

COMMUNICATIONS QUARTERLY

THE JOURNAL OF
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TECHNOLOGY

Spring 1996

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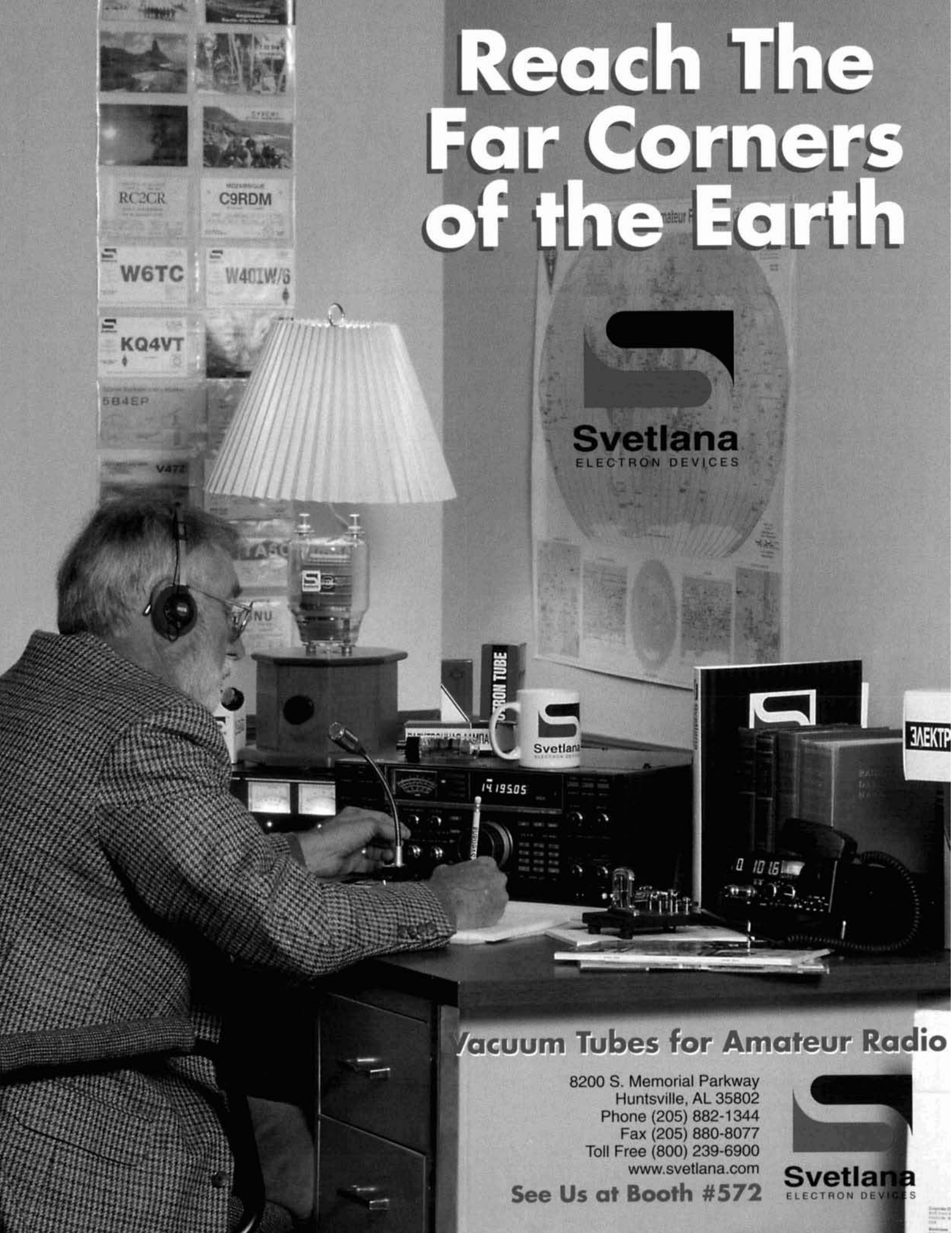
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- Fractal and Shaped Dipoles
- Computer Aided Design for Amateurs
- Low-Cost SMD Prototype Construction
- Using Inexpensive Digital Panel Meters

- The Serpentine "Stealth" Vertical Antenna
- *Single Sideband Systems and Circuits: A Review*
- Software Shortcuts
- SETI Made Simple
- Building Short Stacks and Miniaturized Antennas

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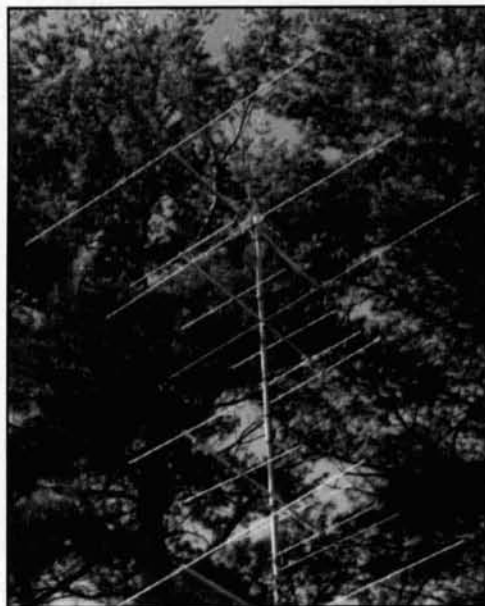
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On the Cover: Antenna segments like those at Cutler, Maine (NAA) dot this surrealistic landscape created by Bryan Bergeron, NU1N. To learn more about these enormous antennas, read "The Monster Antennas" by Bill Byron, W7DHD, beginning on page 5.

EDITORIAL

Jump!

In our search for technical excellence, those of us who are amateur radio experimenters have many times left behind tried and true techniques to embrace new ideas. Despite the fact that we felt both excited and intimidated by these new technologies, we knew we had to either jump and embrace the future or play it safe and stay put in the past.

In the decades of whirlwind technological advances that have made up the 20th century, the populace has experienced discoveries as diverse as the first transcontinental two-way radio transmission and satellite communication. Transportation has moved from the horse and buggy, to the automobile, to the space shuttle in fewer than 100 years. Ham radio experimenters' projects have evolved from creating crystal radios from oatmeal-box coils and galena crystals with cat's whiskers, to regenerative receivers, to solid-state transceivers. And what about our antennas? Simple wire types now compete with computer-optimized Yagis, satellite dishes, and fractals.

The next frontier

It's time to make another leap, because circuit construction is changing dramatically from the through-hole process with which we are all familiar to surface-mount techniques. Building with SMD (surface mount devices) gives a whole new meaning to the phrase "fat-fingered ham." Working with parts that are, in some cases, no bigger than a flea is something I never anticipated when I built my first project!

Of course, much of the surface mount manufacturing done today is automated—eliminating the need for a large force of board stuffers. It also means that parts can be very tiny. However, as more and more of the traditional components we build with are replaced by surface-mount devices, change on our part is inevitable.

One of the difficulties associated with getting up to speed and using surface-

mount technology involves procuring equipment. Surface-mount workstations run upwards from \$15,000—way beyond my budget! However, with a little ingenuity, you can assemble some readily available items that will help you get started. Our Senior Technical Editor Peter Bertini, K1ZJH, started with toothpicks and a magnifying glass, but you can put together a better setup if you check out "Quarterly Devices: Low-cost SMD Prototype Construction," elsewhere in this issue.

We've done it before . . .

Over the years, we've all made many adjustments in the pursuit of technical excellence in our hobby. Remember when we traded in our slide rules for computers? Boy, did we complain! But our computers have led us to such useful applications as antenna design and optimization, and CAD instead of hand drafting. Little by little, we've all grown accustomed to and familiar with technological advances. We just need to get on the learning curve and jump for the top. Surface-mount technology is only one area in which we will be called upon to stretch our minds and our abilities. Also in the wings are: digital FM, spread spectrum, new communications modes (G-Tor, Pactor, Clover, etc.), and high-speed data transfer. Adapting to these new technologies will be a challenge, but it's nothing we can't handle!

Sorry to see you go!

In life there are continual arrivals and departures. With this issue we say so long to two of our columnists: Peter O. Taylor (The Solar Spectrum) and Brad Thompson, AA1IP (Quarterly Computing). Both columnists have loyal followings and I know they will be missed. Thank you, gentlemen, for a job well done.

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A publication of

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76 North Broadway

Hicksville, NY 11801-USA

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Statement of Ownership, Management and Circulation
12-1-95. Communications Quarterly, 76 North Broadway, Hicksville, NY 11801.

Publication # 10539433. Issued four times a year, subscription price \$29.95 per year. Publisher: Richard A. Ross, Editor Terry Littlefield, owned by CQ Communications Inc. Stockholders: Richard A. Ross, Alan M. Dorthoffer, Thomas Krietele, Arthur S. Salsberg, Circulation (Average of 12 Preceding Months): Net Press Run 8,070. Sales Through Dealers and News Agents 1,761. Mail Subscriptions 4,002. Total Paid 5,763. Free Distribution 70. Total Distribution 5,833. Copies not Distributed 1,137. Returns from News Agents 1,100. Total 8,070. Circulation (Single Issue Nearest Filing): Net Press Run 9,200. Sales Through Dealers and News Agents 2,331. Mail Subscriptions 3,667. Total Paid 5,998. Free Distribution 70. Total Distribution 6,068. Copies not Distributed 1,147. Returns from News Agents 1,985. Total 9,200. s/ Simon Schatzmann Circulation Director

Second-class postage paid at Hicksville, NY and additional mailing offices.

Postmaster: Please send change of address to Communications Quarterly, CQ Communications, Inc., 76 N. Broadway, Hicksville, NY 11801. ISSN 1053-9344.

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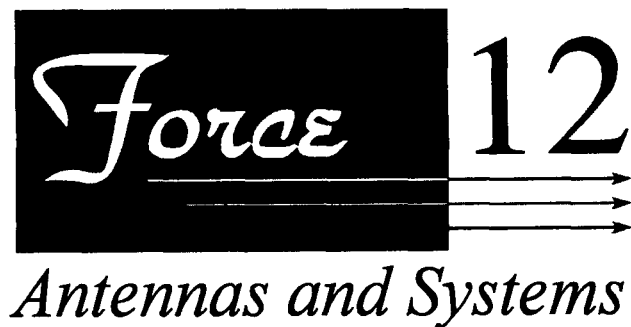
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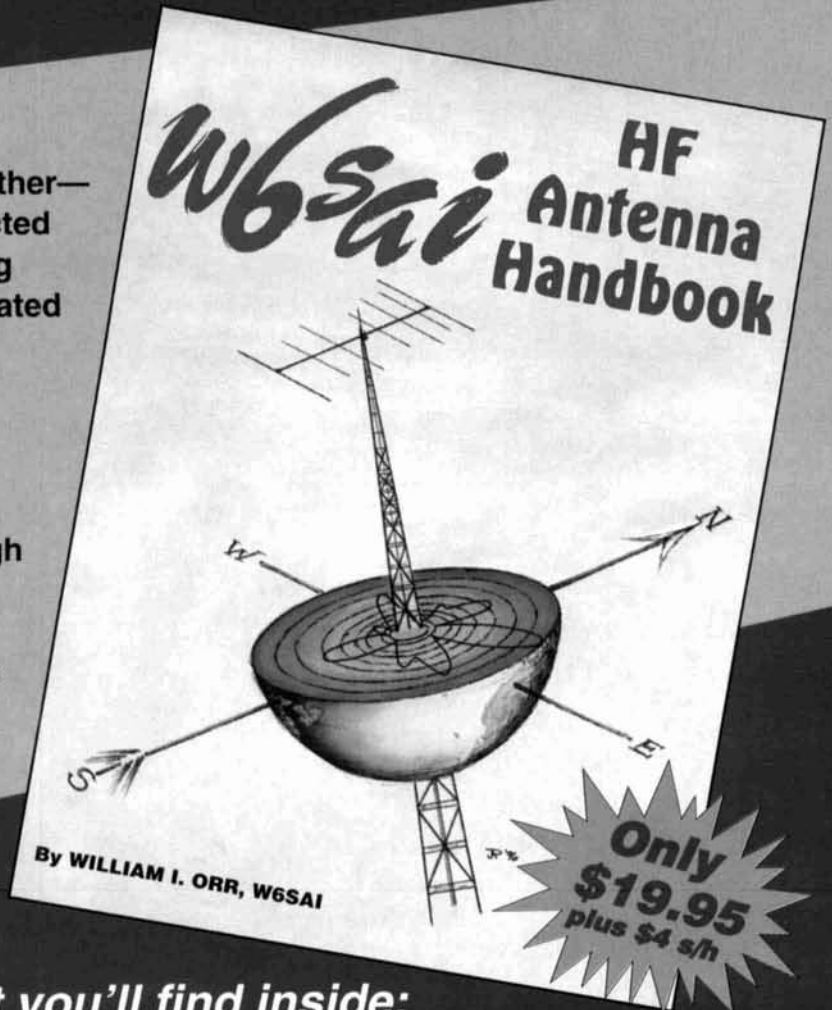
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THE MONSTER ANTENNAS

*Descendants of ancient systems are
alive and well*

To write of VLF (Very Low Frequency) radio transmitters and their auxiliary equipment, including antennas and tuning apparatus, is to recount much of the history of radio itself. There are nearly one hundred years of well-documented information available. Technical data concerning the *very early* VLF systems, however, are scarce.

Except for those living within sight of a VLF antenna, few are even aware of them.

Commercial traffic no longer uses the frequencies; the sole users are, around the world, the military (along with some governmental uses). This is probably the principal reason for the dearth of publications and data; many of the performance details were simply classified. There was a time, however, when these antennas were of great importance both to the public and to national governments. The capability of rapid communication with distant colonies, initially, and the later military applications intensified their popularity.

There were many commercial stations in existence. Marconi, de Forest, and many others were in the commercial radiotelegraph business—each in competition with the submarine cable companies.

Radio transmission had an advantage over *any* hard-wired system. The cables were routed to one terminal only, while radio signals went everywhere—which had its disadvantages (see POZ later). Three of the photos presented here attest to the importance of radio. One is of Goldschmidt and the Kaiser, and another includes Einstein, Steinmetz, de Forest, and Sarnoff (see **Photos A** and **B**). Each was taken in the milieu of a VLF transmitter; the techniques and apparatus were among the most important scientific and engineering activities of the day. **Photo C** was taken at Luchow's restaurant in New York at the Second Annual



Photo A. Goldschmidt and the Kaiser. Taken in about 1910 at Eilwese. Goldschmidt (back to camera) is talking to the Kaiser. Source: Walter Schulz, K3OQF.

Banquet of the IRE in 1914. Ferdinand Braun appears there along with Alexanderson, de Forest, Zenneck, Tesla, and several others of note. This was also one of the last photos of Braun. He died on April 20, 1918, having contracted pneumonia as one consequence of falling on the ice and suffering a broken hip—which never had healed.¹ (Both Zenneck and Braun were in New York as expert witness and litigant, respectively, in a patent infringement lawsuit involving Marconi.)¹

These transmitting activities were of importance to governments everywhere, because all



Photo B. Group photo at the New Brunswick Alexanderson Alternator Station, ca. 1920. Notice both Einstein and Steinmetz in the center. Also included are de Forest and Alfred Goldsmith. Source: Walter Schulz, K3OQF.

of the active participants were busy consolidating, protecting, or expanding colonial or commercial empires. Radio was pre-eminent in communicating with them.

Germany, under the influence of Bismarck, had invaded France in 1870, had occupied significant parts of the country, and had staged a victory march down the Champs Elysees in Paris (it would happen again in 1940—but with drastically different results). By the time the photo of the Kaiser was taken, however, Bismarck had been removed from any position of influence (he died in 1898, but the Kaiser had bypassed him earlier), and Wilhelm II was totally in charge. Germany was busy both militarily and diplomatically creating trouble for France in North Africa, and for England in South Africa. France, England, and the Netherlands were trying to protect their empires; Germany was trying to expand hers.

All of the principal participants in Europe had developed great industrial capabilities. Germany was the most highly industrialized country at the time, and large industrial entities—like the Krupp works—were being used as tools to promote national interests. They were being geared up also for the fiasco of World War I.

The United States was also heavily industrialized. The Alexanderson Alternators, for example, were products of a single very large corporation: General Electric. There was enough capability within GE to perform the research and development—and without outside help—to develop and manufacture the alternators, including all the electrical and mechanical aspects.² It was fortunate that there were very experienced engineers and metallurgists in the Turbine Division. Their influence in the rotor-and-case design is obvious. It is also fortunate that Ernst Alexanderson was at the right place at the right time, with the necessary

understanding and drive that enabled him to spearhead the entire effort. It was fortunate again that Steinmetz was within easy reach. Fessenden instigated the first foray into electro-mechanical alternators, and Steinmetz was involved from the very beginning.

The U.S. also had a sort of “colonial empire.” We were administering to the Philippines as well as to several other territories acquired after the Spanish-American War, which started in Cuba, and we sent Teddy Roosevelt’s “Great White Fleet” around the world. Even *we* were indulging in “muscle-flexing.”

Such distinguished authors as Dr. James Brittain,² Dr. Hugh Aitken,³ Dr. Jonathan Zenneck,⁴ Arthur Watt,⁵ Friedrich Kurylo,¹ and Thorn Mayes⁶ have provided ample information on this subject. The development of VLF antennas has been continuous since the turn of the century, and is probably the *only* radio-related activity that is exactly contemporary throughout its life with the field of radio engineering in general.

Why VLF?

VLF defines a range of frequencies between 3 and 30 kHz. Although the original experiments of Heinrich Hertz produced radio waves in the VHF/UHF regions, subsequent spark transmitters used the VLF part of the spectrum.⁷ The principal reason is that it was impossible to achieve the necessary power for long-distance communications at higher frequencies, even though nobody knew anything about high-frequency propagation then. The capacitor C_1 (see **Figure 1**) always was in series with the primary inductance. It also contained the initial charge at each pulse. Therefore, the total power input to any spark transmitter depended on the value of the capac-

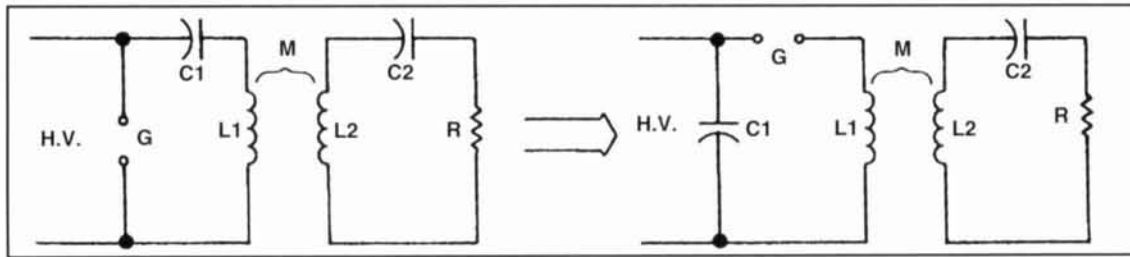


Figure 1. The Braun Circuit—the most successful spark circuit. Developed and patented by Ferdinand Braun, it was used by Marconi in all of his high-power units. (They peaked at 350 kW.) Source: “Arcs and Sparks: Part 1,” by W.J. Byron, W7DHD, *Communications Quarterly*, Spring 1994.

itance C_1 and its charge voltage. The frequency, however, was determined by both C_1 and L_1 . It simply was impossible to produce high-power simultaneously with high frequency. If both C_1 and L_1 were to be reduced in value to raise the frequency, C_1 would be limited to a smaller charge—and thus to a lower power input. The large spark transmitters operated at over 300 kW, but at wavelengths of approximately 10,000 meters. A primary capacitance (the “ C_1 ” noted above) of up to 1.5 microfarads was more-or-less common.

The situation with arc transmitters was completely different, although the net result was the same.⁸ Both high power and high frequency could not be achieved simultaneously. Arc transmitters couldn’t operate at high frequency, no matter what the power level. Arc transmitters operated via relatively low-voltage, high-current DC supplies. The arc discharge (which is a plasma) exhibited a “negative resistance” characteristic; it provided the positive feedback necessary to initiate and to maintain oscillation. Furthermore—and this is crucial—the arc must be extinguished during a few degrees of every radio-frequency cycle. A transverse magnetic field was required to sweep residual ions out of the gap prior to the cyclic re-establishment of the arc. It simply wasn’t possible to achieve at frequencies above a few hundred kHz. Both technologies were thus limited, for very different reasons, to VLF.

