction.

Given the time delays inherent in CD-ROM and magazine publishing cycles, the swap-shop bargains no doubt are long gone. However, you can use the for-sale ads as a rough guide to pricing your own equipment.

All kinds of nuggets crop up in the construction files. One exchange discusses which inks work best in pen plotters for direct drawing of printed-circuit traces on copperclad laminate. In theory, this method would appear ideal for quickly creating one-off PC boards without photoplotting. (The permanent-black ink mentioned, Staedtler 48S 23SAR-9, should be available from drafting- and plotter-supply houses.)

Other additions to AmSoft's CD-ROM include space-research images containing stunning false-color radar maps of the surface of Venus, and many images of Comet Shoemaker-Levy's fragment colliding with Jupiter. You can view these with SVGA version 1.2, a capable shareware image browser provided on disk.

You can also review GIF images of hundreds of missing children compiled by the Heidi Search Center of San Antonio, Texas—a volunteer organization offering assistance to parents of missing and abducted children.

What's not to like? Minor quibbles, mostly. For my taste, *The World of Ham Radio* includes too many spelling errors in its directory entries and program descriptions. If you use a file browser to view and search the disk's directories, keyword searches will overlook misspelled programs and filenames.

Although conventional spelling checkers don't include amateur radio terms, callsigns, and specialized character strings (e.g., CW and SSB), any spell checker worth its salt allows wordlist expansion. There's room here for a shareware product—an amateur-radio lexicon that will find favor with all ham radio CD-ROM publishers and authors.

The World of Ham Radio includes an installation program (INSTALL.BAT) that makes a common assumption—all PCs use C:\WINDOWS as the home directory for Windows files and subdirectories. However, many users have shortened the directory name to \WIN to squeeze more directories into their PC's CONFIG.SYS PATH= statement. Thus, AmSoft's

INSTALL.BAT doesn't work unless you copy and edit the file to reflect your system's naming convention—an obvious and trivial process to old DOS and Windows hands, but one that's potentially baffling to a beginner. To confuse matters further, INSTALL.BAT refers users of alternative configurations to a file (OTHERDRV.DOC) that's missing from the CD-ROM. For most users, these minor problems won't detract at all from the disk's utility.

QRZ! Ham Radio CD-ROM

Volume 4 of Walnut Creek's $29.95 *QRZ! Ham Radio* CD-ROM features an assortment of improvements and updates that add value to an already useful collection. This release includes QRZDLL.DLL, a dynamic linking library that allows individual programmers to use Walnut Creek's callsign database in their own programs. QRZDEMO, a sample program written in Microsoft's Visual Basic 3.0, uses QRZDLL.DLL to search for and display callsigns.

With QRZDEMO as a model and knowledge of Visual Basic or another Windows-related programming language, you can create your own custom callsign-retrieval and QSL card labeling program—incorporating all those nifty features you've wanted, but which standard programs omit.

QRZ!'s on-line callbook continues to expand its coverage, first by including United States radio clubs registered with the F.C.C., and second by listing additional callsigns from Italy, Canada, and the United Kingdom. Unfortunately, providing certain non-U.S. callsign coverage may prove difficult, as a note by QRZ!'s Editor, Fred Lloyd, AA7BQ, explains: "...We made an attempt to obtain the callsign database from Germany, but were told that the 'exclusive publishing rights' had already been sold to another firm. We're truly sorry that other countries around the world (and Germany is only one of many) consider the names and addresses of their radio amateurs to be a private property which may be sold to the highest bidder.... QRZ will continue to publish only callsign data which is in the public domain, so that costs will remain affordable to the greatest number of amateurs...." Economics aside, QRZ! remains an excellent choice for your first CD-ROM callbook.

This issue of QRZ! includes a subdirectory labeled \GERMANY which contains a collection of files of amateur radio-related software from (you guessed it) Germany. One collection of files (Y_LISTE) useful to DXers includes new callsigns assigned to radio amateurs who reside in the former East Germany. The \GERMANY subdirectory also inexplicably includes the latest version of Ghostscript, a freeware work-alike version of the PostScript printer-

```
940182.txt      Ham-Ant Digest V94 #182
        'Bending' beverage
        2 antennas into receiver?
        80 Meter Receiving Loop
        <<Best dual band verticals?>>
        <<Best dual band verticals?>>
        <<Best dual band verticals?>>
        beverage???
        Curing RF Voltage on Rig case in Mobi
        Curing RF Voltage on Rig case in Mobi
        Dielectric antennas?
        help w/antenna/amp problem
        help w/antenna/amp problem
        Mobile Antennas
        moment method
        need MFJ-941D tuner manual
        seek old CDR rotor (or replacement)
        Wind Loading
940185.txt      Ham-Ant Digest V94 #185
        AM Antenna
        Antenna radiation pattern charts
        HF Mobile Antennas
        Hygain 64-B Manual
        Rotator Cable Connectors
        TV antenna question
        Re: 80 Meter Receiving Loop
940187.txt      Ham-Ant Digest V94 #187
        2 rx antennas on a repeater? how to?
        Curing RF Voltage on Rig case in Mobi
        Re: Balloon
940189.txt      Ham-Ant Digest V94 #189
        2 rx antennas on a repeater? how to?
        AM/FM Antenna Splitting
        Antenna radiation pattern charts
```

Figure 2. Use Microsoft Write or any other editor to open QRZ!'s DIgest files and search for topics of interest—here, Beverage is highlighted.

control language. (Why did Walnut Creek place this fileset in \GERMANY? Perhaps because Ghostscript's author's last name is Deutsch!)

While not directly related to amateur radio, PostScript (and Ghostscript) both attract considerable support from their respective fans, who use these languages for everything from QSL card creation to printed-circuit artwork preparation. If you use either scripting language for ham radio tasks and would like to share your experiences, write me at the address given above.

Comprising almost 57 MB of text, QRZ!'s sampling of Internet discussion groups covers topics from antennas to TCP. While QRZ!'s harvest outmasses AmSoft's 12 MB collection, QRZ! does so by assembling excerpts from a longer period of time—January through November 1994—while AmSoft's compilation spans three months. Over a year, the two collections approach each other in size.

QRZ!'s discussion-group indexes have improved significantly from earlier versions. Each index now lists a session number and topic keywords in continuous form, simplifying browsing and keyword searches without requiring any software beyond a text editor. **Figure 2** illustrates an index for antenna topics as viewed via Microsoft's Write editor.

Which of these CD-ROMs should you buy? It's a toss up—both have strengths and weaknesses, and both contain competent domestic callbooks with some overlap in foreign callbook coverage. Both provide a surfeit of Internet coverage—if you read all the messages in either before the next edition appears, you have too much time on your hands!