Mechanical alternators suffered the same disability. There were several in use from about 1910 to 1920, and the Alexandersons were operating through the ’40s. There were other transmitters, too; the Arco-Joly system was one that relied on the production of harmonics in saturated iron transformer cores, the harmonics being siphoned off as the transmitter output. The Goldschmidt alternator used somewhat similar principles in a rotary machine.⁴ **Photo A** is of historical interest because it shows Goldschmidt (back to the camera) talking to the Kaiser (center) and two aides. This was taken at Eilwese, in about 1910.

Reginald Fessenden obtained the original



Photo C. The second Annual IRE Banquet at Luchow’s restaurant in New York. Most of the very influential people are in the photo (except Marconi). Taken in 1914, it may be one of the last photographs ever taken of Braun, standing, second from the left. Luchow’s was a German restaurant, and all the waiters spoke German, as well as English. Zenneck stands fourth from the left. Source: Photo No. 52,269 from The Smithsonian Institution.

patent on the variable-reluctance alternator concept. He then commissioned General Electric to develop the first one, which produced a few kilowatts at 10 kHz. The later well-known high-powered Alexanderson alternators were results of Alexanderson’s and GE’s intense effort. Rotor construction, as can be imagined, was particularly difficult. The rotors were of high-tensile steel, and they were required to survive at shaft speeds of 20,000 rpm in the smaller-sized units, though the 100-kW Alexandersons (with three-foot-diameter rotors) rotated at about 3,000 rpm. The centrifugal force in all of them was tens of thousands of g’s. All transmitters were restricted to VLF, from the most rudimentary spark systems to the electromechanical marvels of the alternators.

Few of the ionospheric characteristics of VLF were known at that time. The propagation of atmospheric disturbances, however, was well-known and remains a problem to this day—as “part of the turf.” There are approximately 44,000 thunderstorms and eight million lightning strokes daily around the world, and the average total power in a large thunderstorm

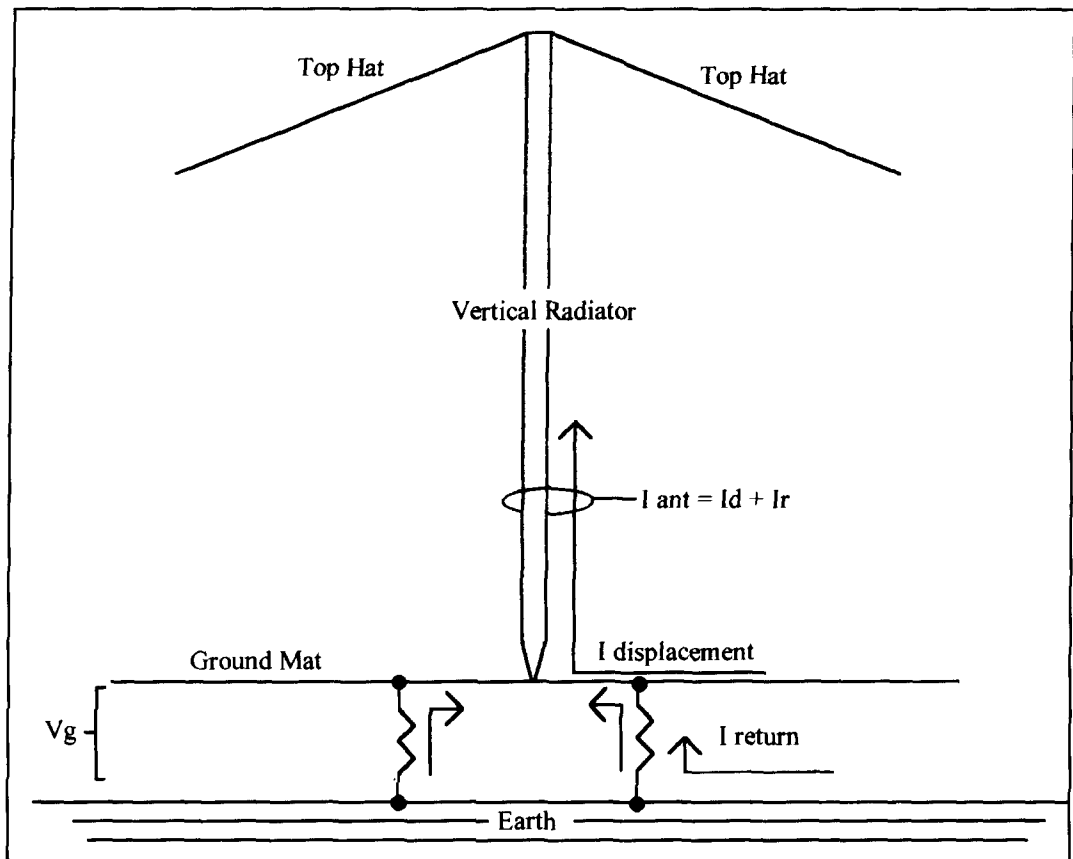


Figure 2. Simplified diagram showing the sources of “displacement” and “return” current. They combine at the base of the antenna and become the total antenna current.

reaches several hundred megawatts. Lightning, of course, dissipates only part of that energy, though a potential difference of several hundred million volts is required to initiate the discharges, averaging about 10,000 amps per stroke.⁹ Zenneck, however, did discuss the day-night behavior of VLF. He published information on this behavior in 1915, though it certainly must have appeared in earlier editions of his book (ca. 1908). It was fortunate that the *only* wavelengths usable were also the ones, which at that time and with the then-current equipment, would enable worldwide day-and-night radio communication. The age of short waves would be three decades into the future, and *it* would depend upon the development of high-power thermionic transmitting tubes and better receivers. The only things that didn’t change much at all, fundamentally, were the *VLF antennas*. They improved over the decades in efficiency, but *nothing could be done to reduce their size*. They actually have grown even larger.

Some VLF antenna characteristics

We have been constructing horizontally polarized antennas for at least three-quarters of a cen-

tury. Some hams have built half-wave doublets for 160 meters, the center heights of which occasionally reached 100 feet or more. Those are rare, of course; the usually more effective *vertical* antennas generally were—and are—more successful than horizontally polarized radiators at that wavelength, though the resultant high-angle radiation associated with low dipoles is beneficial for local contacts. The main problem is that it’s difficult to elevate a 160-meter doublet to sufficient height to be effective. Vertical Marconi antennas do require good ground systems, however, and they (good grounds) are *almost always short-changed by hams*. The 160-meter amateur band is the only one that’s in the MF part of the spectrum (300 to 3,000 kHz), and it is on the threshold of necessity for constructing *vertical* radiating systems. Note that all standard broadcast antennas are vertical, even though most of them probably aren’t Marconis. Standard broadcast stations exist under conditions that require minimum sky-wave propagation, and that alone requires designs which transmit predominantly low-angle radiation. Many of them are just over a half-wave tall (the “5/8-wave” versions), but still vertical.

All VLF antennas are vertically polarized. It’s difficult for some to realize, while observ-

ing an “inverted-L” one mile in length and 600 feet above the ground, that it really is a version of a vertical antenna—but vertical it is; the *only effective radiation originates in the vertical part of the system* (the “downloads”). Is there anything “magic” about the use of verticals for VLF? No; it’s simply the *only practical method that enables one to get most of the generated power “out of the back yard.”* A half-wave doublet for 20,000 meters elevated to a half-wave would be six miles long, at an elevation of 30,000 feet!

A small fleet of very large aircraft (747s) are used by the U.S. and NATO military as flying command posts. Each is capable of trailing a *five-mile-long wire for VLF communication.* They normally fly a fixed orbital pattern at an altitude in excess of 30,000 feet. The antenna they drag is a modern version (in principle, the configuration was different) of the “Zepp” antenna. Zepps hung straight down from dirigibles (or Zeppelins, hence the name) for hundreds of feet.⁴

Photo B is historic its technical content. It reveals the anchor points of the downloads for the large inverted-L in use at New Brunswick. Note the insulators and the corona rings. It is certain that the transmitter was *not* being keyed

at the time of the photo! Both **Photos A and B** contain equipment and principals that were *very important.* The transmitter behind the group in the photo was the very one that transmitted President Wilson’s *Fourteen Points* to the German government, and the Kaiser’s abdication was demanded in one of the paragraphs. The receiving station was POZ. **Photo C** includes two prominent German consultants to Telefunken, the designers and constructors of POZ and other stations. They are Ferdinand Braun and Jonathan Zenneck.

Marconi took advantage of some marginal directional properties of his inverted Ls—about 2 dB off the “back” of the L. We know today that it occurred because of deficiencies in the ground system. None of the texts in the ‘teens promoted very good ground systems as the way to high radiation efficiency. Even so, attempts were made to reduce ground loss, which manifested itself in its worst cases by starting brushfires around ground rods. These fires were the result of the high concentration of return-current in lossy soil. Ernst Alexanderson effectively solved most of the problem with his “multiple tuned antenna” system.²

The concept of “radiation resistance” was barely beginning to be recognized. Even though

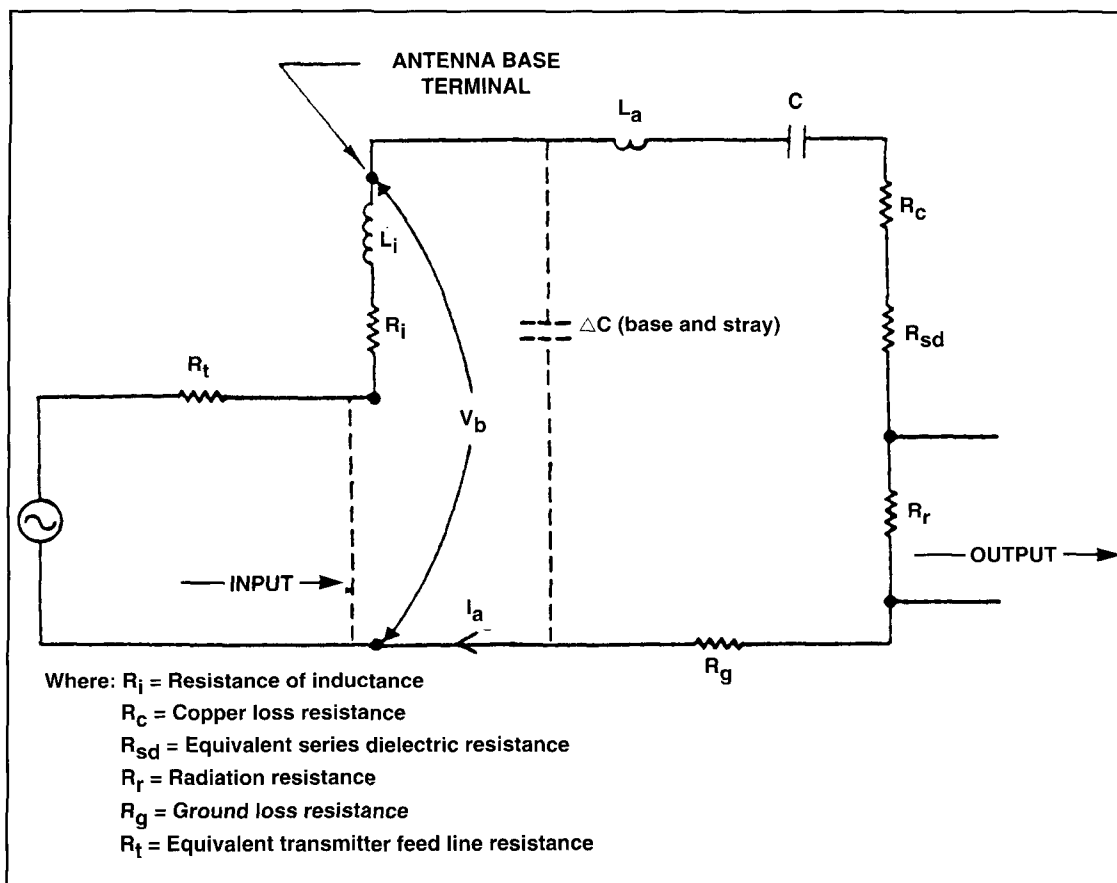


Figure 3. The schematic defining the parameters in the efficiency computation in Equation 1 from VLF Radio Engineering, by Watt, et al.

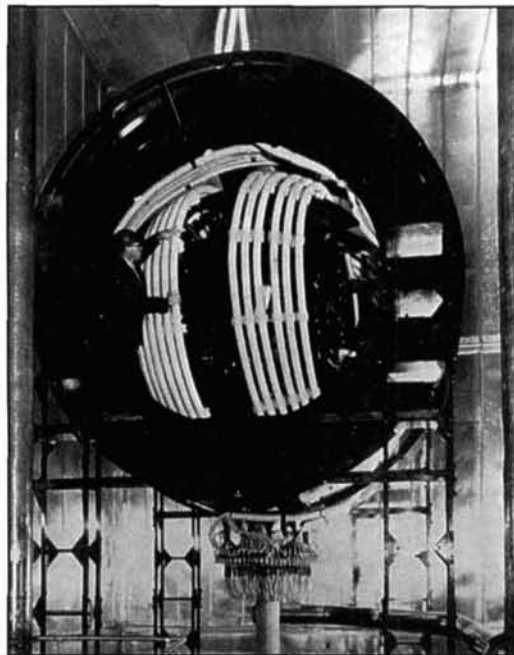


Photo D. One of the antenna tuning variometers at NAA (Cutler, Maine). Those are large litz cables. The power handled by the coils is 2 MW. Source: Continental Electronics.

some VLF antennas are 1,000 feet high, that height seldom represents more than a few degrees of wavelength, and their radiation resistances are seldom ever higher than an ohm—usually much less. We're talking about *radiation resistance* here, not feedpoint resistance. They all are much shorter than the desired quarter-wave, and are versions of a "Marconi," that is, they are base-fed at a current loop as a series-resonant circuit. Incidentally, this definition of a "Marconi" is not shared by all—but I state it here to define what's meant by the term in this paper.

Considerable series inductance is required for resonance, even when the top-hats (or L-lengths) have intrinsic capacitances of a good fraction of a microfarad. Raised counterpoises usually are impractical; therefore, the return path for the antenna current is a combination of displacement current in the electrically short *ground mat* and the *return-current* in the earth around the antenna (see **Figure 2**). It means that the efficiencies of VLF antennas are functions of both ground-return resistance and the resistance of the antenna-loading coils. Every effort has been expended to make those resistances as small as possible, considering both economics and engineering. With the reduction of total circuit resistances (they usually are many times higher than the radiation resistance), the inductance of the loading coils in all modern systems produces *very* restricted bandwidth. The much higher feedpoint impedance of the older antennas resulted in lower Qs, and

it enabled some of the very first voice-and-music transmissions. Nevertheless, some very early *single sideband* experiments were accomplished using the *antennas* as filter elements. As a result, we can conclude that the bandwidth of some 'twenties vintage antennas was sufficient to pass one sideband, but not wide enough to pass both. It's probable that the early SSB experiments were conducted in the early 'twenties (probably by Western Electric)—and thus there were at least a decade's worth of antenna improvements over those of the turn-of-the-century. Those very improvements, principally in the improvement of the ratio of radiation resistance to total system resistance, in subsequent antennas would render even *this* capability impossible. Wide bandpass and high efficiency are mutually exclusive in VLF electrically short vertical antennas.

VLF loading coils

The efficiency of any vertical Marconi system can be calculated by using the expression (refer to **Figure 3**):

$$\text{Efficiency} = \frac{R_r}{R_r + R_c + R_g + R_i + R_{sd} + R_f} \quad (1)$$

Where:

- R_r = Radiation resistance
 - R_i = Coil resistance,
 - R_g = Ground loss resistance,
 - R_c = Copper loss resistance,
 - R_{sd} = Equivalent series dielectric resistance,
- and
- R_f = Equivalent transmitter feedline resistance,

all in ohms.

It's obvious that 100 percent efficiency can occur only when the ground and circuit resistances reach zero. However, this hasn't been accomplished yet and isn't likely to occur in the near future. Cryogenic coils could exhibit even lower resistance, but the grounds have reached the point of diminished returns. The most modern systems exhibit efficiencies of between 30 and 60 percent at the low end (14 kHz) to 75 to 98 percent at the high end (30 kHz). That, in itself, is quite an accomplishment, considering that the *radiation resistances* of VLF antennas are less than 1 ohm (sometimes *much* lower) at the low end of the band.

The reduction of ground resistance is cumbersome and expensive, and will be discussed later. High coil resistances have been worrisome since the very beginning. However, loading coils with Qs of between 5,000 and 10,000 (or more) have been available since shortly

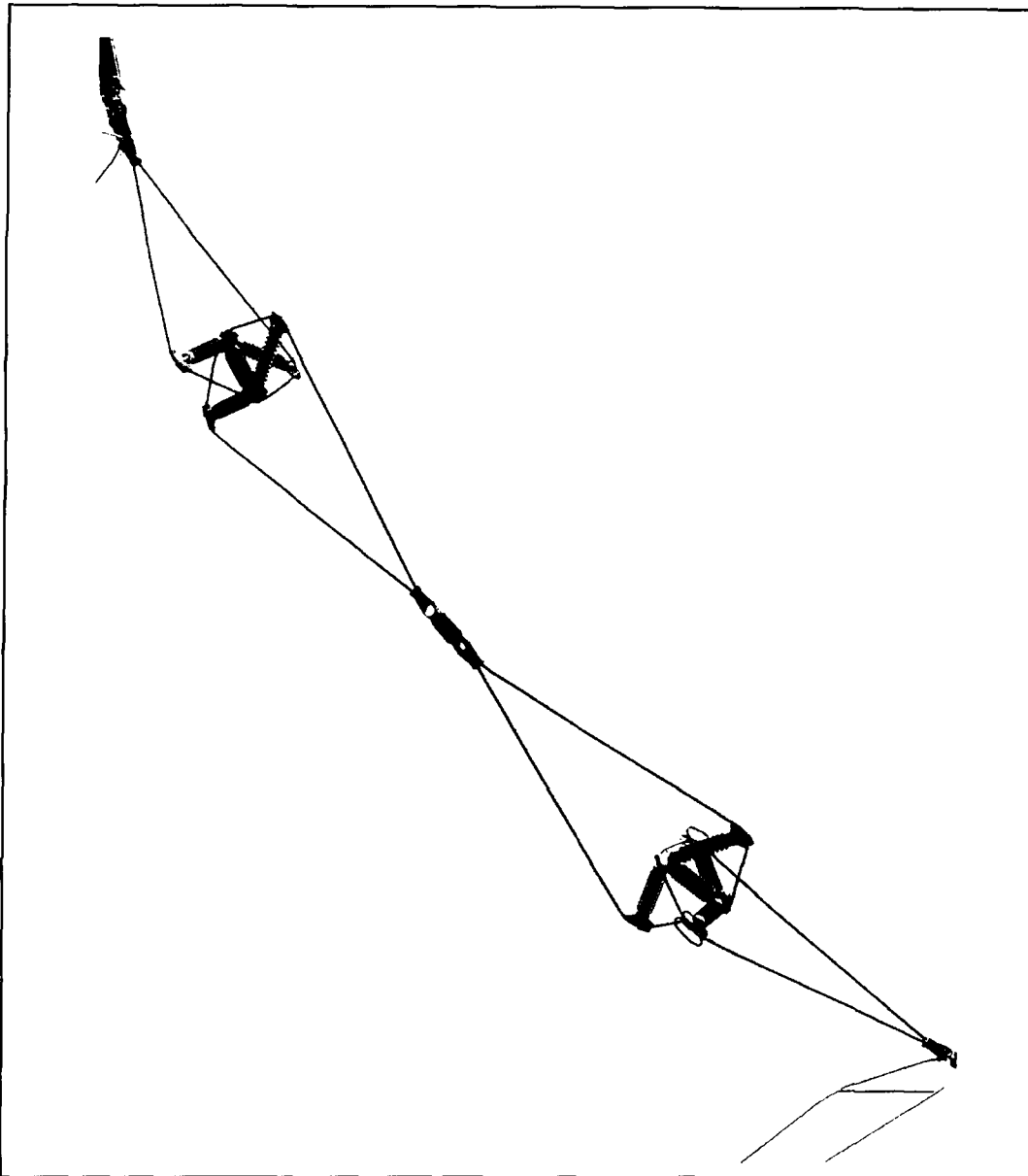


Figure 4. Modern Continental Electronics Strain insulators. This type is not only lighter, it is much stronger. If any or all of the ceramic elements break, the guy is still operative. Two insulators shown, end-to-end. Each weighs 860 lbs. Source: Continental Electronics via Bob Nash.

after the turn of the century. Such numbers are accomplished by the use of “litz” wire (Litzendraht, or “stranded wire”). **Photo D** shows one of the tuning variometers at NAA at Cutler, Maine (one of three in parallel). The conductors are 3.5-inch diameter litz cables.

Litz cable construction

The radio-frequency current flowing in a solid conductor arranges itself—by virtue of the magnetic field it produces—so most of the electron flow is on the outside of the conductor.¹⁰ Its current density decreases expo-

nentially as it approaches the center. In large conductors (relative to the depth of penetration) the current in the center approaches zero. This quantity is known as the “skin-depth,” and is defined as the depth at which the current is $1/e$ of that on the surface. It is not limited to copper wire; the same effect occurs in other conductors and in the earth vis-a-vis induced currents from incident electric fields. It influences ground loss greatly.

The “litz” philosophy of is simple: Force the total current to flow in many parallel insulated fine wires—wires that are sized to be equal to, or slightly smaller in diameter than the copper-wire skin-depth at the frequency in use—and

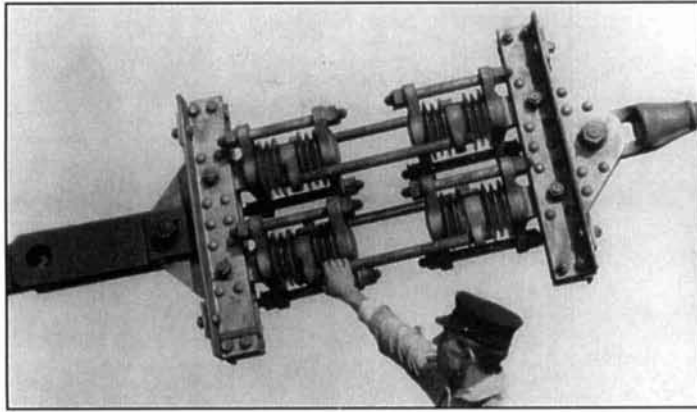


Photo E. Strain insulator, 'twenties style. This gives an idea of their size.
Source: Dr. James E. Brittain.

arrange their spatial positions so each wire is exposed to the same magnetic flux within the cable. Litz can be purchased in several gauges and configurations. The exact composition of a particular cable is determined by engineering considerations, the most important one being the operating frequency.

Litz cables usually look "lumpy" or rope-like in old photos. This is because they *are* rope-like. Design engineers are familiar with "hexagonal close-packed" geometry, which can be symbolized simply by placing seven identical coins on a flat surface so each is in contact with each of its near neighbors, producing a symmetrical arrangement around the center coin. A typical strand of litz may contain as many as 50 very small, insulated wires, with a woven insulation wrapped around the strand. If seven strands are twisted together, the cross-section will resemble the pattern of the seven coins described above. Then seven of these can be twisted similarly to produce an even larger bundle. So far, the construction would allow each individual wire to occupy nearly every radial location in the bundle, when observed over its entire length. This technique is continued up to a bundle-diameter of perhaps three-quarters of an inch. By this time there are wires in the center of the bundle which don't "see" the same magnetic flux, and therefore don't carry the same radio-frequency current. A hemp-center rope is substituted as the cable diameter is increased. Therefore, *any* litz cable larger than three-quarters of an inch typically has a nonconducting core.

Marconi used very large litz cables in the construction of the primary coils for his high-power (>200 to 300 kW) spark transmitters. They were fully 12 inches in diameter to handle the 10,000-amp first-cycle discharge current of the primary circuit (the very circuit that resulted in the patent infringement suit mentioned

earlier). No doubt the coils weren't totally filled with wire for the reason just stated.⁶

VLF propagation

The behavior of VLF waves has been studied and theorized for decades, starting very early with Zenneck and Sommerfeld, circa 1907-8. The present concept assumes that the waves are guided waveguide style between the earth and the ionosphere. There are problems with all of the methods. First off, neither boundary of the "waveguide" is constant in dimensions, nor is it perfectly reflecting. The ionosphere changes height from winter to summer, from day-to-day, and even from hour-to-hour. Add to that the frequency range of VLF transmissions, which spans more than an octave. Thus the modes within that waveguide change, too. Now make the waveguide into concentric spheres, and allow the excitation to expand in two dimensions (plane earth model) or in three dimensions (spherical earth model). These present extremely complicated analytical problems.

The waveguide model is the accepted mode. Most of the behavior can be explained by one or more of the several analytical models; and it is common to use part of one approach up to a point, then use another in order to refine the concept.⁵ Neither the ionosphere nor the earth (most of which is saltwater) is a perfectly reflecting surface. The earth penetration—assumed to be some tens of meters—results in absorption that in turn yields an average conductivity. The earth-side of the waveguide is considered as a sharp boundary, but with that average conductivity. The ionosphere is likewise treated as if it had a reference height with its own reflection and absorption coefficients at its boundary.

Some facts about Marconi VLF structures

It has been emphasized that VLF antennas are *short*. This fact becomes more obvious when one considers a wavelength of 20,000 meters. An equivalent antenna for, say, 40 meters, would be 19 inches tall and 3.8 feet wide—representing a VLF umbrella 1,000 feet in diameter. It is compounded by the fact that a 3000-foot diameter circular ground mat to the same scale would be only ten feet in diameter. To demand high performance from a 40-meter setup of those dimensions would constitute near-masochism. Furthermore, the antenna's power-handling capability would be severely restricted, it being both current and voltage-limited. One of the advantages in operating VLF antennas (among many disadvantages) is

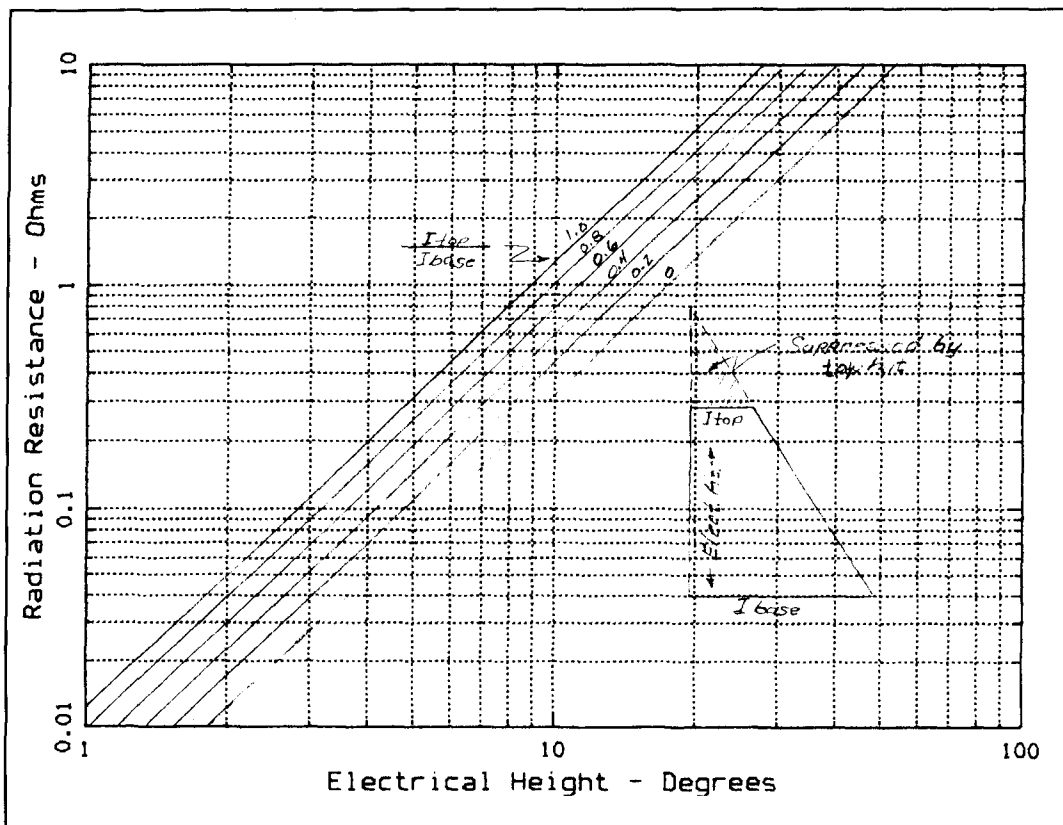


Figure 5. Curves for estimating radiation resistance of short Marconi antennas. Source: *Radio Antenna Engineering*, E.A. Laport, McGraw-Hill, 1951.

their capability for accommodating *very* high power levels. The 40-meter arrangement discussed above would run into voltage limitation *very* quickly. Imagine trying to excite it even at 1 kW—much less at 1 or 2 MW.

That is the “playing field” forced on VLF system designers. There are also many other factors. It’s already clear that it would be impossible to erect a totally top-loaded vertical antenna for those frequencies. What is *not* so clear, however, is that it’s equally impossible to employ total base-loading. The reason is that the voltage buildup across the base-loading coil very likely would exceed the ratings of the insulators, and even exceed the corona threshold of the antenna wires, themselves. The large antennas are near voltage-limitation, even when they have rather large top-hats. All VLF antennas are designed for a combination of base-and top-loading. Not only must the insulators in modern systems hold off 250,000 volts, they must withstand as much as 300,000 pounds of tension. Strain insulators are required in the guy lines for single-mast supports. Sometimes there’s only one central support, while some have up to a dozen or more peripheral masts to support the edge of the top-hat—each requiring multiple guys. The voltages induced in the guys require insulation; several insulators are spaced

uniformly along the length of each of them. They must withstand the tension, but need not have the same voltage stand-off capabilities of the “end” insulators. **Photo E** and **Figure 4** are of typical strain insulators, showing their construction. Notice that *all* of the internal ceramic insulators are under compression, though the overall insulators are under tension. Failure-to-safety design is obvious in both types. The guy anchor-points are massive, indeed, as can be seen in **Photo F** (a ‘twenties anchor). Modern fail-safe strain insulators are available in many sizes and can weigh as much as a ton.

Normal catenary forces are already large, and the insulators must handle additionally as much as two inches of ice on the wires. Elaborate counterbalances and winches must be used in the most extreme cases. Some can be lowered completely to the ground. That might be required in Maine, but not necessarily in Hawaii, where loads are more likely to be caused by the winds associated with large storms.

All VLF systems located in temperate-to-arctic-latitudes have the means to heat the antenna wires during icing conditions. Ordinary, alternating current is used—either from the local utility, or most likely from the station’s own integral power generating system. The technique dates from the very earliest days. It was



Photo F. Massive early Guy Anchor ("dead man"). This one is anchoring four guys. "Twenties vintage. Source: Dr. James E. Brittain.

used in New Brunswick, Radio Central (Rocky Point, L.I.), Marion, Massachusetts, and in almost all of the others of the day. Some modern top-loading systems exhibit a six-fold radial symmetry, which simplifies the direct use of three-phase power. That, in itself, is interesting in that the heating loads on the power system

are at least *twice* the maximum normal station power loads; 4 MW are necessary at a 2.5 MW transmitter site (NAA is one). This is similar to aircraft carriers, where the steam-side of the propulsion system is sized for flank speed *plus* the load presented by the aircraft launching apparatus—the latter being substantial. In the conventional (oil-fired) carriers of World War II, it amounted to about half of the total boiler output. Modern nuclear-powered carriers would hardly notice the increase. (Try calculating the power necessary to accelerate a 70,000 pound aircraft from zero to 150 mph in two seconds, and do it every 15 seconds—from two catapults, of course.)

A base-loading coil for an antenna that possesses 0.03 μF capacity in a top-hat would require about 1.8 mH inductance for resonance on 20,000 meters (the characteristics of the vertical part are inconsequential in this case). The buildup of voltage with an antenna current of 1,000 amps (typical) would be about 125,000 volts—and that's *rms*. Large modern systems produce antenna currents between 500 and 3,000 amps, and the voltages are therefore much higher than they were in 1920.

Photo G displays what happened during a rain-induced flashover at New Brunswick. The hand-written notes on the photo tell the date (6/4/22) and the operating voltage (116,000 volts). Several surviving former operators remember and relate some of the difficulties experienced during operation and servicing the equipment. They tell of having to jump off the running-boards of the then-current automobiles, to avoid being "bitten" as the result of the large potential gradients between the top-hat and the

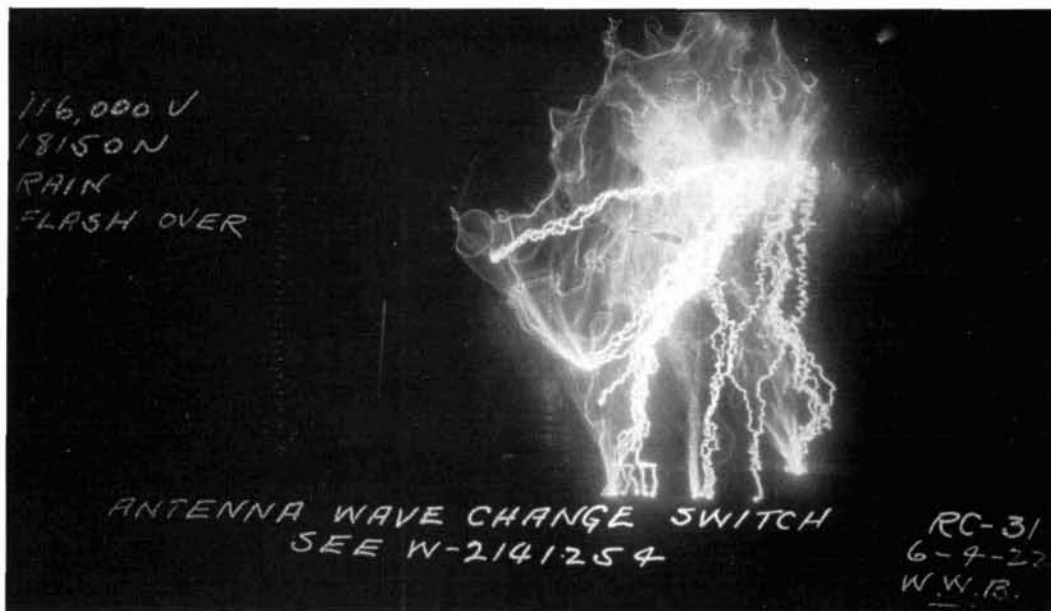


Photo G. Rain-induced RF flashover at New Brunswick. The voltage on the antenna was 116,000 volts. That "ball of fire" is about 10 to 15 feet high. Source: Dr. James E. Britain.

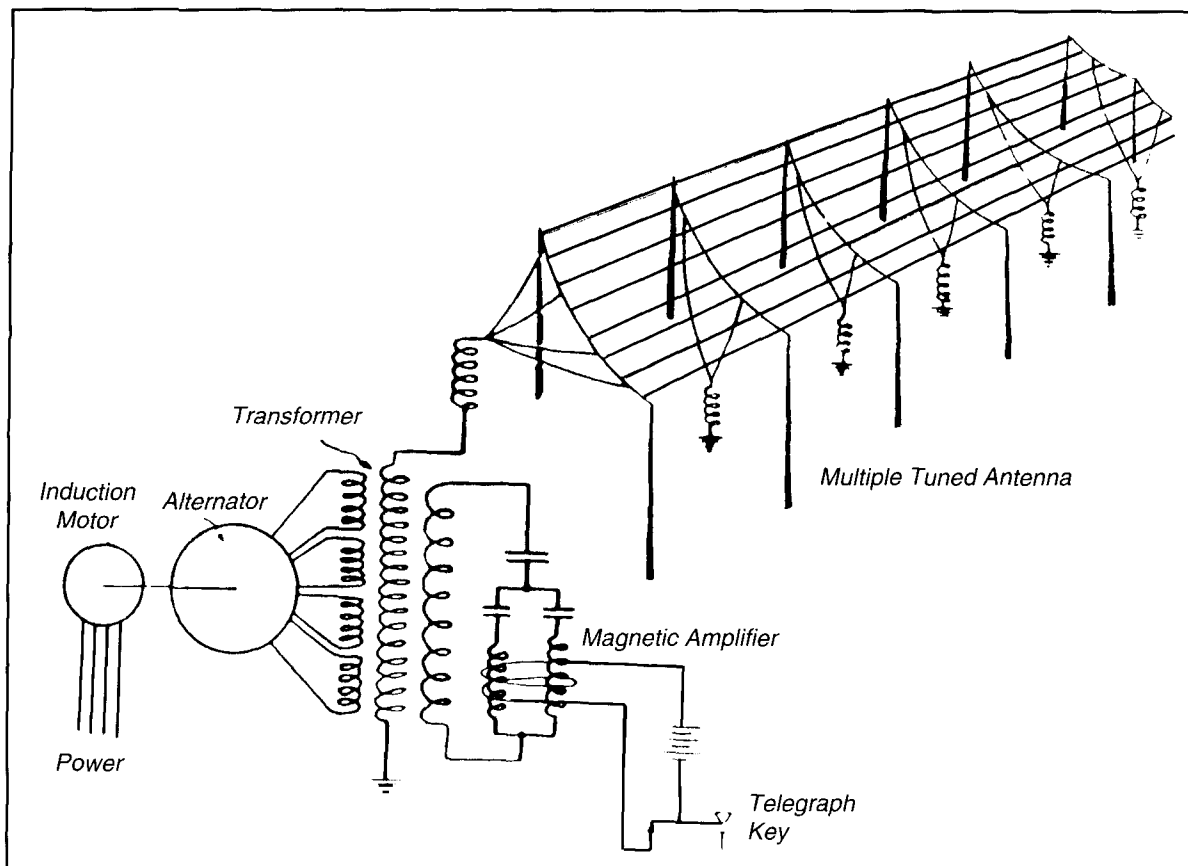


Figure 6. Alexanderson Multi-tuned Antenna in use at New Brunswick, and elsewhere. Source: Thorn Mayes, *Wireless Communication in the United States*, The New England Wireless and Steam Museum.

ground. Similar stories are told about “drawing sparks” off some structures inside the transmitter building, too. A rough estimate would be, for a top-hat potential of 100,000 volts at a height of 500 feet, a gradient of 200 volts per foot. That gradient exists in “free space,” but the capacitance of an auto (semi-insulated from the ground by the tires) and the fact that the voltage is at radio frequencies, would exaggerate the effect. That’s the origin of the statement that the New Brunswick transmitter wasn’t working during the group photo. There, the gradient would be about *10,000 volts per foot!*

These designs require a careful balance of size, cost, and efficiency. The radiation resistances, as mentioned before, are really at the heart of the matter. The lower the radiation resistance, the more influential become the losses in both ground systems (expensive) and loading coils (not so expensive). Yet they still don’t exceed all of the other parameters, including the voltage stand-off capability of the structures. **Photo H** shows the largest antenna in the world in 1920. It was built by the U.S. near Bordeaux for the French government at the end of World War I.^{6,8} Its callsign was LY, and it was known as the “Lafayette” station.

The transmitters were two 1,000 kW arc converters built by Federal Telegraph Company. The support towers were each 820 feet tall; the tallest structures in the world after the Eiffel Tower. They supported the enormous top-hat, which was 1,250 feet wide by 3,937 feet long. The steel towers were triangular in cross-section (the “triatrics”) and were self-supporting. Triatics were installed at many U.S.-administered or U.S.-constructed transmitter sites, mostly at Navy installations. The Navy served as the general contractor in the construction of LY.

The Federal Telegraph Company built the arc converters and designed the entire station. That effort was spearheaded by Leonard Fuller, who was the chief engineer at Federal after Cyril Elwell resigned in about 1912. Fuller was the one who developed arc converters to the megawatt level.