Also, after a while you'll find Internet's headers and repetitions of text from previous messages resemble gravel on the information river bed—the gravel-to-gold runs annoyingly high. Still, you'll miss the nuggets unless you get your hands wet.

In upcoming columns, we'll continue to track recent CD-ROM releases and other software related to amateur radio. If you'd like to suggest software for review, please contact me at the above address.

You can obtain a copy of *The World of Ham Radio* CD-ROM from AmSoft, P.O. Box 666, New Cumberland, Pennsylvania 17070, or call (717) 938-8249 or (717) 938-6767 (fax).

To order a copy of *QRZ Ham Radio* CD-ROM, contact Walnut Creek CD-ROM, 4041 Pike Lane, Suite D-386, Concord, California 94520-9909, or call (800) 786-9907, (510) 674-0783 or (510) 674-0821 (fax). ■

Editor's Note: *By the time you read this, AmSoft's The World of Ham Radio CD-ROM May 1995 version will be available. Information in the callsign database will include calls awarded as of April 5, 1995. Also included is a test drive of the new AmCall Log Book for Windows.*

If you wish to contact AmSoft online, you may do so via the Internet. AmSoft's E-mail address is amsoft@epix.net. *Their world-wide web site is* http:\\hamster.business.uwo.ca.

PRODUCT INFORMATION

New Additions to AEA's PK-12

AEA's PK-12 Packet controller now includes firmware which enables it to connect to GPS receivers with a NMEA-0183 interface. AEA's optional APRS Adapter Cable for the PK-12 was designed for Hardware Single Port Mode operation. This cable lets users running APRS (Automatic Packet Reporting System) software devote only one COM port for the GPS receiver and the PK-12.

When used without the APRS Adapter Cable, the new firmware lets the PK-12 be employed as a Stand Alone Tracking device. This means a PK-12 can obtain positioning information from a GPS receiver and beacon it in Packet over the ham bands through a transceiver without using APRS software; no computer is needed. Vehicles equipped with the PK-12, a GPS receiver and a radio can beacon their location and be seen on a computerized map by APRS users.

All AEA TNCs have the ability to be used with APRS software, but the PK-12 is specially designed for GPS applications. Unlike other TNCs, the PK-12 itself parses GPS data so no computer is needed and the new adapter cable solves many hardware constraints. The PK-12 itself is a 1200bps Packet controller. It features Gateway firmware, so it works as a node; it is compatible with PC PakRatt for Windows 2.0 for ease of use, and it comes standard with 15K MailDrop (32K RAM) which is easily expandable to 100K (128K RAM). The new firmware built into the PK-12 is GPS and Loran compatible. The PK-12 is also ULTIMETER-II compatible which allows users to receive weather information from remote sites; and the PK-12 is ARNAV compatible.

For more information about the PK-12's GPS ability call AEA's Literature Request Line at 1-800-432-8873; or write: Advanced Electronic Applications, Inc., P.O. Box C2160, Lynnwood, WA 98036.

TECH NOTES

Adrian Knott's (G6KSN) "Communications in the Red Zone" novel transmitter and receiver construction project for 319 Terra Hertz (940 nM wavelength) caught my eye when it appeared in the January 1994 issue of Practical Wireless. Although based on inexpensive infrared LED sources and detectors—versus coherent LED or gas lasers—it offers real communications capabilities over a several kilometer path when equipped with suitable optics.

Experimenters might consider some refinements and improvements. The common 555 timer IC is capable of square-wave generation and accepting pulse-width modulation, while sourcing or sinking a 300-mA load. This could eliminate four discrete transistors from the G6KSN design. The current DigiKey[1] parts catalog, besides carrying infrared diodes and detectors, also offers 5-mW Panasonic infrared LED lasers operating at 788 nM for under $30. I welcome reader feedback on any improvements made to any of the projects featured in this column.

Communications in the Red Zone

Adrian Knott, G6KSN
Reprinted with permission from
Practical Wireless, January 1994

I've always been fascinated by the different ways of electronically processing speech and sending it to some remote location via electromagnetic radiation. This circuit uses a frequency modulated subcarrier superimposed on a main carrier at 319 THz (940 nM).

The system I'm describing is immune to most forms of interference which its AM counterparts suffer from very badly. It also has a good range and introduces very little distortion to the original signal and would be ideal for data transmission up to at least 2400 baud.

Project Origins

The project origins started when I tried out an AM baseband system. the received audio quality was excellent but it was very severely affected by mains hum from any incandescent bulbs in the vicinity. Additionally, the original system had no AGC. So, as a consequence, I had to rethink the situation.

If an LED is pulsed on and off very quickly and the speed of the pulses is altered in sympathy with the desired audio, an FM signal superimposed on the light carrier will be created.

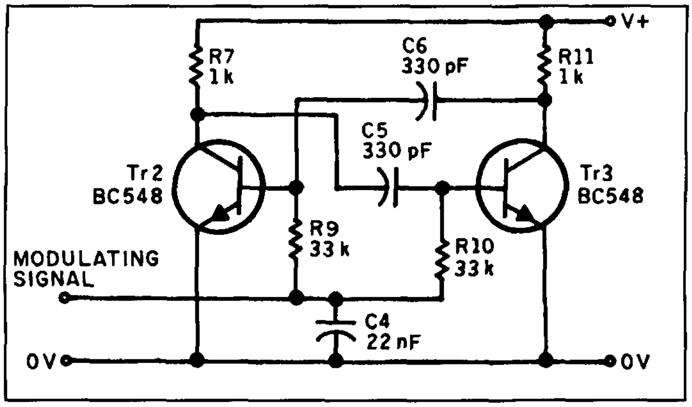


Figure 1. A simple square wave generator, capable of being frequency modulated, forms the basis of the G6KSN infra-red communications project (see text).

I eventually chose 65 kHz for the center frequency. This is a compromise between being able to switch the LED cleanly and maintaining modulator linearity.

The receiver can now be "tuned" to 65 kHz. The input signal is limited and then fed to a frequency discriminator/demodulator, and there's no more mains hum since the receiver is tuned well above the mains frequency.

With the new approach there are no more problems with received audio level. This is because it will remain constant (for a given deviation) and only the signal-to-noise ratio will change (the noise gradually increasing as the signal gets weaker).

The Transmitter

Let's now take a look at the transmitter. A simple square wave generator, capable of being frequency modulated in the form of the astable multivibrator is shown in **Figure 1**.