Four sets of magnet castings were built to fulfill a contract with the U.S. government. Four converters were to be installed in two locations: two at Bordeaux (actually Croix d’Hins, nearby) and two in Georgia. They were conceived to provide communication with the American Expeditionary Forces in France during World War I. It became obvious that the

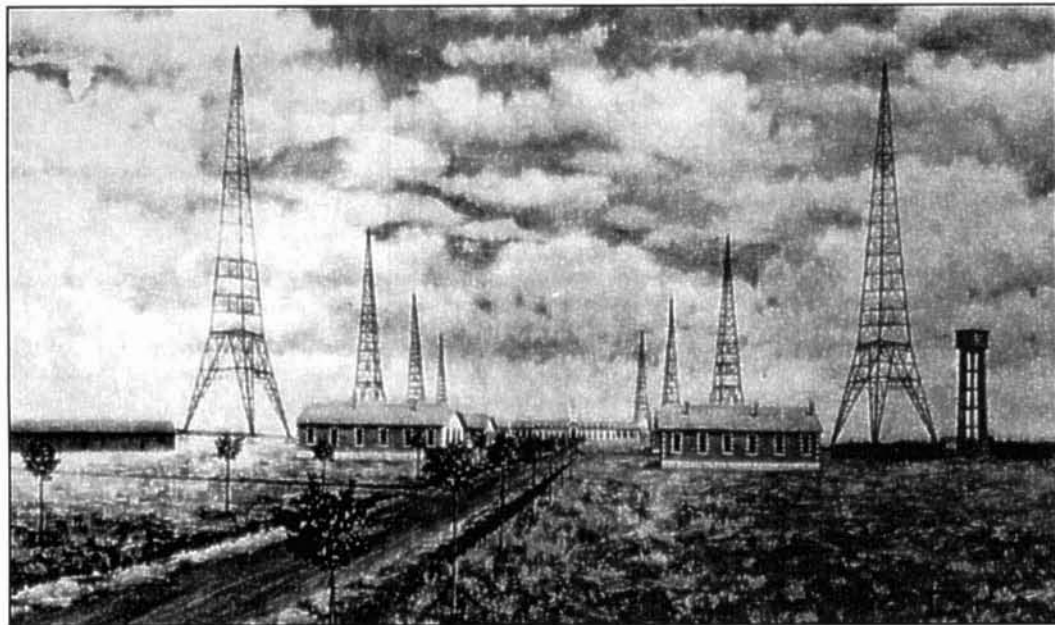


Photo H. The Bordeaux transmitting antenna, 1920. The station operated up to the late '30s. Originally fed by two one-megawatt arc converters. Source: Thorn Mayes.

war would end soon, and the contract was canceled. The French were anxious to have the station, and contracted Federal and the U.S. Navy to finish the French installation—which they did. It went on-line in December, 1920, after having transmitted usable signals to a distance of 12,000 miles. One more fact regarding arc converters must be emphasized: The “carrier” *cannot* be cut off. Therefore, the mode of transmission was an early form (possibly the earliest) of FSK. That meant the receivers were of the heterodyne type. These receivers were very primitive when compared to those of today—and that indicates that the transmitter and antenna systems were very good.

Radiation resistance

The definition of radiation resistance is that value, which when an antenna current is passed through it, will produce the radio frequency field (and power radiated) commensurate with that current. Another description is, “that part of the total loss resistance which arises from loss of energy through radiation.” It is a different number from the *input terminal* resistance, though the latter includes the radiation resistance as well as those of all other dissipative elements in the circuit. It can be demonstrated that the radiation resistance of a totally top-loaded short vertical Marconi will have four times the radiation resistance of one of the same height, but base-loaded. It’s common, at least for the practicing engineer, to assume that the current profile on the vertical element can

be approximated closely by a trapezoid. This is so because if one takes a very small “slice” out of a quarter-cosine (the full-size profile current shape of a quarter-wave vertical) the curvature is barely noticeable. An antenna fully 800 feet tall represents only 4.36 degrees at 20,000 meters. *All* single-mast current profiles can be approximated by trapezoids, with only two exceptions: the total base-loaded case, in which the profile is a triangle, and the total top-loaded case, where the shape is rectangular. We have seen that the two extremes are practical impossibilities in VLF antennas. If one knows the magnitudes of the current flowing into the bottom and out of the top, he can use the curves which appear in **Figure 5**. Therefore, the actual exposed profile is of a small slice near the center of the quarter-wave cosine—somewhere between, say, 30 and 60 degrees. It’s interesting that the radiation resistance of a Marconi antenna becomes essentially a function of the *shape* of its current profile.

Despite the simplicity of **Figure 5**, the precise calculation of radiation resistances of VLF antennas is very difficult because they usually aren’t simple base or top-loaded single mast systems. It usually is done from the other direction. Measuring posts are established at precisely known positions, enabling accurate measurements of the field strengths at various frequencies. Antenna system resistances are measured at the tuning house. Fixed resistances and reactances, as well as the power and system currents, are known. It’s also known what field intensity to expect for any given radiated power, and these factors are all considered in

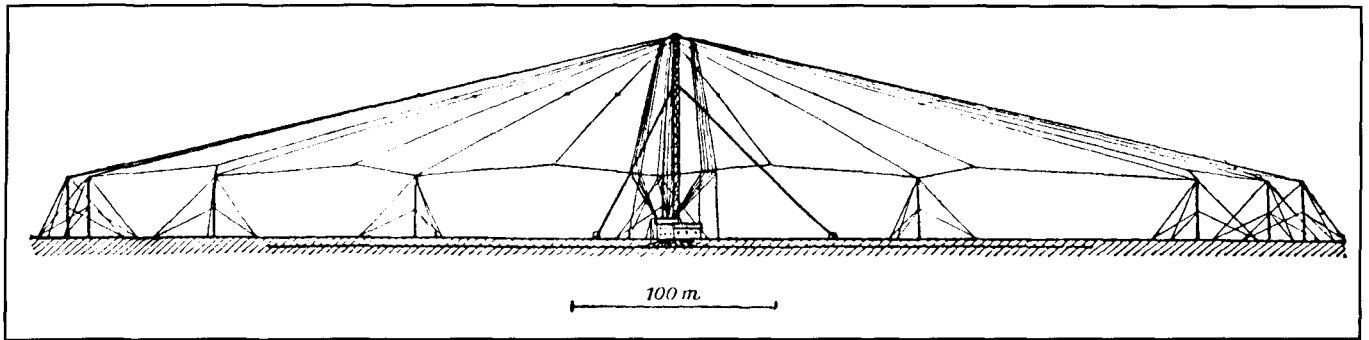


Figure 7. Profile view of the POZ antenna before 1912. Source: *Wireless Telegraphy*, Jonathan Ze-neck, McGraw-Hill, 1915.

determining the radiation resistances of these rather complex antennas.

Grounds and antenna current return paths

If a vertical antenna is constructed so it operates with a raised horizontal counterpoise, far away from earth influences, the antenna current oscillates up-and-down between the radiating element and the counterpoise—which in this case should be resonant. This type of oscillating current is called *displacement current* (see **Figure 2**). Such a system normally would have no significant losses other than radiation resistance. There are probably thousands of VHF antennas built in this manner. VLF requirements render this impossible. There the antenna current is composed of two main components: the displacement current from the ground mat and that which returns via ground conductivity—*return current*. It's in the latter that the major losses occur. The total antenna current is the sum of the two.

It's obvious that provision of full-length

quarter-wave or half-wave radials is not only expensive, but physically impossible for VLF systems. Because all the antenna types—including the inverted-Ls—possess very large-area horizontal top-structures, ground mats large enough to intercept most of the local electrostatic field between the top-hats and the ground mats are constructed. They act very much like the bottom plate of a large capacitor, whose circulating current becomes the “displacement” current described above.

Ground systems vary widely; local geology and ground conductivity, as well as economics, govern the design at each location. Some of the sites incorporate hundreds of ground-rods like those used in the age-old spark and alternator systems. This system is used (with some modifications) at both Jim Creek and Haiku. As with those of decades before, the rods are clustered in “stars” and there are “groups of stars” that compose the ground system. Ground penetration, as well as that of saltwater, of VLF energy is high—measured in tens of meters, or more, and much earth-return current arrives at the rods from below. It was recognized (or postulated) by the early engineers that much return

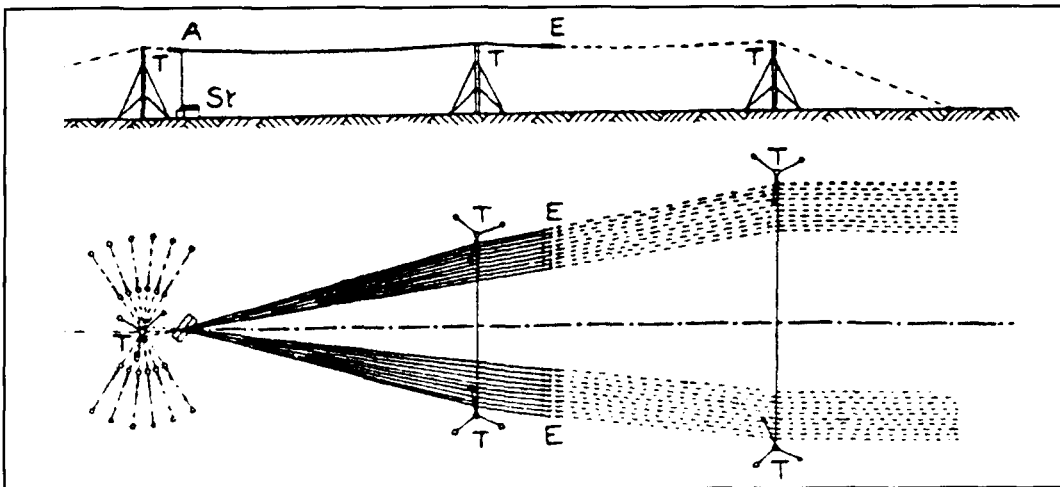


Figure 8. The POZ antenna after 1912. Source: Dr. Desmond Thackeray, Byfleet, Surrey, England.

current arrives in a “surfacing” manner. Many early ground-rods were slanted so the bottom ends of the rods were closer to the axis of the radiator, thus presenting most of their length at a right-angle to the return current path. This philosophy is echoed—in a manner—in a relatively modern National Bureau of Standards publication on lightning and fault-current grounds, which states that the conductivity to nearby earth is relatively insensitive to the surface area of a ground rod, but is *directly proportional to its length*.

The Alexanderson Multiple-tuned Antenna

All of the Alexanderson alternator stations used the inverted-L antenna. As mentioned earlier, there were some problems associated with this type, which still used the “star” system with ground rods. With antenna currents of about 1,000 amps, the return current was highly concentrated around the rods. Couple that with high-resistance sandy soil, and one finds that the heat produced would vaporize whatever moisture was present at the time, and the heating compounded to the point where there was incandescence. That would start brush fires, for

which there had to be a “fix.” Actually, there were *two*. The first, and most important one, was the use of multiple feeds, as shown in **Figure 6**, which is of the New Brunswick antenna. The second was the installation of buried 1,000-foot long wires extended (on both sides) at a right angle to the axis of the L, fish-bone-style, each of which was joined to the grounding system at the center.

If several equally spaced downloads were grounded through loading coils, and each inductance was adjusted so all the currents were equalized (and exactly the same value as the current entering from the transmitter) then, as in the figure, the current returning to each was one-sixth the feedpoint current that would exist with only one download. The power dissipated in the lossy soil would be one thirty-sixth of that of the single download. Because the power into the antenna must remain at the full output of the transmitter, the *input impedance* of the feedpoint is *36 times* that of the single-download system. Not only was the local heating problem eased, the feedpoint impedance was easier to match. The addition of the transverse wires actually helped, too, because they intercepted probably as much return current as did the rods. So the multiple-feed system was, in addition, an impedance transformer. We see

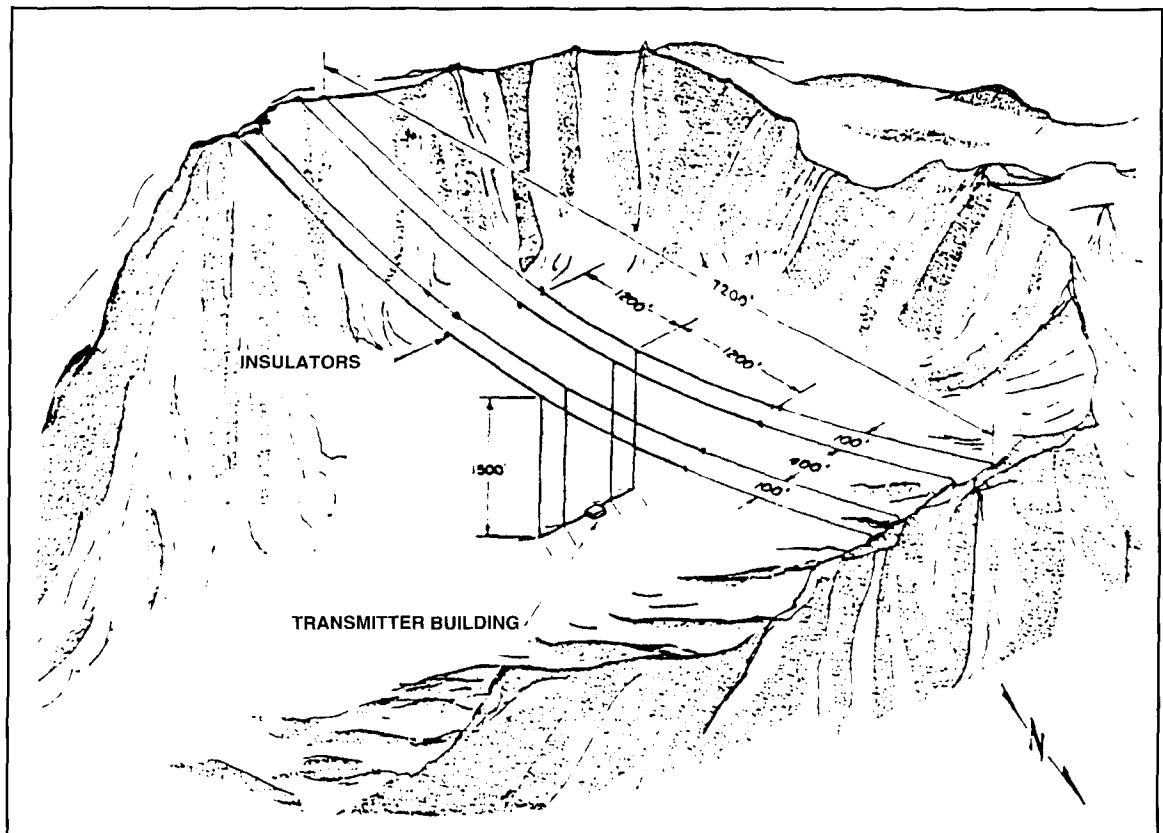


Figure 9. Antenna system at Haiku, Hawaii. It was stretched across an extinct volcano. Source: *VLF Radio Engineering* by Arthur D. Watt, et al., Pergamon Press, 1967.

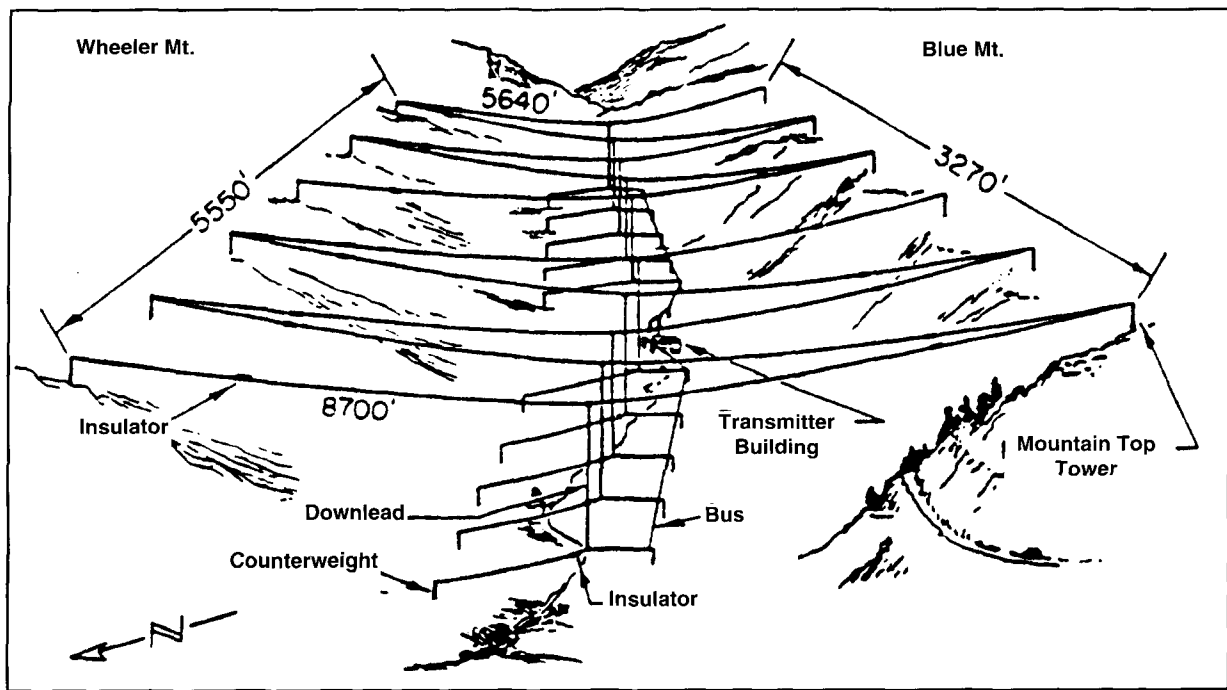


Figure 10. NPG (Jim Creek, Washington) Antenna, strung between two mountain ridges. Ibid.

the same thing in multiple downlead wires in our own “folded monopoles.”

Station POZ and its antennas

A symmetrical top-hat single mast antenna was employed at POZ up to 1912, when a severe storm toppled the center mast. Multiple leads were used to carry antenna current to the top-hat; they acted as a single downlead. The reason for the separation was to enable ice-melting in inclement weather. A side-projection of the antenna is reproduced in **Figure 7**. After 1912, the station used a “V” arrangement, shown in **Figure 8**. The “V” represents only the top view; it really consists of two Ls electrical-ly in parallel.

POZ was, in its day, as famous as any transmitter in the world during and after World War I. As I mentioned earlier, it was the receiving station for the “*Fourteen Points*” message from President Wilson. The station was used throughout the war for messages to the High Command of the German army, as well as to the German Submarine Corps, and relating some of its history is appropriate.