The transmitter output frequency, being proportional to Vin (within limits) is ideal for the purpose. The final circuit is shown in **Figure 2**.

The input from R2 via the pre-emphasis components R1 and C1 is fed into the base of TR1 via C2. The transistor TR1 forms an audio amplifier which provides the modulating voltage for the astable multivibrator, TR2 and 3, whose free running frequency is set by R5 to 65 kHz (peak deviation is about ±12 kHz).

The collector of Tr3, whose output is a square wave, is fed to the voltage follower/buffer TR4. The transistors Tr5 and 6 form the output driver and are configured as a Darlington pair.

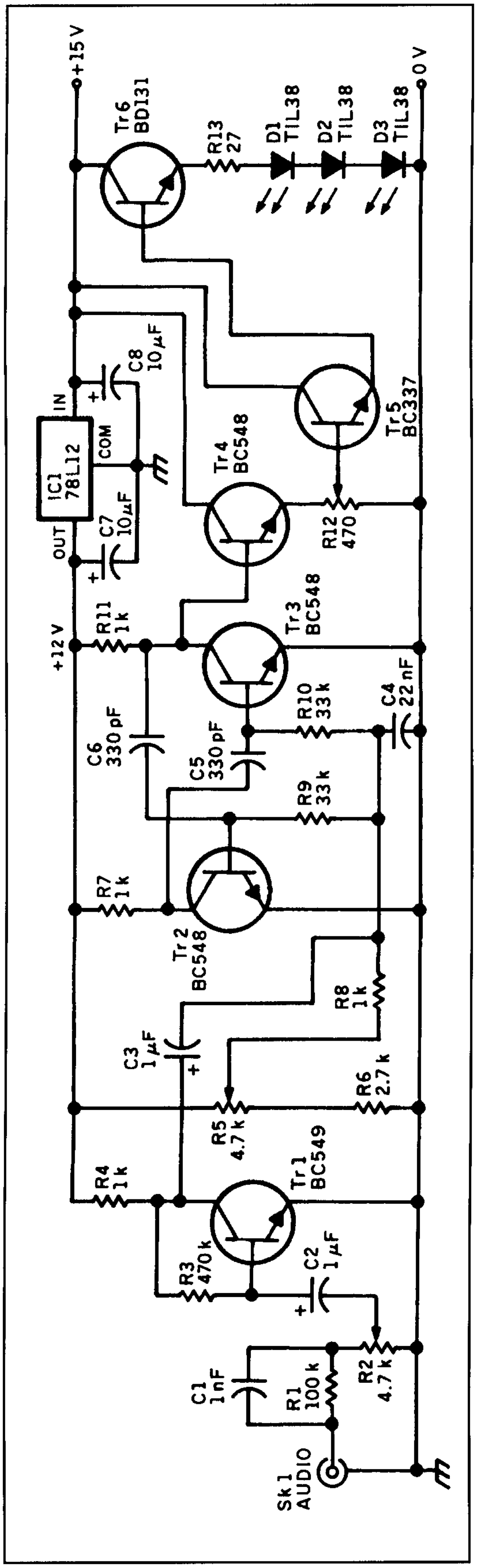


Figure 2. Circuit diagram of the infra-red transmitter (see text).

The resistor R13 serves as a current limiter. It can be used to monitor the diode drive which is set by R12 and must be set such that the LED(s) are not overdriven.

Receiver Circuit

The receiver circuit diagram is shown in **Figure 3**. The infra-red signal is received by D4, which is DC coupled to the wideband amplifier Tr7.

The output of Tr7 is capacitively coupled to the tuned circuit formed by C10 and L1. The now filtered output is fed to the base of Tr8, this is another amplifier which brings the signal level up sufficiently to directly drive the TBA120S FM limiter/detector.

The capacitor C13 is included to roll off the very high frequencies which may otherwise cause instability. The capacitors C16 and C18 are included to enhance the low frequency response of the IC. This is because the internal capacitors are for use at typically 10.7 MHz, and they don't provide adequate coupling in this application.

The tuned circuit formed by L2, C17 is damped by R20. This damping effect is in order to improve the bandwidth and thus minimize distortion.

The demodulated output is taken from pin 8 of the IC via C20. The capacitor C19 is part of the de-emphasis noise reduction circuitry.

Variable resistor R21 sets the audio level. It also feeds into op-amp IC3 which is biased to run from a single rail. The transistors Tr19 and 10 form the audio output stage, the standing current being set by R29.

The main feedback path is via R26 and 27, and C24. These components set the gain of the amplifier and also help to minimize distortion.

The loudspeaker is AC coupled to the emitter junctions of Tr19 and 10. These devices should preferably be matched for gain (H_{fe}).

Construction Straightforward

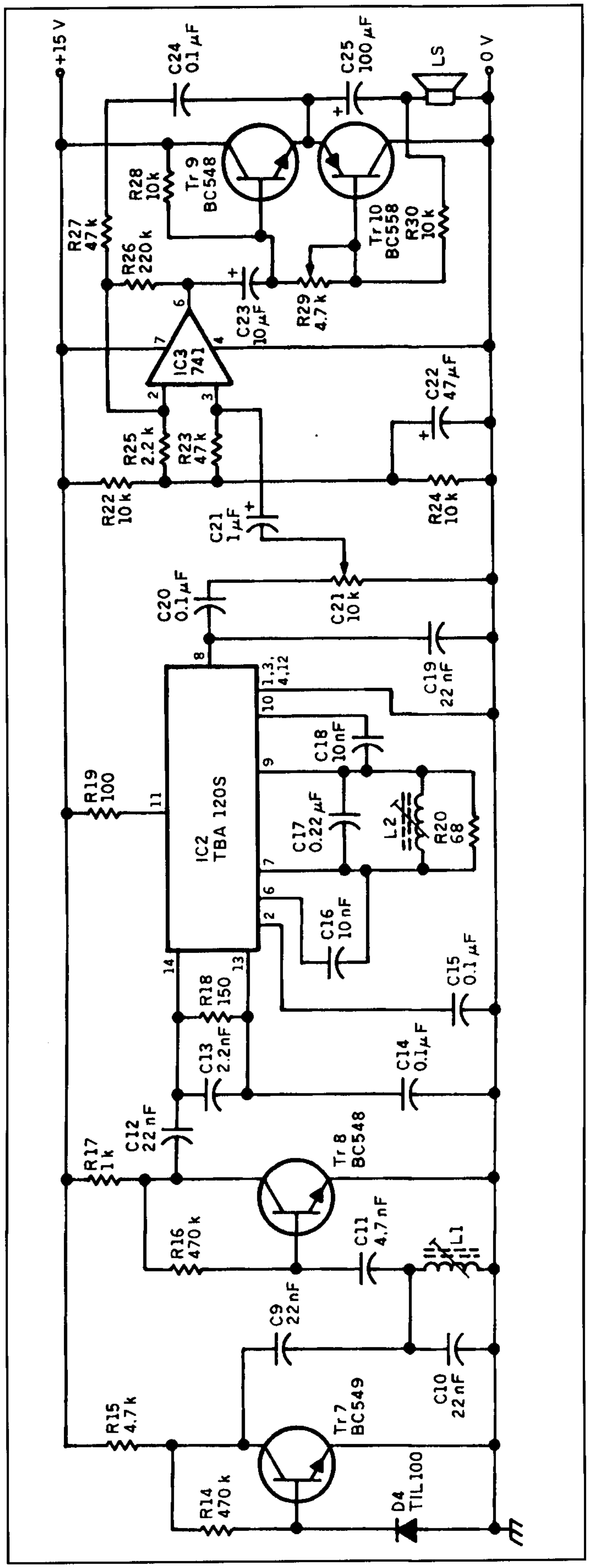
Construction is quite straightforward and the two units can be built on Veroboard or in similar fashion. Layout is not critical because the frequencies handled are not high.