Considerable maritime freight traffic was handled through Marseille and other ports on the Mediterranean. There were, in response, several submarines on duty there to intercept as much of the shipping as possible. The submarine skippers would surface at night to recharge batteries and receive the latest news about shipping schedules from POZ. The German High

Command received the information (originally from two turncoat French spies) about shipping schedules; thus the submariners could place themselves in a position to intercept. The spies were caught later and executed (the French and English cryptanalysts had been reading every message). The Germans became predictable and careless in their encryption with respect to code keys (not really “code” but encipherment; codes are *different* from ciphers). They used keys for their Vigenere tables, which became easier and easier to fathom. One such key might have been the phrase, “Gott mit uns” along with other equally predictable phrases. Field recipients had enough trouble without worrying about remembering the day’s key, so simple ones were generated. It’s the “which ones?” that got them into trouble.¹¹

The chief engineering consultants to Telefunken were Drs. Ferdinand Braun and Jonathan Zenneck. Telefunken was perhaps the most famous company in Europe (in addition to Marconi, of course), and it had built POZ as well as the directed the installation at Tuckerton, New Jersey. Both those gentlemen figured in a lawsuit in the United States. Marconi was the defendant in a patent infringement case, and both Zenneck and Braun were expert witnesses—Braun being actually the complaining litigant. The hearing occurred during the beginning of the war—before we were belligerents. Both Braun and Zenneck were in New York for the trial, which also coincided with a very large influenza epidemic; one that

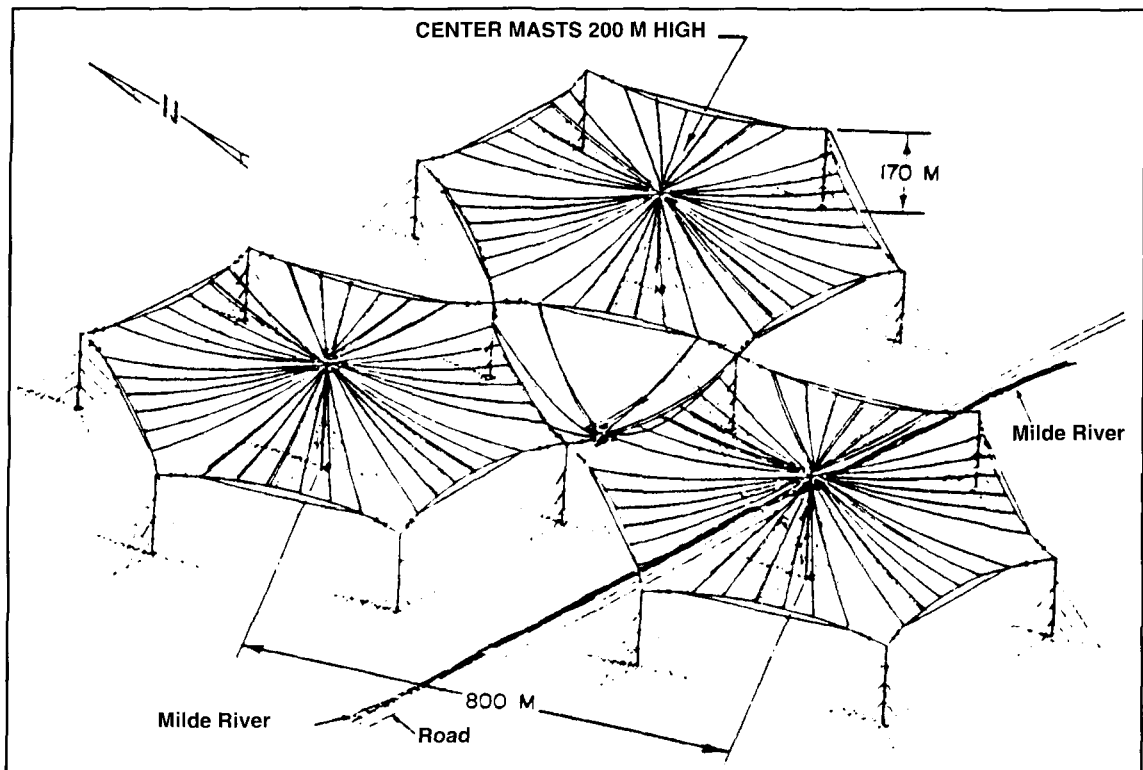


Figure 11. Goliath antenna. This antenna was built at the beginning of World War II. It operated until the end of the war, when the Soviet government dismantled the entire station and re-erected it in Russia, near Gorky. Ibid.

took tens of thousands of lives. Zenneck avoided the illness, but as luck would have it, the U.S. declared war on Germany and he was interned for the duration in Fort Oglethorpe, Georgia. The IRE here tried desperately to get him “sprung”—but without success. Braun was allowed to remain “free,” although he was no doubt under constant surveillance, living in the New York City area. He fell on the ice frequently present in that part of the country, and broke his hip. It never healed; his condition worsened, and he succumbed (as was mentioned earlier) on April 20, 1918 to pneumonia. Braun would have been allowed to return to Germany, had there been neutral transportation. There wasn’t. It is tragic that his wife died in Germany during the war, and Braun never saw her again. Incidentally, both Braun and Marconi were Nobel Laureates, which may have taken some of the “heat” off of Braun while he was here.

We entered the war as the final result of British decipherment of the famous “Zimmerman Telegram.” Radio signals had the advantage of being receivable almost *anywhere*, although the Zimmerman telegram was intercepted from a submarine cable that surfaced in England. They also had a great *disadvantage*: the cipher text of any encrypted message was free for the taking by anyone with the desire—or need—to decrypt it.

Zenneck figured prominently in the POZ antenna design. It was, as can be seen in the figure, a symmetrical umbrella-type (before 1912), with a ground mat believed to be about three thousand feet in diameter (detailed antenna design data are virtually nonexistent regarding POZ) and the transmitter at that time was a 100 kW quenched spark. The philosophy of the symmetrical system enabled the Germans to anticipate Marconi, Alexanderson, and many others; the single-mast top and base-loaded antenna concept was employed at both POZ and Tuckerton. The Goliath antenna (see later) uses a symmetrical arrangement. Many modern stations use symmetrical center-mast designs. One, NAA, is an example, though it consists of two such configurations. They may be operated independently, or both in parallel. Nothing about large VLF antennas has captured our imagination as have the stories of large antennas that are anchored on two “mountains,” with the antenna spanning the entire intervening valleys. Short descriptions of three such antennas follow.

Malabar, Java (PKX)

A very high-power transmitting station was built in Java and operated for a short time right after World War I. There are some very important facts and characteristics concerning the station. It had the largest *arc converter* ever built,

in addition to its being the last one constructed. Its power level wasn't matched or exceeded until the middle of this century. Leonard Fuller was a consultant to the engineering staff; up to that time, he had built the arc converters installed at the French station at Bordeaux—which possessed two converters of 1-MW size. He is also the one who raised the power to the megawatt level.

Although the IRE article¹² does report some facts about antenna-supporting hawsers (presumably hemp), insulators, downleads, and voltages, there's nothing which describes the antenna except that it spans a valley between two mountains. In De Groot's defense, however, definitive studies on antenna behavior were only just beginning. It was *much* more interesting to talk about equipment and the construction of the largest arc converter ever built. It certainly is interesting enough, even today, to be included here.

Java at that time was controlled by the Dutch Government, and the transmitter was built to communicate directly with Holland. A mountain-to mountain (really ridge-to-ridge) antenna was erected in the interior mountains. The site was totally wild. Roads, buildings, several diverse transmitters, and *two* power plants were built: one hydro-electric and one steam. All of the power was produced at the site. There were very difficult circumstances—the station was

built during World War I, and the equipment was hard to come by. It came from wherever it could be obtained—partly from Germany (before hostilities), and partly from Sumatra, Japan, the USA, etc.

The power input was 2.5 megawatts. It was the most powerful station in the world, and would be for several decades. The political climate apparently was so unsatisfactory for the Dutch that the station was shut down and disassembled in about 1925.

The maximum efficiency of an arc converter is exactly 50 percent. The antenna efficiency probably was no more than, say, 10 percent. Of those 2.5 MW, only 1.25 MW actually reached the antenna. Ten percent of that power, or approximately 125 kW, were radiated. It was enough to accomplish its purpose, and then some. The Bordeaux station was capable of sending readable signals to a distance of 12,000 miles, using 1 MW input, but with probably a more efficient antenna.

Haiku (NPM) and Jim Creek (NPG)

Both these stations were (and NPG still is) in U.S. Navy service. The NPM antenna is stretched across the crater of an extinct volcano (**Figure 9**). The antenna for NPG is stretched

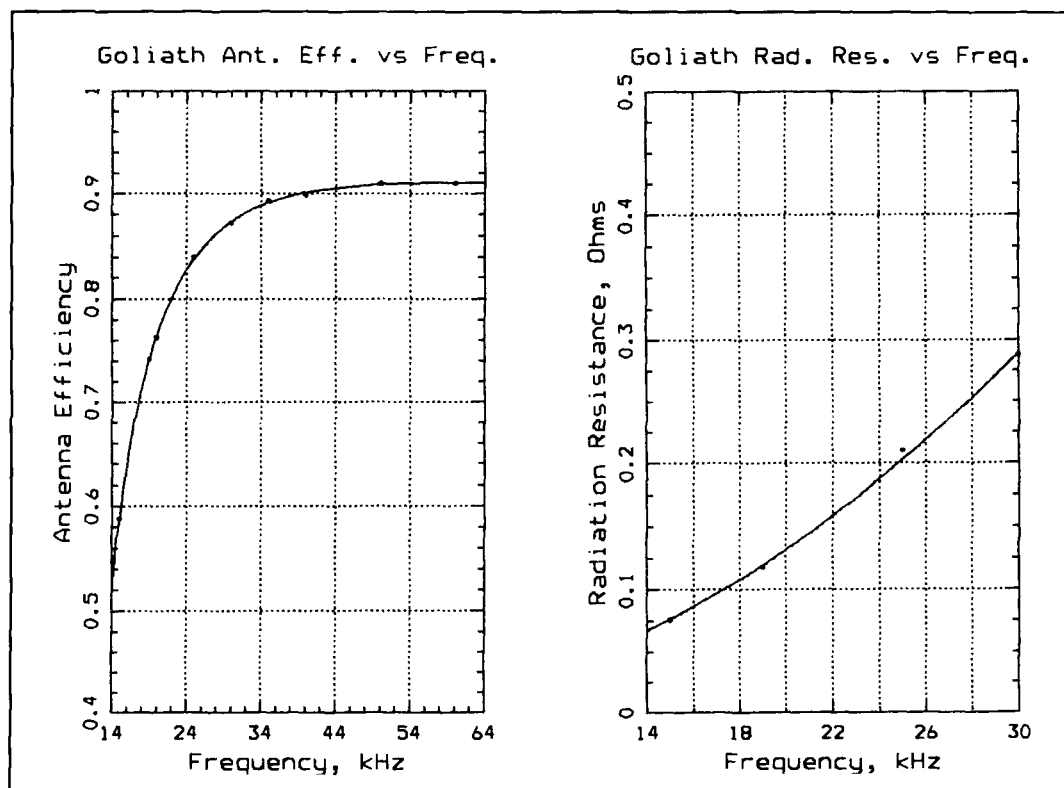


Figure 12. Curves generated from tabular in *VLF Engineering* by Watt. They were plotted by Byron with the aid of a curve-fitting program. The curves are of (A) efficiency and (B) radiation resistance.

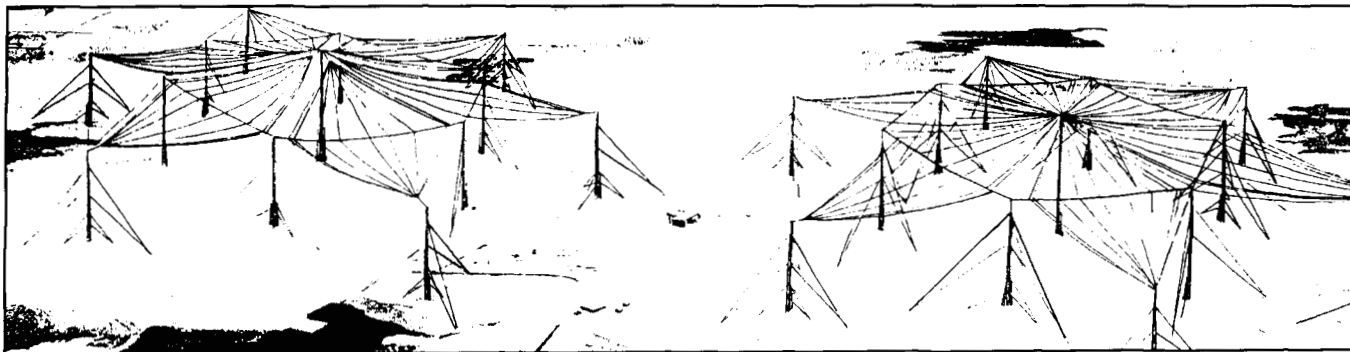


Figure 13. View of the antenna at NAA (Cutler, Maine). From the edge of one top-hat to the edge of the other is more than two miles. The tiny building between the two hats is 5 floors high. Source: Continental Electronics, via Bob Nash.

between two mountain ridges (see **Figure 10**). The dimensions of the systems are shown in the figures. It is possible to construct support towers 2,000 feet tall, but these installations are no doubt much less expensive, and are placed where aircraft can be prohibited. Thus, there is little or no friction with the FAA.

Haiku has four long catenaries, which can be fed singly or in any grouping. It's also possible to operate two catenaries on one frequency and the other two on another. The heights above the crater floor vary from 1453 to 1200 feet. The ground system consists of 16 stars spread over an area 5,000 by 3,000 feet. Best operation occurs when all four catenaries are driven. Their combined static capacitance is 0.031 μF , and its inductance is 0.287 mH.

The antenna at Jim Creek (NPG, Oso, Washington) is stretched zigzag style between two ridges, one at 3000 feet elevation and the other at 3200 feet. The 200-foot high stub supports along each ridge add about 200 feet to the height above the valley floor, which is 700 feet agl. The spans are all longer than 1 mile. The catenaries are constructed of 37 strands of No. 7 extra high strength copperweld, making its diameter 1.01 inch. Downleads are 0.92 inch diameter hollow copper tubing. This system, too, is capable of operating on two frequencies simultaneously. This larger antenna (all sections in parallel) has a static capacity of 0.078 μF .

One would imagine that a single catenary over a mile long would expand and contract considerably with changes in temperature—and it does. Not shown in the figure are the counterweights at each anchor point. They keep the tension constant. Jim Creek has presented difficult (but interesting) problems with its ground system and general efficiency. A sort of surprise appeared when it was determined that there is a transition from voltage-limitation to power limitation at about 18 kHz. The first parameter involves wire diameters and voltage stand-off capability of the insulators; the second involves both corona and transmitter maximum power output. The maxi-

imum power limitation on the antenna is approximately 1.14 MW.

Goliath

Late in the Fall of 1941, the German government designed and built a large, high-power transmitting station near Kalbe. Its structural shape can be seen in **Figure 11**.

It consisted of three regular hexagonal top hats, with three tubular, 200 meter high insulated masts surrounded 15 shorter grounded masts, 170 meters high, but insulated from the top-hats. Antenna tuning is accomplished at four different points. One tuning inductance is located at the base of each central mast (in the hexagons), and one at the transmitter house in the center of the array. This is a very modern version of the "multi-tuned" antenna. If all feeds are adjusted for equal currents, then the resultant feedpoint resistance is 16 times that of only one vertical radiator. The center point consists of six downleads (see **Figure 11**). It's grounded by four separate star-like systems, each with 204 galvanized iron conductors, 2 cm by 0.1 cm in cross-section, buried at about 0.4 meter. Heavy interconnecting bands connected all together. It was comprised of a total of 350 km of these straps. Constructed over the Milde river, the ground conductivity probably was relatively high. This is borne out by the efficiency, which reached 90 percent (total circuit) at 60 kHz (see **Figures 12A and B**). It was driven by a 1-MW transmitter.

It is believed that the Goliath installation was dismantled by the Russians at the end of World War II and transported to the Soviet Union, where it was reconstructed near Gorki (east of Moscow). That would explain the lack of complete information this antenna.

Cutler, Maine (NAA)

The call sign NAA is probably the very first

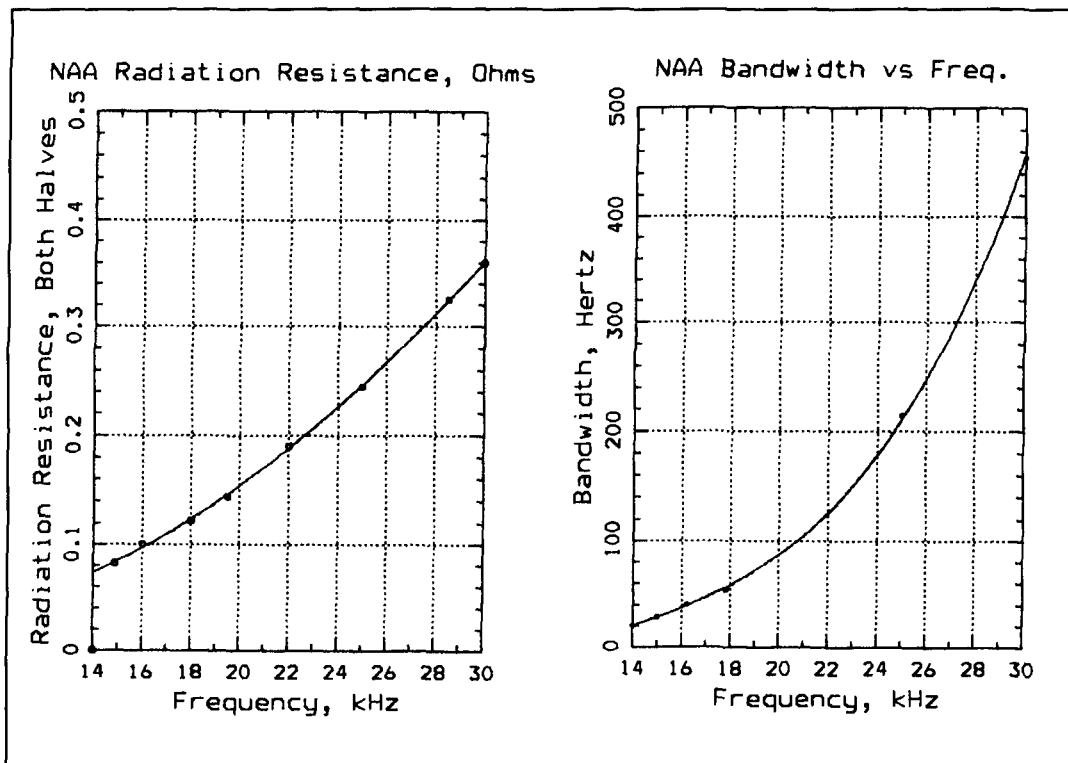


Figure 14. Curves for the Cutler antenna, generated by the same method as those in Figures 20a and b. (A) shows radiation resistance, (B) shows bandwidth in Hertz. Source: Watt, et al.

one issued by the Navy in the early 'teens; its original location was in Annapolis. NAA was relocated in 1961, when the present station was placed in operation. A drawing of the layout appears as **Figure 13**. The antenna is composed of two rather large six-leaved stars (called panels), each one a mile in diameter, and roughly 1,000 feet high. Either one or both may be excited. The ground system is largely radial, using 208 miles (1.1×10^7 feet) of No.6 bare copper wire, buried 1 foot deep (George Brown's study on radial ground systems for vertical antennas has been honored hundreds of times). The transmitted power of NAA is 2 MW *maximum*. Operation at some reduced power is usual, however, as the field-strength objectives can be met with only one antenna in operation.

Some curves (**Figures 14A and B**) reveal two important numbers: antenna efficiency and bandpass. It demonstrates amply a statement made earlier—that wide bandpass and high efficiency are mutually exclusive in these antennas. At 14 kHz, the efficiency of the antenna alone is 76 percent; at 30 kHz, it is 90 percent. The transmitter and auxiliary equipment were designed and largely built by Continental. The transmitter and its immediate and necessary auxiliaries also were built by Continental (see the large variometer from NAA in **Photo D**). Static capacitance of the

system is 0.225 μ F, and the intrinsic inductance is about 0.05 mH (both halves connected).

Discussion

I've discussed many, if not most, of the characteristics of VLF antennas in the previous paragraphs. Topics touched upon included: the occurrence of decreasing bandpass with increased efficiency and the *requirement* for good (and expensive) ground systems. VLF systems are so expensive (for several reasons) that private industry, namely for commercial endeavors and the news media, could not afford them. We are lucky that HF filled the bill for the decades of the late 'twenties and the period up to about 1970 or so. Then came the great advancement with satellites. Even HF isn't really essential, now—except as back-up.

Both the military and certain government activities *require* 24-hour reliable communication. Foremost would be those that involve national security. Great strides have been made in the art and science of cryptology, and this fits "hand in glove" with teletype machine technology (even of the Kleinschmidt; i.e., mechanical variety), allowing both encryption and decryption *right on the machine*. The massive development of the personal computer has given even

“John (or Jane) Doe” a tool with capabilities beyond the wildest dreams of the practitioners of World War II vintage. We, the Japanese, the Germans, and the Russians all used mechanical or electro-mechanical cryptographic tools.

Many of us are familiar with the Enigma machine. William Friedman¹¹ broke the Japanese PURPLE code, as well as other Japanese Navy codes. We had forewarning of a probable attack by the Japanese because of that capability. We didn't know where, or when. “Second guessers” often forget or ignore those facts. The attack on Pearl Harbor would not have been a “sneak attack” if the Japanese Embassy in Washington had not elected to retype the very long (thirteen part) message. As a result, the telegram was delivered to the U.S. State Department *after* the attack started. Those are *facts*, not apologies. The decrypting of Japanese Navy codes by Lt. Rochefort of station HYPO (Honolulu) enabled the ambush and destruction of Japan's four largest carriers at Midway—and actually turned the tide of the Pacific War. Those carriers had been the main force in the Pearl Harbor attack.

When we World War II veterans listened to VLF (mostly Navy) transmitters, we found that press was transmitted in “clear text” CW so it could be copied all over the world. I remember reading NAA and NPG, plus others whose calls I don't remember. That would be impossible today. The messages are transmitted via *very* narrow shift RTTY—necessary because of the narrow bandpass of the antennas—and they are encrypted *at the keyboard*. Of course, they are *decrypted* at the receiving posts. Many of these “posts” may be a hundred feet under salt water, or thirty thousand feet up in the air. *All* the Navy (and civilian) VLF arc transmitters of the 'teens and 'twenties had to be keyed RTTY fashion; it was integral with their design and operation. The present necessity for RTTY, however, has nothing to do with the transmitter, but has *everything* to do with the antenna—namely, its limited bandpass.