If full duplex working (two-way operation) is required, then obviously two of each circuit will be required. By carefully positioning the TX and RX diodes and employing a screen between them, a telephone-style conversation can be achieved.

Incidentally, L1 should not be mounted directly next to L2 otherwise the receiver may tend to self oscillate. In my prototype, these inductors were mounted about 75 mm apart.

The diodes should be fed remotely via

Figure 3. Circuit diagram of the infra-red receiver developed by G6KSN (see text).



screened cable. But watch the capacitance of the cable used to connect the receive diode since the impedance is rather high.

Unscreened cable should not be used. If you do, it may cause the transmitter to radiate or the receiver to pick up one of the VLF transmissions such as MSF on 60 kHz.

Setting Up

When the construction stage is completed you can start setting up. Begin by checking the boards for any unwanted solder bridges, etc.

If all appears to be well, you can set the receiver R21 to minimum volume. Then set R29 to minimum resistance and with a multimeter (set to read milliamps) in line, apply 12 to 15 volts to the receiver.

The current consumption should be very low, about 10 mA. If it's much more than this, switch off immediately and check for shorts on the board.

If all is well, advance R29 so that the current rises by 2 to 3 mA. Then turn up R21 and white noise should be heard on the loudspeaker.

Now you can start with the transmitter. Turn R2 to minimum, R5 to its central position, and R12 to minimum.

Monitor Current

Now apply 15 volts and again monitor the current which should be only a few milliamps. Next, you can rotate R12 clockwise and the current should start to increase.

If all is well, disconnect the meter and reapply power. Set the meter on the low volts range (0 to 3 volts typical) and monitor the voltage across R13.

Now you can adjust R12 for the required drive level; i.e., I_{av}=V/27. So, for 1, 2, or 3 TIL38s this can be set about 75 mA or 2 volts on the test meter.

If more than three diodes are to be used, it's better to add another feed resistor from the emitter of Tr6. But of course, each resistor/diode combination should be identical. Watch also for the temperature of Tr6, as a heatsink may be required for large stacks.

You can now adjust R5. And if a frequency counter is available, this may be set precisely to 65 kHz by monitoring the emitter of Tr4.

If a frequency counter is not available, R5 can be set approximately by placing the transmitter unit close to a long-wave receiver. The receiver is then tuned to the harmonics.

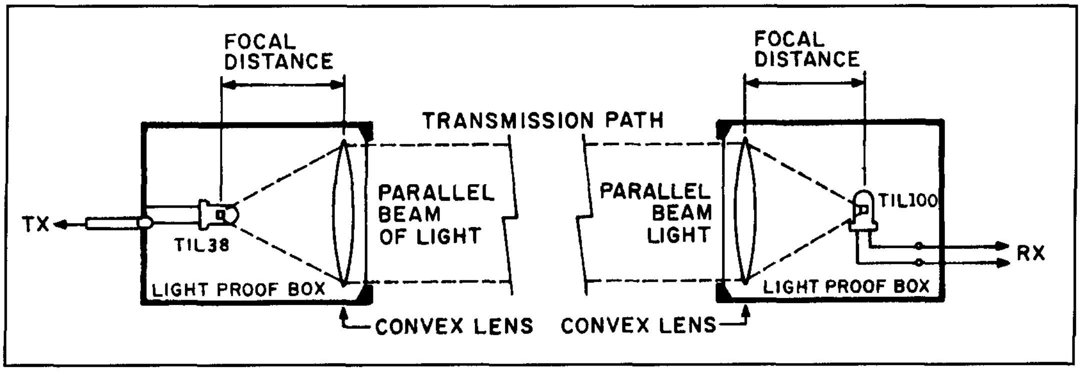


Figure 4. To extend the range of the infra-red communications system, a suitable lens is required for each installation. For practical operation, G6KSN recommends mounting the optical assembly on photographic tripods (see text).

Parts List

Resistors

Carbon/Metal Film 1 watt 5 percent		
27 ohms	1	R13
Carbon/Metal Film 0.4 watt 5 percent		
68 ohms	1	R20
100 ohms	1	R19
150 ohms	1	R18
1 k	5	R4,7,8,11,17
2.2 k	1	R25
2.7 k	1	R6
4.7 k	1	R15
10 k	4	R22,24,28,30
33 k	2	R9,10
47 k	2	R23,27
100 k	1	R1
220 k	1	R26
470 k	3	R3,14,16
Skeleton Preset (Linear law)		
470 ohms	1	R12
4.7 k	3	R2,5,29
Skeleton Preset (Linear law)		
10 k	1	R21

Capacitors

Miniature disc ceramic		
1 nF	1	C1
2.2 nF	1	C13
4.7 nF	1	C11
10 nF	2	C16,18
22 nF	5	C4,9,10,12,19
Miniature Polyester		
100 nF	4	C14,15.20,24
220 nF	1	C17
Miniature Polystyrene 5 percent		
330 pF	2	C5,6
Miniature electrolytic 16-volt working		
1 µF	3	C2,3,21
10 µF	3	C7,8,23
47 µF	1	C22
100 µF	1	C25

Inductors

L1	50 turns close wound enameled copper wire (e.c.w.) on a 5mm former with a ferrite core.
L2	100 turns pile would e.c.w. on a 5 mm former with a ferrite core.