I could describe several more transmitting antennas. It's difficult to know where to stop, so I have included representative types—making this a subjective evaluation, at best. There is one very large transmitter and antenna system not included in this paper. It's absent because I had no data by which it could be described. The station is located on the north coast of Australia, and known presently (by me) as the Harold E. Holt station. It was designed and built by Continental Electronics, and is of the same general power as NAA, but with only one very large mast-and-top-hat. I am informed that it has the most efficient antenna system in the world.

The valley-spanning antennas seem to appeal

to many, so I reported on three examples. It has been an education.

Acknowledgments

This manuscript, in various degrees of completion, has traveled across the Atlantic at least twice. Dr. Desmond Thackeray has been very helpful; he supplied the information about the post-1912 POZ antenna, along with very valuable advice. I am grateful to him.

There is, however, one important resource who has helped me, encouraged me, and provided all but three of the photographs here. He is my mentor: Dr. James E. Brittain, Professor Emeritus of the History of Technology Department at Georgia Tech. I owe much to him, not the least of which is my membership in the Radio Club of America.

Hank Olson, W6GXN*, has been a sounding board, and has contributed much to me in general, and some priceless information in particular. He also has made very pertinent suggestions, and has commented on the article along with Dr. Brittain and Dr. Thackeray. All three are authors—and that makes favorable comments worth more than I can express. Jerry Minter and Vivian Carr (both of the Radio Club of America) have been particularly helpful, for which I am very grateful. Vivian spared no effort in encouraging me in this effort, and Jerry has reviewed this manuscript, made many very good suggestions, and gave it his blessing.

Robert G. Nash, Manager of VLF/LF Systems for Continental Electronics, also reviewed this manuscript. He speaks with real authority, as he oversaw the design and construction of NAA and other VLF transmitters. He corrected some errors, informed me about the Harold E. Holt complex in Australia, and has given the article his approval. My thanks go to all. ■

* *We are sorry to report that Hank became a silent key on March 9, 1996. Ed.*

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Fractal and Shaped Dipoles

By Nathan “Chip” Cohen, N1IR

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Belmont, MA 02178

Summary: The article explores simple fractal dipoles design. *EZNEC* simulations are used to illustrate the performance of several designs.

Spring 1996 issue, pages 25-36.

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CADA

Computer Aided Design for Amateurs

MININEC has shown many amateurs the value of computer analysis for determining the worth of an antenna design before it's turned into hardware. This article is devoted to another aspect of computer analysis—that of determining the worth of a circuit before it's built up as a breadboard.

Of course, design programs have been around for a long time. Collections of public domain software are available for almost every computer, and include much helpful material. In the amateur field—beyond programs for Morse code generation, logging, and even station operation—there are programs for Ohms Law, design of attenuators, inductances, filters, timers, and so on. Most of these are in the nature of aids: they help in design, but don't tell you if the overall design will work, or if it can be improved.

Here we have a situation with a parallel to that of antenna analysis. There's an available program specifically designed to analyze large complex circuits. It's called SPICE, which is an acronym for Simulation Program with Integrated Circuit Emphasis. It's especially intended for solid-state circuits, and takes their strengths and weaknesses into account. Nonlinearities, temperature effects, junction, capacitance, leakage, and flicker noise are some of the items modeled. For example, a complete MOSFET description may include some 48 parameters, although perhaps 30 may be neglected for most work.

SPICE is a two-stage model. It first solves for the DC no-signal condition, to determine the quiescent operating point. It then solves for the effect of a small AC signal, varying about the DC point. Small signal distortions can be calculated, as can the noise present. A separate calculation shows the large signal distortion in terms of the additional frequency components introduced by the overload. Some common circuits, such as modulators, require "tricks" with

modeled components. Others require data be saved and then studied with a post-processor.

The point of this discussion is that SPICE is a BIG program of great capability. Learning some of the elements of its use isn't difficult, but there are many features. There's even a free version of a commercial SPICE program just for that purpose. However, this won't handle many problems, so the full version is needed. It seems a better starting point would be an easier-to-use program—one that incorporates some of the large programs' techniques, provides useful answers, and also serves as "spring training." Such a program is available, and is the subject of the rest of this article.

Elements of nodal analysis

A circuit can be regarded as a collection of points connected together by components. Each point is usually called a node, so the analysis can be called nodal analysis. The entire assembly of components can also be called a network, so an alternative name is network analysis. The originator of the SPICE-like program described here¹ called it NET80. This was based on an earlier program,² and has since been modified by others—for example, as NET85.³ The version discussed here, NET94, includes still more additions.

In the circuit or collection of nodes, there is normally one node pair used for a signal input, and another pair for signal output. One node should be common to many components, in addition to one of the input and one of the output nodes. The usual term for this common node is ground, or occasionally, signal ground.

Analysis consists of calculating the voltage at the output for a given value of input. One of the limits of this particular analysis is that it neglects nonlinearities, so the exact input isn't important. For convenience, the input is set to 1.0 volt.

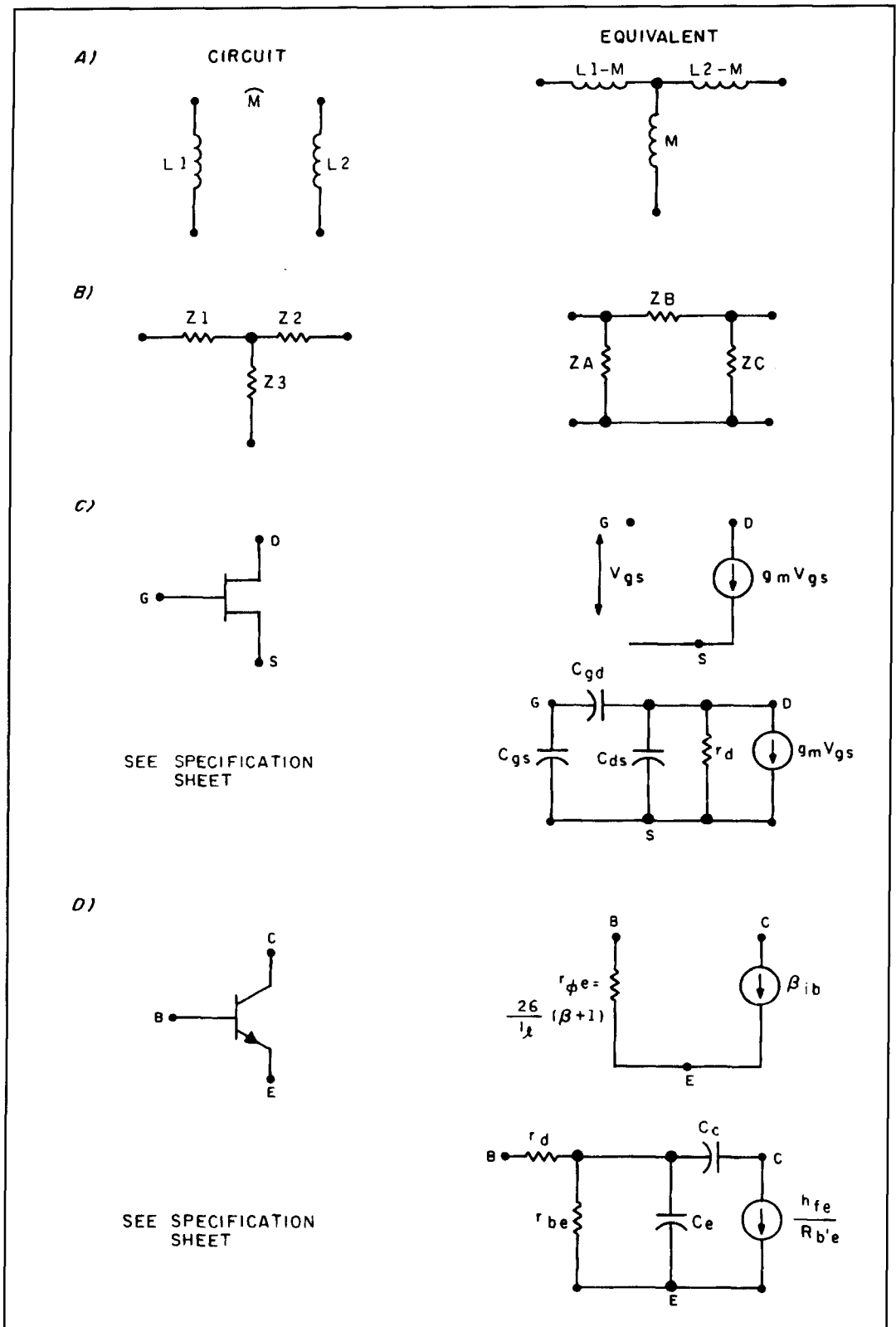


Figure 1. Some of the equivalent circuits usable in design. (A) Replacing a transformer with a T-network. (B) Tee to Pi transform: see the *ARRL Handbook* for equations. (C) Low-frequency and high-frequency equivalent circuits for a FET. The low-frequency model is used by the program. The three capacitors and the resistors may be added as external elements, and are typically required above about 10 MHz. (D) As (C), but for NPN transistors. In addition, the decrease in beta with frequency can be approximately modeled by placing a capacitor across the load resistor. The magnitude is equal to $1/(2 \times \pi \times F \times R)$ where F is the beta cutoff frequency and R is the load resistance.

Another limit of this particular analysis is that it is for AC signals only (see below for a method of DC analysis). For AC, the important quantities are the magnitude of the output voltage, and the phase shift. These are referred to the input, the 1.0 volt input assumed to be at an angle of zero degrees. The most common problems relate to the way the output varies with frequency, so the program calculates the output over a range of frequencies, as specified. Several output data forms are provided.

Describing a circuit by nodes

In analysis, each junction of two components is a node; in practice, at least one or more components may be connected to a node. Each component is entered into the program separately. Three types of input data must be specified. One is the type of component, and the second is its node connections. The third is one or more quantities, as needed, to describe the magnitude of the component size.

The components that can be used in the circuit program are limited to those listed in **Table 1**, which also shows the number of component connection nodes involved, and the number of quantities needed to describe component magnitude.

Thus, there are three types of elements. The first are the simple ones: R, C, and L. Then there are the active elements—either solid-state or vacuum tube. The last three are really passive elements, but the presence of resonance means they must be calculated as if there were one or more active elements present.

Note that there are no nonlinear elements on the list. This restriction means that some component connections can't be analyzed. One example is a transistor with both base and collector connected to a single node to form a diode.

It's possible to add routines to the program and extend the list in **Table 1**. See the references for examples that show how this is done.

The simple elements can usually be regarded as pure over much of the frequency range; that is, a resistor is only a resistor, and so on. However, circuit specification sometimes requires the emulation of a component by two or more of these basic components. For instance, a pair of coupled coils are replaced by their equivalent 3-inductor T-net of values L1-M, M, L2-M.

Accurate calculation of the high-frequency response requires the addition of more "pure" elements to represent the strays that can be neglect-, or low- and mid-frequencies. Lead inductances of resistors and capacitors, and resistances representing inductor loss, are examples. They are needed occasionally, even at low frequencies, for the loss and leakage of an electrolytic capacitor.

Component	# Nodes	# Variables
Resistor	2	1
Inductor	2	1
Capacitor	2	1
Transistor	3	2
FET	3	1
Opamp	4	2
Triode	3	2
Pentode	3	2
Transmission line	4	2
Shorted stub	2	2
Open stub	2	2

Table 1. Components used when describing a circuit by nodes.

The active elements also have strays, which must often be modeled. Examples are the capacitors representing the junction capacitance of transistors, or the inter-electrode capacitance of tubes. Critical circuits may require modeling of such factors as transistor leakage circuits. In general the modeling of the active elements requires more care than the passive ones.

Note that only one type of transistor is shown, the NPN. Some circuits use PNP types. If all are NPN, just ignore the difference. If both types are present, it may be possible to account for the difference by entering BETA as a positive value for NPN units and as a negative one for PNP types. This won't work when there's a common connection for two different types of transistors, as in the complementary-symmetry single-ended amplifier. While the program is powerful, it won't model all possible circuits.

Note also that some component parameters are variables. Solid-state devices are typical, for example, transistor BETA being a function of frequency. The value entered into the program must be valid for the frequency specified. In many cases, this can be done by entering an appropriate equivalent circuit, but it's often easier to set up a model with a single component value, determine output over a small frequency range, then repeat with a new parameter value and frequency range. (See later for changes to components.)

The program's main menu is in two parts. One is for component selection, just discussed. The second is for actions to be taken. This includes starting the actual analysis, controlling output to the printer or to save-to files, and rerunning the program. Most input errors will give a message, then return to the main menu, but there are errors that stop the program completely. It's a good idea to save problem data to file before starting analysis or modification.

The current list of actions is:

```
STOP PROGRAM
ANALYZE NETWORK
SET PRINTER MODE
LOAD NETWORK FROM DISK
SAVE NETWORK TO DISK
RERUN PROGRAM
REPEAT CALCULATION
```

It's not difficult to add routines because the source code is in BASIC.

How the program solves networks

When the program starts, it asks for the number of nodes in the circuit to be analyzed.

(Important: There must be a connection to each node. This may be a dummy connection, such as a 1-meg resistor to ground.) The program then sets up 4 square arrays designated as P, Q, R, and S. Array "P" stores data for resistances and some other real quantities. "Q" is for capacitances, "R" is for inductances, and "T" is for transmission lines. Entry is by array row and column corresponding to node connections. Values are entered as admittances. For resistance and inductance, this is $1/\text{input-value}$; for capacitance, it's the input value. Quantities are entered four times. For example, for a resistance of 10 ohms connecting nodes 3 and 5, the value 0.1 is entered into resistance array elements P33 and P55, and the value -0.1 into the elements P35 and P53. Entries for three- and four-terminal elements may produce up to eight entries. Because these involve transconductances, the entries may not be symmetrical (A51 is not equal to A15). See the references for details.

When these arrays are completed, the input and output nodes are specified, then the frequency and step values. Two new arrays, "A" and "B," are then created—one for real and the second for imaginary quantities. These are used twice. First, a numerator quantity is defined by masking the common node row and column and the input row and output column. The remaining elements of the four arrays are multiplied as a scalar by 1 for resistances, $j*\omega$ for capacitances, $1/(j*\omega)$ for inductances, or j times a trig function for transmission lines. The results are separated as real and imaginary parts in the A and B arrays. The complex determinant of these is saved. A denominator is then calculated by the same process, except that the masking is for common row and column and for input row and column. Complex division of the two determinants provides the output/input ratio. Because the input is unity at an angle of zero, the division gives the output magnitude and phase shift.

This process is faster than the more common one of setting up the full Z impedance array and calculating its Y admittance array reciprocal. Only two determinants are calculated, each for a smaller array, instead of the inverse values of each element of the original array. With a fast computer and typical problems, output speed is limited by printing speed.

Actually, there's no need to be concerned with the process details. They are automatically handled when the component or program action desired is selected from the list of **Figure 1**—the program's main menu.

The process of analysis

The best place to begin analysis is with a simplified version of the circuit diagram. Leave out nonessentials, such as switching, metering, power supplies, cooling fans, power supply supplies, and so on. Remember to connect all power supply leads to the common ground.

It's necessary to omit components or processes that depend on nonlinearities. This includes oscillators, modulators, limiters, and such. Modeling for systems with these present is done by analyzing performance up to the nonlinear element, then separately modeling the circuit after the element, up to the next nonlinearity, or to the final output. For example, a receiver can be analyzed as an RF section, an IF section, and an audio section. In this instance, mixer and detector loss are calculated manually, as is the overall gain. An oscillator is analyzed by opening its feedback loop and calculating the gain between the two nodes. If it's less than unity at 180 degrees, the circuit won't oscillate; if it's much greater, there may be instability.

The next preparatory step is to number the nodes. Customary practice is to start at the input and move towards the output. This program requires that the common node must have the highest number, but there's no other numbering limitation. When this numbering is complete, move to the analysis program itself.

The program starts by showing the approximate number of nodes possible with available memory. This amount depends on the computer, and whether the BASIC or compiled form of the program is used. With several megabytes of memory, several hundreds of nodes are allowed. Note, however, that the program speed will decrease at about the square of the number of nodes, so it may be better to divide the schematic into sections for separate and faster analysis. Some operating systems allow one to set the amount of memory made available to the program.

Before starting component description input to the program, it's good to use the menu "Action to Take" item, "Set Printer Mode,"

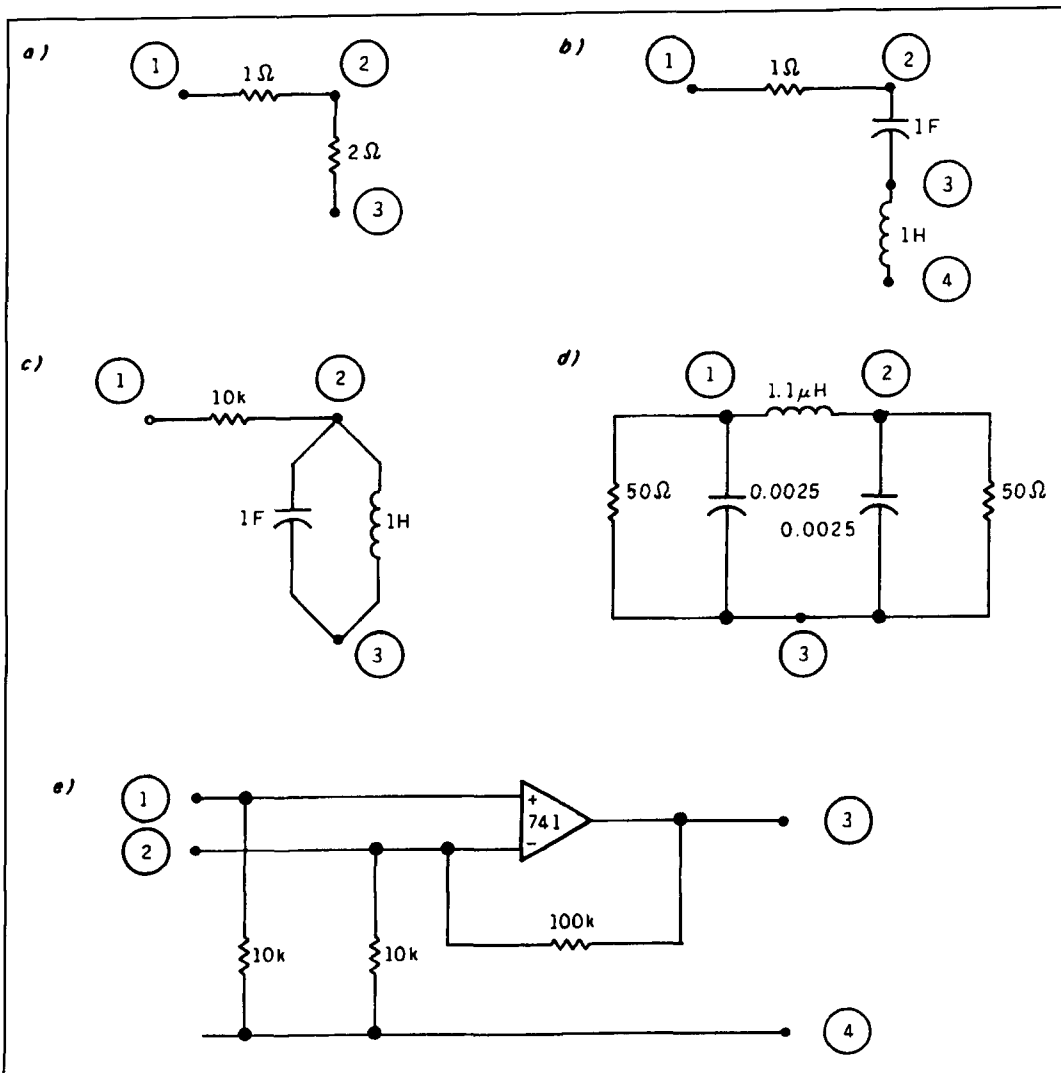


Figure 2. Simple circuits for practice in analysis. (A) A voltage divider. (B) Series-tuned circuit: Input at 1 and output at 2 or 3. (C) Parallel-tuned circuit. (D) A pi low-pass filter, approximately for the low end of 80 meters. (E) An opamp. For correct modeling in the inverting mode, the 10-k resistor between the minus input and common should be in series with the input. Note the difference in performance for the \pm inputs with this connection.

then the sub item, "Component List ON." As each component is entered, its serial number, type, node connection, and value are sent to the printer, as well as being entered into the appropriate elements of the four arrays. This provides a permanent log of the schematic, and is especially useful in checking for input errors.