Semiconductors

Transistors		
BC337	1	Tr5
BC548	5	Tr2,3,4,8,9
BC549	2	Tr1,7
BC558	1	Tr10
BD131	1	Tr6
Diodes		
TIL38	3	D1,2,3, (or any infra-red transmitter diodes).
TIL100	1	D4 (or any infra-red detector spectrally (color) matched to Ds 1-3.
Integrated Circuits		
'741	1	IC3 (any manufacturer).
78L12	1	IC1 (any manufacturer).
TBA120S	1	IC2

Miscellaneous

Interconnecting wire, miniature coaxial cable, suitable boxes and hardware to house the project, plugs and socket to suit, lenses and housing (optional), loudspeaker, a regulated 15-volt power source.

For the optional optical components (mirrors, filters, lenses, and lens housings) contact:

Comar Instruments at 70 Hartington Grove,
Cambridge, Cambridgeshire CB1 4UH.

Whistle Tuned

The harmonics should occur at 195 and 260 kHz. A 3 kHz whistle should be heard when tuned to Radio 4 at 198 kHz. But, make sure by checking at 260 kHz because it may be oscillating at 48.7 kHz (4th harmonic 195 kHz).

Once the receiver is tuned, apply audio line level to the transmitter (about 500 mV rms) and set R1 at the midway point. If the transmitter is now brought close to the receiver, the receiver noise should reduce and audio should be resolved.

Now adjust L2. Then you should separate the transmitter and receiver until the signal becomes noisy. Then adjust L1 on the receive board for best signal-to-noise ratio.

If the core of L1 has to be screwed fully in, then C10 can be increased to 27 nF and L1 retuned (in practice this is unlikely to happen). The units are now aligned and may be installed.

Ready for Use

The infra-red units are now ready (reddy?) for use. If the required path is indoors, then no more needs to be done. If, however, the path is long or is in a brightly lit location, then a tube fitted over the receive diode should minimize interference from the sun, etc.

If the path is very long but still "optical," then lenses may be required. Placing the transmit (only one is used now) and receive diodes at the focal lengths of converging lenses (**Figure 4**) depending on lens quality, ranges of several kilometers should be possible.

In general, if the path is "optical" and the lenses are sufficiently good, then the system will work. For ranges up to 1 km, lenses of 32 mm diameter should be adequate.

The receive diode should be mounted in a tube. I found that plastic drainpipe works well, as this minimizes the incidental radiation from the sun.

Communications via obstructed pathways are also possible, providing that some means of scattering the light round the obstruction is available. Signals via scatter of reflection from buildings are likely to be very weak.

Obstructed Pathways

With obstructed pathways, large lenses giving high "gain" must be used in order to obtain an acceptable signal-to-noise ratio. With any lenses in use, the "beam" is very tight and alignment will be critical (to within a couple of degrees in both horizontal and vertical directions, so be warned!).

I recommend that a tilt and pan mount should be used and it must be mechanically very stable. For portable use, photographic tripods work well.

I've also got a tip about the weather. If the diodes are to be mounted for outdoor use, it's a good idea to weatherproof the installation to prevent the ingress of moisture.

Hours of Fun in the Red Zone

In use, the unit has proved reliable and has provided me with hours of fun experimenting with various pathways, etc. I hope my "red zone" project will be of use to others either for fun, or perhaps some more serious work in this fascinating part of the electromagnetic spectrum.

REFERENCES

1. DigiKey Corporation, 701 Brooks Avenue, South, P.O. Box 677, Thief River Falls, Minnesota 56701-0677.

PRODUCT INFORMATION

B&B Electronics' Multipurpose Four Port Serial Board

B&B Electronics Manufacturing Co. has announced its new Model 3PXCC4A serial card, featuring four serial ports in a single slot. Each of the 3PXCC4A's ports can be independently configured for any I/O address and any IRQ, as well as RS-232, 422, or 485 data protocols. TD, RD, RTS, CTS, DSR, DCD, and DTR port lines are supported by the RS-232 mode, with each port using a buffered, high speed UART (16550A). Additionally, the 3PXCC4A has interrupt sharing capabilities and an Interrupt Status Register to increase throughput in shared IRQ applications, as well as increase the number of available interrupts in your system. The serial card uses 8 conductor RJ45 connectors. Pre-wired adapter kits (Models MDB9 & MDB25) are available. These kits enable you to convert to DB-9 or DB-25 connectors.

For more information about the 3PXCC4A and to receive B&B Electronics' free catalog of *Serial Communication Interface and Control Equipment*, contact: B&B Electronics Manufacturing Co., 707 Dayton Road, P.O. Box 1040, Ottawa, IL 61350 (phone: 815-434-0846; 8 am to 4:30 pm Central; 24-hour fax: 815-434-7094; 24-hour BBS: 815-434-2927; Internet: catrqst@bb-elec.com).

Corrections

Turning the table

We inadvertently printed the wrong version of **Table 2** in "Power on a Budget" (Marv Gonsior, W6FR, Winter 1995, page 55). Here's the corrected table:

Zin[1,2] (ohms)	Freq. (MHz)	C1[3] (pF)	L1 (µH) (pF)	C2 (µH)	L2
1500	1.80	784.	14.047	2621.	8.917
1500	2.00	636.	14.047	1982.	8.917
1500	3.50	403.	7.117	1348.	4.518
1500	4.00	318.	7.117	991.	4.518
1500	7.30	174.	3.900	543.	2.476
1500	7.00	188.	3.900	596.	2.476
1500	14.00	93.	1.984	292.	1.259
1500	14.35	89.	1.984	276.	1.259
1500	21.00	62.	1.327	191.	0.843
1500	21.45	59.	1.327	185.	0.843
1500	28.00	48.	0.959	152.	0.609
1500	29.70	43.	0.959	134.	0.609
2000	1.80	591.	17.933	2355.	8.917
2000	2.00	478.	17.933	1788.	8.917
2000	3.50	304.	9.086	1211.	4.518
2000	4.00	239.	9.086	894.	4.518
2000	7.00	142.	4.978	534.	2.476
2000	7.30	131.	4.978	490.	2.476
2000	14.00	70.	2.533	264.	1.259
2000	14.35	67.	2.533	249.	1.259
2000	21.00	47.	1.694	173.	0.843
2000	21.45	45.	1.694	167.	0.843
2000	28.00	36.	1.224	135.	0.609
2000	29.70	32.	1.224	120.	0.609

Table 2. Pi-L values[1] Q = 12

Notes:
Zin from the formula:

$$RL = \frac{2500}{1.5 \times 1} = 1666\Omega$$

1. *ARRL Handbook*, 1989 edition, page 15-3, 15-8.
2. Collins, *Amateur Single Sideband*, 1962, page 68.
3. Includes output capacitance plus strays (12 + 5 pF).