It's a good idea to run a trial analysis with a small number of frequencies, say ten covering the range of interest. This will show if there are serious entry errors. If there are no problems, set up the desired printer and disk output, and proceed with the full analysis. It's good practice to print the numerical values first, then call for a printer graph.

In evaluating the results at this stage, the first four columns of numerical output are the important ones. The ones marked REAL and

IMAG are sometimes useful, but are really for a later procedure. First look at the results with a view of confirming or denying the expected performance. An amplifier should show gain, a tuned circuit resonance, and so on. If results are markedly different from design expectations, look for the reason. It may be an entry error, such as a skipped digit or an incorrect node. It may be misreading of a component value, or of component performance data. Or, it may be that the circuit can't perform as expected. Thought is required when program results and general expectations don't agree.

When they do, look at the detail results. Check for stray frequency responses, which may show as amplitude change, or as a magnitude or sign change in the phase column. These are a sign of stray resonances. Look for extremely

```

X
COMPONENT CONNECTION LIST FOR SER OF 110194

COMPONENT # 1 , RESISTOR= 10 OHMS, A END= 1 B END= 2
COMPONENT # 2 , CAPACITOR= 1 FARADS, A END= 2 B END= 3
COMPONENT # 3 , INDUCTOR= 1 HENRIES, A END= 3 B END= 4

X

```

Figure 3. An example of the component connection list sent to the printer. This list should be a part of the record for the model run. This is for Figure 2B.

```

4 4
0 0 0 0 0 0 0
.1 62.83189 .1 0 0 0
0 -62.83189 -.1 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
-.9999974 -1.591544E-03 -.1 0 0 0
9.999975E-02 -1.575388E-02 .1 1 0
0 0 0 -1 0 0
0 0 0 0 0 0
0 0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 -1 0 0
0 0 0 1 1 0
0 0 0 0 -1 0
0 0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 -1 0
0 0 0 0 1 0
SER
160494

```

Figure 4. The saved file of matrices for the model of Figure 2B. The first two numbers are the specified nodes, and the number actually used. The line of seven zeros are output values, and show if the model was run before saving values. A line of six values are for the A, B, P, Q, R, S, and T matrices starting from elements 1,1, 1,2 and progressing to N,N. The model connections can be recovered from this file, but not easily. See the program list for exact file structure.

high gains, a sign of potential instability. Watch for rising response at harmonic frequencies. The model doesn't provide information about harmonic or other nonlinear distortion, but high response at an overtone frequency is a signal that trouble may exist if the circuit voltages or currents go into a nonlinear regime.

If critical, power supply regulators and filtering can also be modeled. Supply impedance can be modeled by introducing a bus node. This is good practice if there's any reason to suspect that coupling of circuits through the power supply common mode impedance may exist. An appreciable amount of signal voltage at the power supply bus node is a warning of poten-

tial instability due to common mode coupling through the power supply impedance.

The major point of this discussion is that art enters into this type of analysis. It's important to have the experience to know when a factor can be neglected, plus the curiosity to ask about possible changes when there's some anomaly in the analysis results. It's a good idea to practice with designs of known performance.

Circuit impedance calculation

Because of the calculation technique used, node impedance data is not directly available. A separate calculation is required with this program, using a known input current.

The easy way to set this up is to introduce another node connected to the gate of a FET. The source is connected to common ground, and the drain to the desired node. The FET transconductance is set to -1 mho, which provides a drain node sourcing current of 1 amp when the gate is used as the 1-volt input node. The output node voltage is thus read directly as the node impedance, Z11 when the first node is being checked. The last two columns of the screen data give the real and imaginary components of this impedance. The impedance table may also be printed out.

The suggested technique is to always include an additional node in circuits, labeled node 1. It should be connected to common ground by a convenient resistance, say 100 ohms. The regular input then becomes node 2. After regular analysis is completed ignoring this node, add the FET and connect the drain to input node 2. Rerun of the analysis with node 1 as input and node 2 as output now gives the input impedance at node 2.

Other nodes can be used as output to calculate the mutual impedance from the drain-connected node. For example, with the drain connected to node 3, with node 1 as input and node 5 as output, the calculation gives the mutual impedance Z35. Z53 is identical because analysis is limited to linear circuits. Similarly, other nodes than 2 can be used as the FET connection, to obtain the impedance at that node.

Note that this method of impedance calculation really involves creating a constant current generator. Occasionally, this is a useful component in an analysis. The magnitude of the current in amps is equal to the magnitude of the FET transconductance in mhos.

Correction errors, introducing changes

Because all analysis is linear, any component can be "removed" from the circuit by entering

X

FILE SER OF DATE 110194

INPUT NODE= 1			OUTPUT NODE= 2		
FREQ	OUT/IN	DB	PHASE	REAL	IMAG
1.000E-02	.846	-1.455	-32.244	.715	-.451
1.125E-02	.815	-1.775	-35.398	.664	-.472
1.266E-02	.781	-2.152	-38.686	.609	-.488
1.425E-02	.742	-2.588	-42.071	.551	-.498
1.604E-02	.701	-3.088	-45.511	.491	-.5
1.805E-02	.657	-3.654	-48.959	.431	-.495
2.031E-02	.611	-4.286	-52.371	.373	-.484
2.285E-02	.563	-4.983	-55.705	.317	-.466
2.572E-02	.516	-5.744	-58.924	.266	-.442
2.894E-02	.469	-6.568	-62	.22	-.415
3.257E-02	.424	-7.452	-64.912	.18	-.384
3.665E-02	.38	-8.397	-67.648	.145	-.352
4.125E-02	.339	-9.404	-70.204	.115	-.319
4.642E-02	.299	-10.477	-72.582	.09	-.286
5.223E-02	.262	-11.622	-74.79	.069	-.253
5.878E-02	.228	-12.853	-76.839	.052	-.222
6.615E-02	.195	-14.19	-78.743	.038	-.191
7.444E-02	.165	-15.663	-80.517	.027	-.163
8.377E-02	.136	-17.324	-82.179	.019	-.135
9.427E-02	.109	-19.255	-83.745	.012	-.108
1.061E-01	.083	-21.609	-85.234	.007	-.083
1.194E-01	.058	-24.699	-86.663	.003	-.058
1.343E-01	.034	-29.359	-88.049	.001	-.034
1.512E-01	.01	-39.753	-89.41	0	-.01
1.701E-01	.013	-37.497	89.236	0	.013
1.914E-01	.037	-28.605	87.872	.001	.037
2.154E-01	.061	-24.24	86.481	.004	.061
2.424E-01	.086	-21.273	85.046	.007	.086
2.728E-01	.112	-18.987	83.548	.013	.112
3.070E-01	.14	-17.097	81.97	.02	.138
3.455E-01	.169	-15.464	80.295	.028	.166
3.888E-01	.199	-14.01	78.505	.04	.195
4.375E-01	.232	-12.689	76.583	.054	.226
4.924E-01	.267	-11.47	74.514	.071	.257
5.541E-01	.304	-10.334	72.285	.093	.29
6.236E-01	.344	-9.271	69.884	.118	.323
7.017E-01	.386	-8.272	67.305	.149	.356
7.897E-01	.43	-7.335	64.546	.185	.388
8.886E-01	.475	-6.458	61.612	.226	.418
1.000E+00	.522	-5.642	58.517	.273	.445

Figure 5. The main output of a model run of Figure 2B, always sent to the screen and optionally to the printer. For most work, the first three columns are the important ones. The presence of resonance is shown by both amplitude and phase change.

its negative. For example, if a 560-ohm resistor connects nodes 3 and 6, it can be removed by entering a -560 ohm resistor for the same nodes. Another positive value can now be entered. This

makes input error correction possible. It's much less time consuming than complete reentry of a circuit with one value changed.

The same steps allow study of the effect of

X

FILE ZSER OF DATE 111194

INPUT NODE= 1

OUTPUT NODE= 2

FREQUENCY	OUT/IN	ANGLE	REAL	IMAG.
1.00E-03	159.463	44.053	10	-159.154
1.27E-03	126.066	42.012	10	-125.674
1.60E-03	99.734	39.977	10	-99.236
2.03E-03	78.989	37.951	10	-78.358
2.57E-03	62.669	35.941	10	-61.871
3.26E-03	49.858	33.955	10	-48.849
4.12E-03	39.836	32.006	10	-38.565
5.22E-03	32.038	30.113	10	-30.441
6.61E-03	26.018	28.305	10	-24.023
8.38E-03	21.424	26.618	10	-18.951
1.06E-02	17.975	25.093	10	-14.94
1.34E-02	15.439	23.772	10	-11.766
1.70E-02	13.621	22.684	10	-9.251
2.15E-02	12.353	21.835	10	-7.254
2.73E-02	11.492	21.208	10	-5.664
3.46E-02	10.921	20.765	10	-4.391
4.38E-02	10.55	20.465	10	-3.364
5.54E-02	10.314	20.268	10	-2.525
7.02E-02	10.166	20.143	10	-1.828
8.89E-02	10.076	20.065	10	-1.233
1.13E-01	10.025	20.022	10	-.707
1.43E-01	10.002	20.002	10	-.221
1.80E-01	10.003	20.003	10	.252
2.29E-01	10.027	20.024	10	.74
2.89E-01	10.08	20.069	10	1.269
3.67E-01	10.173	20.149	10	1.869
4.64E-01	10.326	20.279	10	2.574
5.88E-01	10.569	20.481	10	3.424
7.44E-01	10.951	20.789	10	4.465
9.43E-01	11.537	21.242	10	5.756
1.19E+00	12.421	21.883	10	7.37
1.51E+00	13.72	22.747	10	9.396
1.91E+00	15.579	23.851	10	11.949
2.42E+00	18.168	25.186	10	15.171
3.07E+00	21.683	26.722	10	19.243
3.89E+00	26.359	28.419	10	24.393
4.92E+00	32.482	30.233	10	30.909
6.24E+00	40.41	32.13	10	39.158
7.90E+00	50.589	34.081	10	49.596
1.00E+01	63.609	36.07	9.999	62.823

Figure 7. A run result for drive impedance, printed for real and imaginary components. The data may be presented in the format or graph of Figures 2 and 3.

changes of a component value. This is important in "optimizing" a circuit.

The same process is useful in complete node impedance analysis. The input node is first checked, then the FET connection is removed. Connection can now be made to another node

to determine its impedance, and continued until all nodes have been checked.

DC conditions

Remembered that, ideally, all inductors are

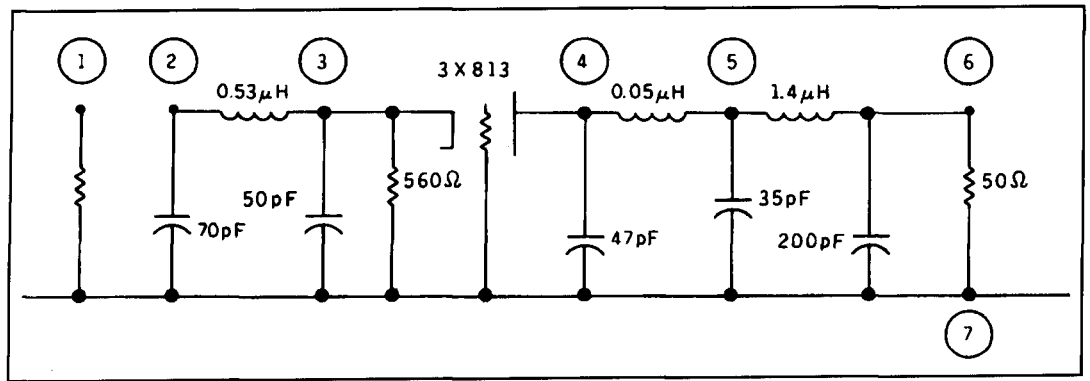


Figure 8. A more complex practice example, a simplified diagram of a G-G linear. A good exercise is to try adjusting LC values for maximum output. Check also the impedances at nodes 2 through 6. See text for use of node 1.

short circuits at DC, and all capacitors are infinite impedances. Transmission lines are simple low-resistance connections. These facts allow preparation of another circuit diagram for DC analysis. The ends of inductors and transmission lines become common with another node. Capacitors are simply omitted, but watch the requirement that there's at least one connection to each node. In critical circuits, resistance of inductors and capacitor leakage may replace the ideal component.

Power supply points must be freed from the common node, so they may be used for input. If only one point is used for power input, the point may be left floating, as it is the only input. If there are two or more power supplies, each supply one should be grounded through a small resistance. This represents the regulation of the power supply.

The voltage at a node when using this technique is a per-unit voltage—the node voltage for 1 volt of power supply voltage. Multiply by the actual power supply voltage. If there's more than one supply, the node voltage is the arithmetic sum of the voltages calculated this way for the separate supply point. Check the calculated no-signal operating point against component curves and data to see if the input parameters agree with those used in analysis.

If transistors are present, it may be necessary to make several tries to determine the bias point. This is due to the program assumption that the base resistance is a function of the base current—an input parameter. If bias conditions provide a different bias current, the assumed input value must be changed, and the bias calculation repeated. Repeat until there's negligible change in bias.

The programs on the disk

The program disk includes both source BASIC code (ASCII format) and the same code

in executable form. The source code is for those who want to try their own extensions to the program. In addition, the code is provided in DOS and Amiga format. Despite its lesser popularity, I consider the Amiga to be the best low-cost personal workstation.

Also included are several sample nets, callable from the program by entering 0 at the request for the number of nodes. Figures 2A through E show the node connections of the first set—the simple problems. As always, the spelling of the program name and the path to the file must be correct, or an error results. A second attempt can be made if an input error occurs.

Figure 3 shows the Component Connection file made when entering the circuit of Figure 2A for analysis. These files become a little more complex when active elements are entered to record the component parameters. This file is important because it's very difficult to determine the component connections and parameters from the array of files. This is evident in Figure 4, a printout of the file that describes the circuit of Figure 2A. See the NET94 program for file structure information.

Figures 5, 6, and 7 show the I/O table, the I/O graph, and the impedance table for the circuit of Figure 2A. These show the information provided by this program. The files shown in this figure may be used with many word processor and spreadsheet programs, or they may be printed directly using the TYPE command.

As a final example for study, I'll use a 100-watt linear amplifier that I designed and constructed. It uses three type 813 tubes in a grounded grid, and was described fully in Reference 4. The hand-drawn simplified circuit for analysis is shown in Figure 8. Here switched or variable elements have been replaced by a fixed component; values for the 15-meter amateur band are used. The input node is #1, the output #5, and the common node is #6. The plate-cathode capacitance appears between nodes 3 and 4. The input

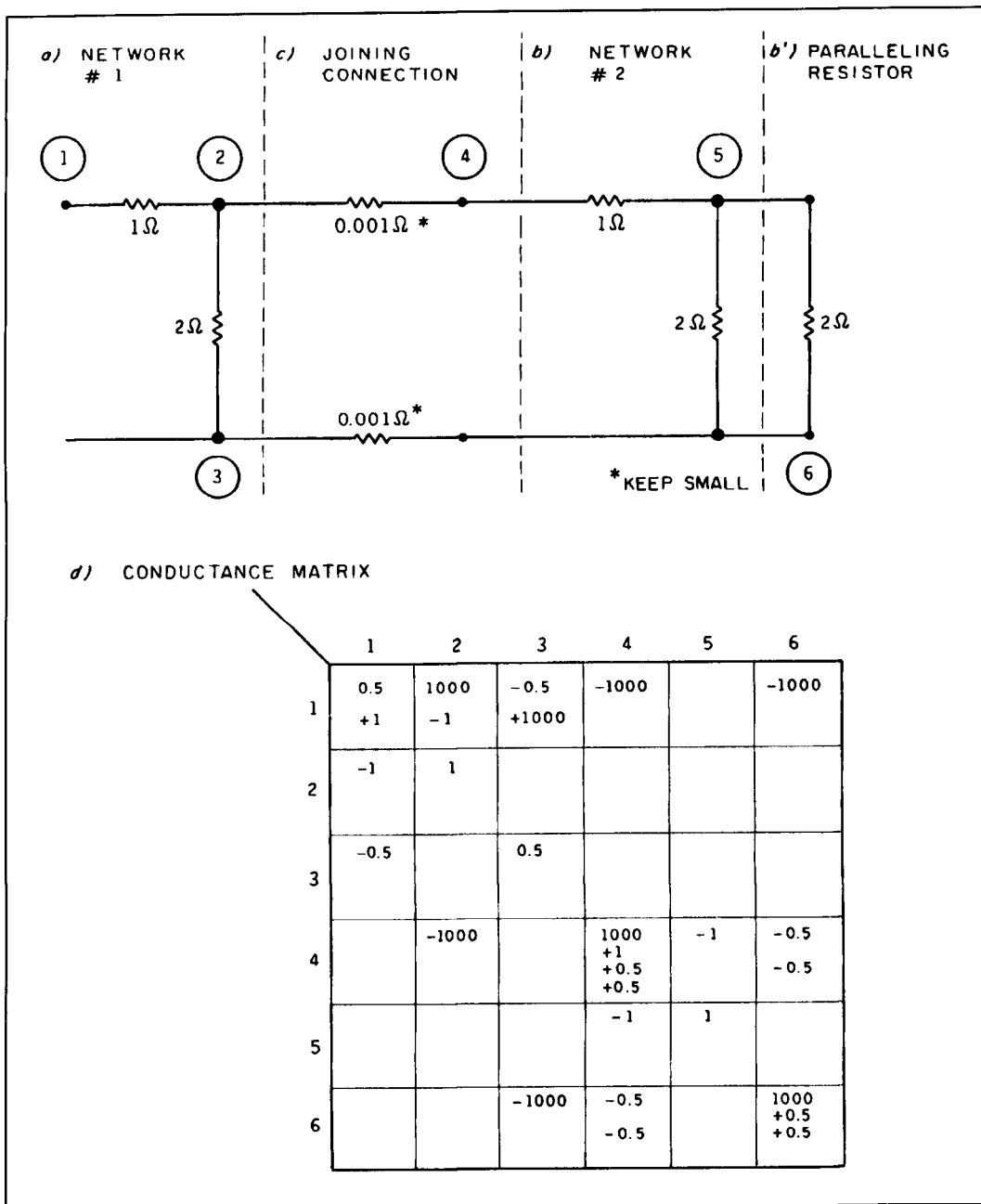


Figure 9. A simple example of use of the JOINNET program to create a more complex net. (A) Shows Figure 2B, used as is for the first net. (B) Shows how it's also used for the second net, but with a paralleling resistor. (C) Shows the combined net, as recorded by the matrix file. (D) Shows how this is prepared for analysis using NET94, by adding the paralleling resistor and two jumpers, represented by 1-milliohm resistors.

capacitance is absorbed in the capacitor between nodes 3 and common, and output capacitance is between node 4 and common. The small inductance between nodes 4 and 5 represents the plate lead inductance, important at 30 MHz!

Note that this amplifier uses a fixed step-up low-pass filter at the input, instead of the more common switched low-Q tuned circuit. A few components of the original aren't modeled, such as the inductance of the filament choke,

the plate feed choke, or the safety choke shunting the output capacitor. If conditions for another band are analyzed, the components 4-5, 4-6, and 5-6 would change.

The linear should show gain at the design frequency of 21 MHz, and should drop off on either side as frequency is changed. The curve should be close to the textbook resonance curves for a circuit Q of 12.

This circuit shows some of the practical analysis problems that may be encountered.

None of the available specifications provide grounded-grid operating conditions for the tube used. For this analysis, the screen mu-factor is used as the G-G gain. The plate resistance is assumed to be one-tenth of the pentode resistance, with three tubes in parallel. The plate-to-cathode and output capacitance are shown in the node diagram.

The circuit also illustrates another matter—that of input accuracy. In the tuned circuit, only two significant figures were used in input. This limits output accuracy. The point of resonance isn't exactly as designed. Also, the load presented to the tube is lower than needed for proper performance. The measured power gain of the amplifier is just over 10 dB, so the calculated gain should be slightly higher, because inductor loss is neglected. Varying component values to obtain the best operating point is a good practice exercise. Another practice item is to calculate the input and output impedances, as well as that presented as load to the tubes.

The JOINNET program

It's convenient to be able to treat small networks as components, joining them together to form a larger network. Examples of small networks would be a low-pass TVI filter, an IF amplifier, a audio stage, and so on.