A radical change

Dick Weber, K5IU, faxed in two corrections to his article "Aerodynamic Balancing: Part 2" (Winter 1995, page 89). In the second part of **Equation 7**, the radical sign should encompass the entire expression. In the second part of **Equation 8**, the radical sign should encompass the entire expression, and an e should be added to sum on the first line of the equation. The corrected equations are shown below:

$$y = \sqrt{\frac{0.86\mathrm{ABS}\ (\mathrm{sum})}{R_{pe}}}$$

Equation 7

$$y = \sqrt{\frac{0.71\mathrm{ABS}\ (\mathrm{esum})}{R_{pe}}}$$

Equation 8

A missing line

In **Figure 6** of "Connecting Computers to Radios—Adding DDS Frequency Control" (Howie Cahn, WB2CPU, Winter 1995, page 9), a line was omitted from the program used to test the DDS board. The corrected section of code is:

```
'Shift out the bits to SDATA . . .
FOR i = 31 TO 8 STEP –1
temp& = (clk&/ (2 ^ (32 – i)))
IF (remain& – (temp&) > 0) THEN
j2
```

The statement that begins "FOR i = 31 . ." was missing.

Joe Fedele
12900 N. Bayshore Drive
North Miami, Florida 33181-2151

THE FINAL TRANSMISSION

FCC to institute rule changes for tower owners

This January, the Federal Communications Commission (FCC) released a Notice of Proposed Rule Making (NPRM 95-5) that would streamline the process of approving tower sites for use as transmitting locations and provide for better enforcement of its rules concerning the painting and lighting of such structures. As of this writing (March 1995), the Commission had not made a final ruling, but was waiting for reply comments (due April 1995).

The FCC has always held each licensee responsible for tower filings—regardless of how many licensees there are at a particular site. Presently, licensees that lease tower space for the purpose of voice or data transmissions are required to file for antenna structure clearance with the Federal Aviation Administration (FAA) prior to activation of such transmissions. Furthermore, some changes to existing towers, such as increases in overall height, must be filed for by all licensees at the site regardless of whether or not they institute the changes.

The new rules would shift the burden of filing tower registration from the holders of antenna licenses to the owners of the tower structure. By enacting this change, the Commission expects to maintain a more pro-active approach to tower maintenance and safety issues.

The FCC's strategy is outlined in a plan designed to reduce the overall number of filings made by individual licensees and permitees. It is hoped that this new system will also speed up the process by which tower sites are catalogued and registered.

Tower owners would be primarily responsible for registering the antenna structure with the FCC. Their responsibilities would also include the painting and lighting of the antenna structure in accordance with the Commission's Rules, and notifying the Commission of any changes in overall tower height, coordinates, or ownership. Owners must even inform the Commission if the structure is removed from service or dismantled.

Under existing rules, anyone filing for a new application is required to identify the coordinates and height of the tower structure and obtain a finding from the FAA as to whether or not the structure is a potential hazard to air safety or navigation. The FAA may recommend that the tower be lit, painted, or even shortened. The FCC then specifies these recommendations in the licensee's instrument of station authorization.

The FCC estimates that there are nearly half a million antenna structures in the United States. Of these, over 70,000 structures were subject to FAA clearance prior to construction. Estimates show that there are an average of twelve individual licensees authorized on each tower. Consequently, there are an overlapping number of tower filings per site. Implementation of these rules would reduce the number by a factor of twelve, making the streamlining effect immediate from the first day of inception. The FCC states that "the proposal would not impose a greater net filing burden on the public, but would instead decrease the number of entities affected by these requirements."

This proposal even includes a process that would allow the FCC to develop a "uniform procedure for registering antenna structures and provide for the creation of a common database listing structure information." This database would provide the Commission with an up-to-date and complete listing of sites to be used "during investigations related to air safety or radio frequency interference." The Commission would then be capable of identifying each antenna structure owner for the purpose of enforcing "the new Congressionally mandated provisions related to owners." It will also allow for speedier processing of requests involving a change in coordinates, structure height, or change in painting and/or lighting. Finally, this database would simplify the antenna clearance process for both industry and the Commission.

On the matter of air safety, the FCC cites that "each licensee on a multi-use antenna structure is separately and jointly responsible for the installation and maintenance of the structure" and, that, "oftentimes the antenna structure owner is not a Commission licensee and therefore, has no vested interest in compliance. This poses a hazard to air commerce in cases where all Commission licensees vacate an antenna structure and the tower owner fails to paint, light, or dismantle the structure."

The FCC also proposes to incorporate two advisory circulars published by the FAA into this ruling. These advisories, "Obstruction Markings and Lightings (AC 70/7460-1H)" and "Specifications for Obstruction Lighting Equipment (AC 150/5345-43D)" provide guidelines for tower safety markings. The addition of this to existing rules would force tower owners to maintain their structures in accordance with FAA standards at all times.

The imposition of these new rules would allow the FCC to levy fines against tower owners. The rules read, "antenna structure owners who fail to comply with the requirements set forth in Part 17 may be subject to administrative sanctions. Currently, licensees are individually responsible for antenna structure maintenance, even in cases where they neither own nor have a legal right to maintain the structure. While still recognizing the ultimate shared responsibility of licensees, permittees, and owners, we are proposing rules to hold the owner primarily responsible, in the first instance, for the installation and maintenance of painting and/or lighting for each antenna structure.

"This means that the Commission would look first toward antenna structure owners to ensure that their structures are painted and lighted in accordance with Part 17. In cases where reliance on the structure owner proves ineffective, the Commission would turn toward the tenant licensees and permittees to ensure that the structure is properly painted and lighted. For instance, if the structure owner cannot be reached, the Commission would have the option to require tenant licensees and permittees to maintain the structure. By focusing on the single entity which has control over all aspects of the antenna structure, the Commission hopes to speed resolution of problems associated with lighting outages and vacant antenna structures."

The changes proposed in the NPRM would apply to all structures requiring FAA authorization under Part 17 of FCC rules, regardless of the type of service. This includes Amateur Radio Services (Part 97), Aviation Services (Part 87), Cable TV Relay Services (Part 78), Domestic Public Fixed Radio Services (Part 21), Private Land Mobile Public Services (Part 22), Private Operational-Fixed Microwave Services (Part 94), Mobile Radio Services (Part 90), Radio and TV Broadcasting (Part 73 & 74), and Satellite Communications (Part 25). Some Cellular phone systems and Personal Communications Systems (PCS) would also be included in this rule change.

The Commission has proposed that these new rules become effective on January 1, 1996. As of that date, all applicants for the construction of new antenna structures would be required to file a revised FCC Form 854. All existing structures whose individual licensees request a modification of their current facilities, which require an alteration in the overall height of the tower, are also required to file the same.

The Commission is still in the exploratory stage of deciding just how to implement these changes, and there are several routes to this end. The first possibility might be to divide the country geographically by either states, groups of states, latitude and longitude, or "natural boundaries."

Another way to proceed would be to group antenna structures together by height. It would be advantageous to group the taller towers together and investigate them first would be because the larger structures would have a greater proportion of licensees, which could be accounted for all at one time.

The third way the FCC could implement the new rule changes would be to tap into the renewal process. This would spread full implementation over a ten year period. This time period was chosen because it reflects the longest license term currently on record for any one license authorization.

Cellular systems and PCS may be treated a bit differently than conventional single point transmissions because they are not normally required to specify the locations of all their structures prior to license authorization.

Aside from safety and regulatory issues, the FCC expects to realize substantial savings for both the Commission and individual licensees if this proposal is enacted. Based on 1993 figures, the Commission estimates savings in excess of $500,000 annually due to the decreased number of hours spent on processing applications. They also estimate that licensees will save over $320,000 annually in fees paid to consulting engineers, whose assistance will no longer be necessary under the new rules. ■

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- OUTPUT VOLTAGE: 13.8 VDC ± 0.05 volts (Internally Adjustable: 11-15 VDC)
- RIPPLE Less than 5mv peak to peak (full load & low line)
- All units available in 220 VAC input voltage (except for SL-11A)

SL SERIES

- LOW PROFILE POWER SUPPLY

MODEL	Colors Gray	 Black	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H × W × D	Shipping Wt. (lbs.)
SL-11A	•	•	7	11	2⅝ × 7⅝ × 9¾	12
SL-11R	•	•	7	11	2⅝ × 7 × 9¾	12
SL-11S	•	•	7	11	2⅝ × 7⅝ × 9¾	12
SL-11R-RA		•	7	11	4¾ × 7 × 9¾	13

RS-L SERIES

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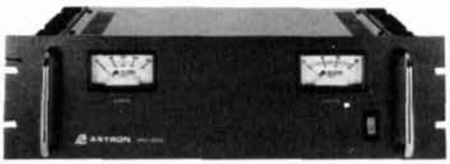
MODEL	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H × W × D	Shipping Wt. (lbs.)
RS-4L	3	4	3½ × 6⅛ × 7¼	6
RS-5L	4	5	3½ × 6⅛ × 7¼	7

RM SERIES



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MODEL	*Continuous Duty (Amps)*	*ICS* (Amps)*	*Size (IN) H × W × D*	*Shipping Wt. (lbs.)*
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RM-35A	25	35	5¼ × 19 × 12½	38
RM-50A	37	50	5¼ × 19 × 12½	50
RM-60A	50	55	7 × 19 × 12½	60
• Separate Volt and Amp Meters				
RM-12M	9	12	5¼ × 19 × 8¼	16
RM-35M	25	35	5¼ × 19 × 12½	38
RM-50M	37	50	5¼ × 19 × 12½	50
RM-60M	50	55	7 × 19 × 12½	60

RS-A SERIES

MODEL RS-7A

MODEL	Colors Gray	 Black	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H × W × D	Shipping Wt. (lbs.)
RS-3A		•	2.5	3	3 × 4¾ × 5¾	4
RS-4A	•	•	3	4	3¾ × 6½ × 9	5
RS-5A		•	4	5	3½ × 6⅛ × 7¼	7
RS-7A	•	•	5	7	3¾ × 6½ × 9	9
RS-7B	•	•	5	7	4 × 7½ × 10¾	10
RS-10A	•	•	7.5	10	4 × 7½ × 10¾	11
RS-12A	•	•	9	12	4½ × 8 × 9	13
RS-12B		•	9	12	4 × 7½ × 10¾	13
RS-20A	•	•	16	20	5 × 9 × 10½	18
RS-35A	•	•	25	35	5 × 11 × 11	27
RS-50A	•		37	50	6 × 13¾ × 11	46
RS-70A	•		57	70	6 × 13¾ × 12⅛	48

RS-M SERIES

MODEL RS-35M

MODEL	*Continuous* Duty (Amps)	*ICS** (Amps)	*Size (IN)* H × W × D	*Shipping* Wt. (lbs.)
• Switchable volt and Amp meter				
RS-12M	9	12	4½ × 8 × 9	13
• Separate volt and Amp meters				
RS-20M	16	20	5 × 9 × 10½	18
RS-35M	25	35	5 × 11 × 11	27
RS-50M	37	50	6 × 13¾ × 11	46
RS-70M	57	70	6 × 13¾ × 12⅛	48

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MODEL VS-35M

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MODEL	Continuous Duty (Amps) @13.8VDC	 @10VDC	 @5VDC	ICS* (Amps) @13.8V	Size (IN) H × W × D	Shipping Wt. (lbs.)
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VS-20M	16	9	4	20	5 × 9 × 10½	20
VS-35M	25	15	7	35	5 × 11 × 11	29
VS-50M	37	22	10	50	6 × 13¾ × 11	46
• Variable rack mount power supplies						
VRM-35M	25	15	7	35	5¼ × 19 × 12½	38
VRM-50M	37	22	10	50	5¼ × 19 × 12½	50

RS-S SERIES

MODEL RS-12S

- Built in speaker

MODEL	*Colors* Gray	 Black	*Continuous* Duty (Amps)	*ICS** Amps	*Size (IN)* H × W × D	*Shipping* Wt. (lbs.)
RS-7S	•	•	5	7	4 × 7½ × 10¾	10
RS-10S	•	•	7.5	10	4 × 7½ × 10¾	12
RS-12S	•	•	9	12	4½ × 8 × 9	13
RS-20S	•	•	16	20	5 × 9 × 10½	18
SL-11S	•	•	7	11	2¾ x 7⅝ x 9¾	12

*ICS—Intermittent Communication Service (50% Duty Cycle 5min. on 5 min. off)

EDITORIAL

(from page 4)

Personal Communications Center—all via your PC. Recent issues of *CommQuart* have also featured articles on "Connecting Computers to Radios," by Howie Kahn, WB2CPU, that showed how to provide a "virtual radio" interface (including DDS frequency control) between simple radios and your computer.

While the hardware-oriented individuals will lament the passing of the traditional receiver in the ham shack—i.e., the touchy, feely hardware—SWLs and active hams, more interested in logging stations and results, will probably be less concerned with the actual mechanics involved than whether the equipments helps them achieve their desired objective.

Does this growing revolution in receivers mark the passing of the homebrew receiver? I think not. There has been a resurgence in interest in phasing-type receivers, which use an elegant mathematical solution rather than a brute force filtering system to produce or demodulate a single signal, and I predict you will see more projects offered along these lines in the near future. Harris has introduced the HSP50016GC digital downconverter IC, which is virtually a complete Weaver, or third method, receiver implemented digitally on a CMOS chip. A 16-bit or better A/D converter operating at 52 megasamples per second is needed to digitize the RF input signal, and a similar 16-bit D/A converter is needed to produce the audio output.

On a more traditional plane, Analog Devices has the AD607 3-volt receiver RF/mixer/IF subsystem—almost a complete receiver on a chip. The chip features an onboard mixer with a -15 dBm 1 dB compression point, a 100-dB gain linear IF amplifier with internal AGC and RSSI output, and an internal LO preamplifier.

So while I'm saddened by the untimely demise of Softwave, it seems that the options for hardware, software, and homebrew-centered receiver aficionados are expanding rather than dwindling. And I, for one, am eagerly looking toward the future!

Peter Bertini, K1ZJH
Senior Technical Editor

PRODUCT INFORMATION

Kodak Berkeley Research's Programmable Error Control Evaluator

Test the power of Reed-Solomon coding before you specify error control—with the new Model 270 Forward Error Correction Evaluator.

Available on loan from Kodak Berkeley Research, the programmable unit allows convenient performance evaluation and sampling of coding rates, channel speeds, and code interleaving depths. It can be used for specifying custom error protection over noisy communications channels where error rates are worse than 10^{-3}, or when retransmission of important messages is impractical. The Model 270 implements Reed-Solomon error correction codes RS (62,32), RS (62,48), and RS (62,56) over GF (64) for respective code rates 1/2, 3/4, and 7/8 including built-in synchronization. Two full-duplex channels allow independent local or loopback testing in seven speed ranges from 16 Kbps to 1.3 Mbps. Users can simulate higher speed systems by modeling. Choice of six interleaving depths demonstrates increased burst error protection in the data stream. The unit can be set to TTL, RS-232, or RS-422 interface levels.

For more information, contact: Jerry Walker, Manager, Systems Engineering, Kodak Berkeley Research, 2120 Haste Street, Berkeley, CA 94704 (phone: 510-649-2700; fax: 510-548-2358).

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For further information, contact: Henry G. Dietz, The Henry G. Dietz Co., Inc., 14-26 28th Avenue, Long Island City, NY 11102-3692 (phone: 718-726-3347; 718-726-7270; fax: 718-728-3976).

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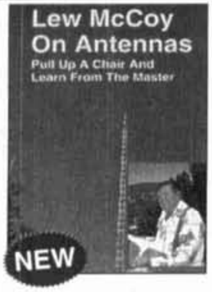

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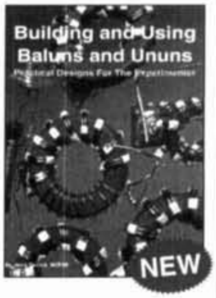

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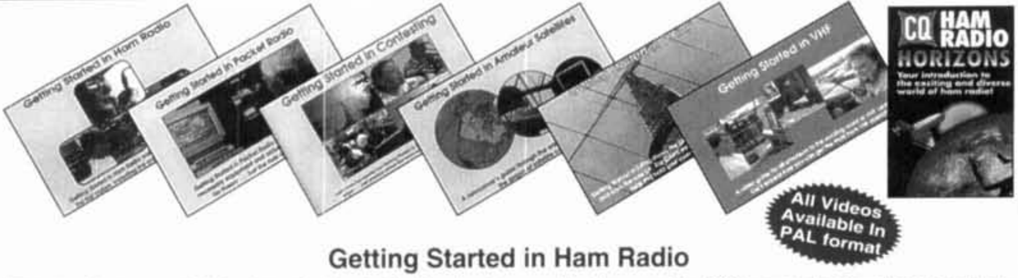

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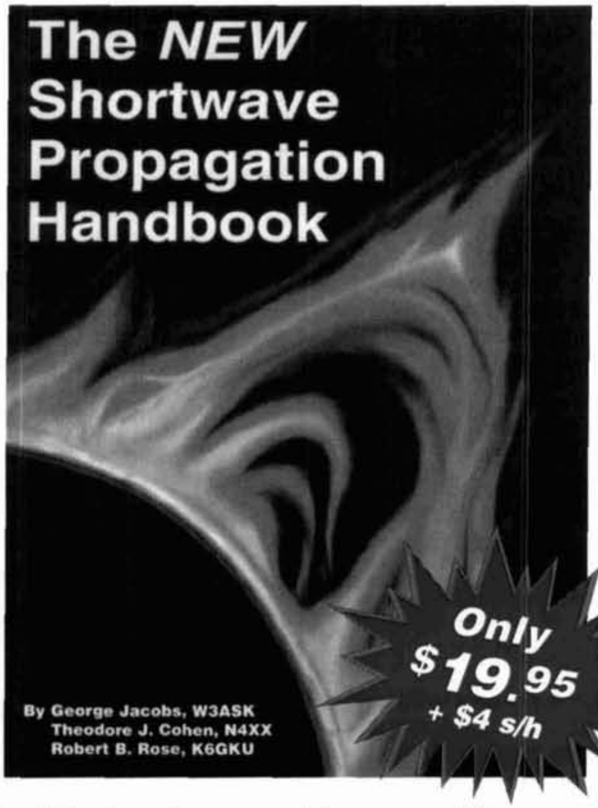

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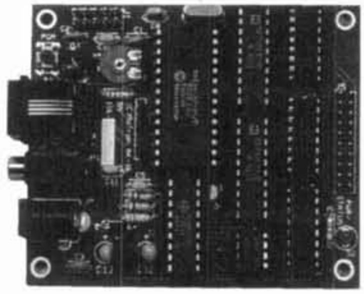

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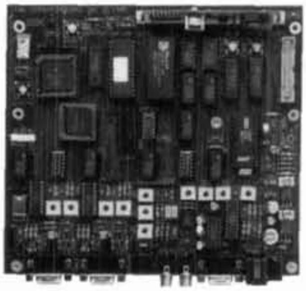

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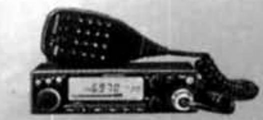

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