The NET program structure isn't fully suited to this because of the array structure and the requirement that the highest numbered node be the signal ground. However, with a few work-arounds, two networks can be combined. This is the purpose of the JOINNET program.

Figure 9 shows a very simple junction problem—the cascading of two voltage dividers. The first half, nodes 1–3 are in the disk file DIV1.NET. The second half, nodes 4–6, isn't provided; instead, DIV1 is called—the intention being to change 2-ohm resistor 5–6 by paralleling another 2 ohms across the same nodes. The other operation needed is to join the two halves. As shown, this can be by a very small resistance, to simulate a wire connection. Alternatively, additional components can be introduced. However, to obtain proper input conditions, the common nodes of the first and second halves must always have a very low impedance between them, a small resistor or inductor or a large capacitor.

The joining procedure isn't difficult. JOINNET is started and the name and path of the two source nets entered. The name and path of the joined net is then entered. The program reads the number of nodes that will require later connection. The program then reads lines from the first

source net, padding these with null components as required by the size of the second net, and entering the result to the new net. The second source net is then read, padded, and saved. Finally, the name and reference date of the new net is saved. The process can then be repeated using the new net as one of the sources.

When complete, the new net is entered into NET94. Jumpers or new components can be entered, as required, to complete the final net schematic. Components can be either removed or replaced; shunt components can be introduced to obtain the desired values. Analysis can then proceed.

A weakness of this method is that an unnecessary node is created at each joining. One result is that complex nets are slower to execute than they would be if the net were created as a unit. The size of the component representing jumpers must be watched, because these can be feedback-producing mutual impedances.

Final comments

This program doesn't have the full power of SPICE analysis, but it does a very good job of analysis in the linear range. It's also very easy to use. Additionally, it's a very helpful tool for understanding how circuits work and, especially, which components are critical.

The program won't design circuits for you, but it sure helps perfect a design.

Obtaining copies

To obtain a paper copy of NET94 and its supporting program, send a legal sized envelope with \$1.28 in postage to: *Communications Quarterly*, P.O. Box 465, Barrington, New Hampshire 03825-0465.

A copy of the program on disk is available from MiniLab Books for \$7.50 per copy, plus shipping and handling. The NET94 program disk includes the text of the article and legends and supporting files for practice with the program. Be sure to specify NET94 disk, and state whether you desire a 5-1/4 or 3-1/2 inch disk. Send orders to: MiniLab Books, P.O. Box 21086, Daytona Beach, Florida 32121. ■

REFERENCES

1. Edward Niemeyer, "Network-analysis program runs on small computer system," *EDN*, February 1981, page 126.
2. W.A. Schneider, "Verify network frequency response with the simple BASIC program," *EDN*, October 7, 1997, page 87.
3. Richard B. Kolby, "The Poor Man's Engineering Workstation," *RF Technology Expo 86*, Anaheim, 1986.
4. R.P. Haviland, "Low-cost Linear Design and Construction," *Ham Radio*, December 1982, page 12.

QUARTERLY DEVICES

Low-cost SMD prototype construction

From an RF-design standpoint, surface mount device (SMD) construction has much to offer. Many troublesome high-frequency layout problems literally vanish when ultra-small leadless parts replace larger through-hole components. Automated SMD is also good news for manufacturers faced with the huge labor cost of manually stuffing boards. However, for those experimenters lacking \$15,000 SMD workstations and a library full of training materials, the road to SMD competence can be rough. Indeed, some consultants recommend avoiding SMD unless you're ready to memorize reams of data about industry standards, learn complex CAD programs, master specialized prototyping systems, and acquaint yourself with all the limits and quirks of your company's production equipment. Fortunately, despite the intimidating complexities of automated manufacturing, there are practical ways for us to "make stuff" using SMD without resorting to years of cloistered study, or settling for pushing chip resistors around with tooth-

picks under a magnifying glass. I'll cover some of those alternatives here.

The ESP Rework Kit

One useful item for the experimenter comes from ESP, Inc. of Lincoln, Rhode Island. They offer an introductory-level rework kit that provides basic tools and materials for repairing or prototyping small SMD circuit boards. One of the first lessons SMD builders learn is that most of the components are way too small to handle with your fingers! To make this task easier, the ESP Rework Kit contains an extremely useful device called a VACTweezer™. The VACTweezer is a small squeeze-bulb powered vacuum tool you can use to pick up extremely small SMD components and move them around on the pc board (see **Figure 1**). Several twist-lock pad/tip attachments come with the VACTweezer to accommodate various size and shape SMD packages. These are essentially the

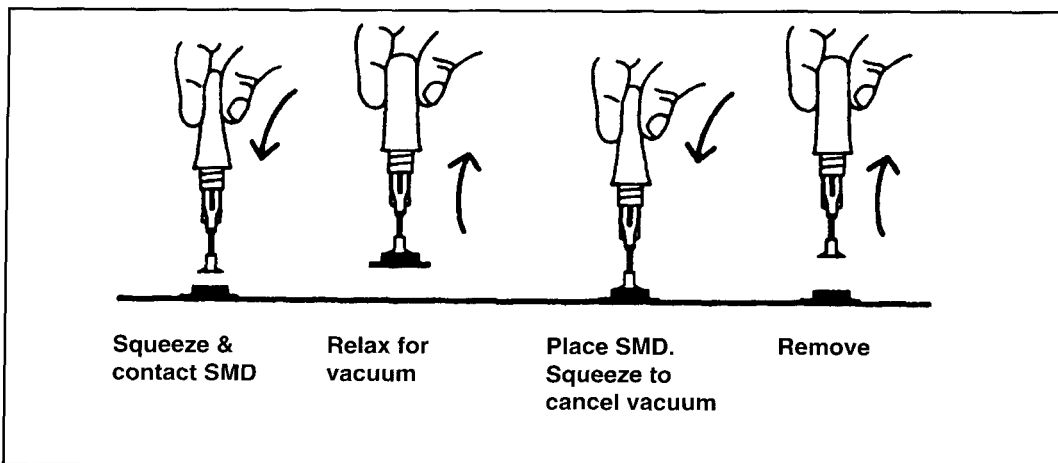


Figure 1. The VACTweezer squeeze-bulb powered vacuum tool.

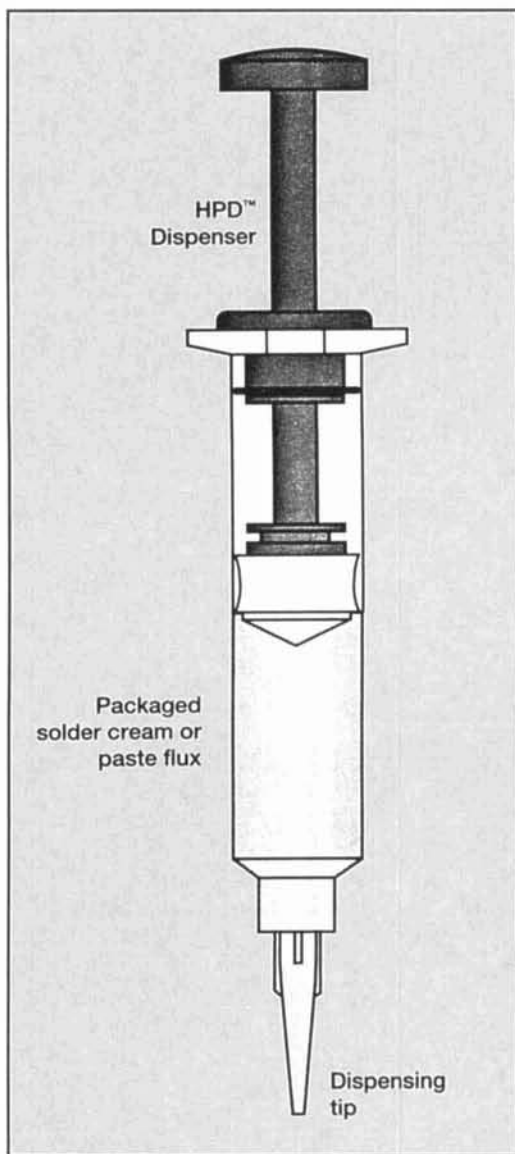


Figure 2. The ESP HPD dispensing system.

same tips you'd get if you purchased a more expensive suction-driven tool. However, in this instance, the vacuum is provided by a small squeeze bulb rather than by a motorized pump. For the part-time experimenter, the ESP VACTweezer offers a good alternative to a costly work-station vacuum pen.

The rest of the ESP Rework Kit is devoted to a simple system for dispensing solder paste and solder flux. If you want to get into SMD, you'll need to learn about various types of solder pastes and how to use them. The ESP kit provides a perfect opportunity. Solder paste is, in many ways, the solder of the future—in SMD pc-board production, wire solder is rarely used. Solder paste consists of a carefully formulated mixture of metal alloy particles that have been coated with flux and suspended in a sticky binder solution. In production, a carefully-con-

trolled portion of solder paste is applied to each pad before parts are installed on the pc board. Because the paste has a tacky consistency, this serves as a temporary adhesive with sufficient strength to hold newly installed parts in place until the board is heated. Heating the board in a controlled fashion causes the flux to activate, solvents to evaporate, and the metal alloys to liquefy—all in a carefully timed sequence. However, paste soldering methods need not be restricted to large-scale manufacturing. Indeed, it can work equally well for SMD repairs or one-of-a-kind prototype construction.

The ESP Rework Kit comes with two pre-filled 10-cc syringe hand dispensers containing ESP Solder-plus™ solder paste (also referred to as solder cream). The pre-filled solder-paste syringe makes up the main body of the ESP HPD™ dispensing system, shown in Figure 2. Other elements of the HPD system consist of a reusable plunger assembly, a disposable twist-lock applicator tip, and storage caps for the syringes. The disposable dispensing tip has a 0.023-inch diameter opening to shape and control the flow of solder cream during application. A box of 8 tips is provided with the kit, and packages of 50 may be reordered from ESP. Other opening diameters are available for different flow rates. When used properly, a little bit of solder cream goes a long way. ESP maintains that the use of solder creams can reduce solder use by from 50 to 80 percent. Thus, the two 10-cc dispensers that come with the kit should last most experimenters quite a while. Replacement boxes containing 10 refills are available directly from ESP. If you plan to store ESP solder paste for an extended period, keep it refrigerated to prevent deterioration. Guaranteed shelf-life at room temperature is approximately six months. In addition to two solder cream dispensers, the ESP Rework Kit also contains two pre-filled dispensers of a paste-flux. These will prove especially useful if you're using wire solder. Incidentally, if you do use roll solder for SMD work, choose a small diameter wire—no larger than 0.015 or 0.020 inch—to ensure good flow control.

Paste soldering can be accomplished with many heat sources. In industry, hot air, microflame, hot plate, laser, induction, convection, and IR are all used. However, most of us will probably begin our SMD prototyping careers using an iron. Paste soldering with an iron requires a somewhat different technique than wire soldering. For one thing, you probably won't need as much heat to produce wetting because the solder is already partially digested into 45 to 75 micron particles before you heat it. Also, solder pastes should be heated gradually at first, through pad or track conduction. If you plunge the tip of your iron

Tip Diameter	Catalog Number	Plating	Illustration of Tip	Tip Shape
No. 6 3/64" (.047", 1.1mm)	6-IS	Iron		Spade
	6-NS	Nickel		
	6-G	Gold		Chisel
	6-IC	Iron		
	6-NC	Nickel		
	6-3-IS	Iron		
	6-3-IC	Iron		Chisel - stubby length
No. 46 1/16" (.063", 1.5mm)	46-IS	Iron		Spade
	46-NS	Nickel		
	46-IC	Iron		Chisel
	46-NC	Nickel		
	46-3-IS	Iron		
	46-3-IC	Iron		Chisel - stubby length
No. 56 5/64" (.078", 1.9mm)	56-IS	Iron		Spade
	56-NS	Nickel		
	56-IC	Iron		Chisel
	56-NC	Nickel		
	56-3-IS	Iron		
	56-3-IC	Iron		
No. 8 (tapered to .012)	8-I	Iron		Needle
	8-X	Unplated		
	8-G	Gold		
No. 9 (tapered to .012)	9-I	Iron		Stubby Needle
	9-X	Unplated		
No. 20 (tapered to .020)	20-I	Iron		Cone with .035" Flat
No. 2 3/32" (.094", 2.3mm)	2-IS	Iron		Spade
	2-NS	Nickel		
	2-IC	Iron		Chisel
	2-NC	Nickel		
	2-G	Gold		
	2-NP	Nickel		
No. 86 1/8" (.125", 3.1mm)	86-IS	Iron		Spade
	86-NS	Nickel		
	86-IC	Iron		Chisel
	86-NC	Nickel		
No. 3 5/32" (.156", 3.9mm)	3-IS	Iron		Spade
	3-NS	Nickel		
	3-IC	Iron		Chisel
	3-NC	Nickel		
No. 4 3/16" (4.7mm)	4-NS	Nickel		Spade
	4-IC	Iron		
	4-NC	Nickel		Chisel
.187 Wide x .060	4-HK	Chrome		Hot Knife

Dimensions are before plating. For Iron Plated tips, add .010" to the tip diameter. If you don't find the tip you need here, give us a call. We're in business to make you more productive.

Table 1. Series 140 tips for Models M, C, G, and CSTC miniature soldering irons from M.M. Newman.

directly into a solder cream deposit and heat it rapidly, the flux solvents will boil off and spatter rather than evaporate normally. This, in turn, may cause gas voids and poor wetting. In manufacturing, paste soldering equipment is designed to heat connections in two stages—

first to a median temperature that will activate the flux and evaporate off solvents, and then to a higher temperature that will liquefy the metal alloys. For best results, you'll need to roughly simulate this process with your iron (not nearly as difficult to do as it sounds). Three common

fluxes are available with the ESP Rework Kit, and you must choose the one you prefer when ordering. RMA flux is a mildly activated rosin similar to that used in most wire-type electrical solders. RMA is highly effective, but leaves a sticky and mildly corrosive residue that requires the use of a flux solvent to remove. WS, or water soluble flux, is also quite effective—and it is becoming increasingly popular with pc-board manufacturers for environmental reasons. NC, a chemically stable no-clean flux, leaves a hard noncorrosive residue. NC flux is especially popular for prototype work and repairs because no additional cleaning steps are required. All three kits provide Sn62 solder, which has a liquidous alloy temperature of 354 degrees F (179 degrees C). Specific ESP Rework Kit order numbers are shown below:

- Sn62 solder with rosin flux (RMA) 6-KIT-18
- Sn62 solder with water soluble flux (WS) 6-KIT-19
- Sn62 solder with no-clean flux (NC) 6-KIT-20

Each ESP Rework Kit comes housed in a resilient bright yellow molded-plastic case, along with an illustrated instruction sheet describing how to use the VACTweezer and the solder dispensing items provided. If you aren't interested in the VACTweezer or prefilled flux dispensers, you may order a solder cream evaluation kit that provides all dispensing items plus 5 syringes of solder cream in any alloy and flux type (specify type when ordering). Rework Kits and Product Evaluation Kits both sell for \$59.95 when ordered direct. To obtain a catalog or place an order, call ESP at (800) 977-4377. For technical assistance with special applications, call (800) 338-4353. ESP Rework Kits may also be purchased from several catalog-house electronic distributors. In addition to the introductory products described here, ESP carries a complete line of fluxes and pastes, along with assembly-line time-pulse dispensers and vacuum pens. ESP, Inc. is located at 14 Blackstone Valley Place, Lincoln, Rhode Island 02865-1145, USA.

Antex Miniature Soldering Irons from M.M. Newman Corporation

Although there are many sophisticated soldering systems available for SMD products, most of us will be forced to forgo purchasing a \$3000 deluxe focused convection setup and settle for a low-wattage soldering iron with a small tip. Enter the Antex miniature irons.

Designed especially for SMD applications, the Antex iron is physically small, reasonably priced, and very easy to handle. Despite its small physical size and relatively low wattage, warm-up time is fast and heat delivery is efficient. This is because the iron's heating element is located directly beneath the tip rather than midway down the iron stem. Indeed, the manufacturer claims their 18-watt model delivers about the same heating capacity as most 30-watt irons. Three miniature models are available for different tip temperature:

- **Model M:** Has a 12-watt heating element that produces a tip temperature of 600 to 650 degrees F (316 to 343 C). Ideal for work with heat-sensitive components. Single lot price is \$19.46 for 3-wire, \$18.98 for 2-wire.
- **Model C:** Has a 15-watt element that produces a tip temperature of 665 to 700 degrees F (343 to 371 C). Useful when somewhat more heat is required for prototype and assembly work. Single lot price is \$19.73 for 3-wire, \$19.27 for 2-wire.
- **Model G:** Has a 18-watt element that produces a tip temperature of 700 to 750 degrees F (371 to 399 C). Highest wattage miniature iron available. Useful for all applications, and the best choice for use with the optional Dial-temp Heat Controller. Single lot price is \$19.95 for 3-wire, \$19.56 for 2-wire.

You must specify a 2- or 3-wire power cord when you order. Personally, I recommend ordering a 3-wire version—the cord diameter is small and cord material extremely flexible. Use of a grounded iron is always a good idea, especially when installing FETs and CMOS devices. To specify 3-wire, add /3U to the letter designating the iron of choice (Model G/3U, for example). For a 2-wire cord, specify /2U. All irons are also available in 24-volt AC or DC models. Tips aren't included in the base price, and must be ordered separately.

Speaking of tips, M.M. Newman offers over 50 sizes and shapes, including those with nickel, iron, chrome, and gold jackets—plus bare copper (see **Table 1** for a complete listing). Tip shapes include spade, chisel, needle, cone, and knife; tip diameters range from 3/64 to 3/16 inch. These tips are specially manufactured in the U.S. for M.M. Newman, and are designed to friction-fit over the iron's heating element without a set-screw or threaded shaft to corrode and lock up. For starters, a small-diameter chisel tip is probably best. However, you may want to experiment with more than one style tip for various SMD parts. Tips can be exchanged quickly without turning off the iron. Single-lot pricing ranges from \$1.71 for nickel-plated economy-grade models to \$5.76 for gold plat-

ing. Iron-clad tips offer the best compromise between long life and low price. Quantity-discount pricing is available on all irons and tips.

In addition to providing miniature irons and a wide selection of tips, M.M. Newman also manufactures a Dial-temp Heat Controller that is an extremely useful workstation addition—especially if you work with temperature-sensitive components. This compact AC power unit provides full control over heating element output, and will work with virtually any iron rated from 15 to 1600 watts. The Dial-temp Heat Controller includes a 3-wire plug and AC receptacle for \$35.23.

Components for Antex irons are made in England, and irons are assembled to customer specification at the M.M. Newman plant in Massachusetts. M.M. Newman has been in business since the 1950s, and began importing and assembling Antex products in the 1970s. They offer a full line of soldering products, and provide quantity discounts on all irons and tips. A catalog and price list is available on request. For more product information, price quotes, or to place an order, contact them at 24 Tioga Way, P.O. Box 615, Marblehead, Massachusetts 01945, or call (617) 631-7100. To fax, dial (617) 631-8887.

SMD construction aids from the Mall

While there are a few low cost-items available in the electronic catalogs to support SMD construction, other items are quite expensive. This leaves plenty of room for improvisation as you round up your collection of SMD tools. Consider, for example, the task of inspecting and reading the microscopic numbers printed on chip resistors and capacitors. One solution is to purchase a 10-20X stereo-view lighted microscope for about \$1400. However, before you put down your money, you might want to check out the RadioShack X30 illuminated microscope for \$9.99 (RS 63-851). This simple hand-held device is perfectly adapted for inspecting SMDs, and costs about \$1390 less than the alternative suggested in major industrial catalogs.

Lighted inspection magnifiers are another item where you can save money. While industrial-grade magnifier lamps cost from \$150 to \$350, you can pick up a perfectly adequate unit at your local discount department store for \$15 to \$40. RadioShack also sells a useful lighted hand-held magnifier for a mere \$5.99 (RS 63-848). And, while you're in RadioShack, why not pick up an inspection penlight for \$2.69 (RS 61-2626) and a dental probe set for \$9.95 (RS 64-1941). For tweezers, try a drug store or

This kit contains 10 chip resistors of every 5% value from 10 ohms to 10 megohms (145 values + 0 ohm jumper), plus a bonus of 10 additional chip resistors in the 8 values of 0 ohm jumper, 10 ohms, 100 ohms, 1k, 10k, 100k, 1 meg, and 10 meg. This is a total of 1540 resistors.

000 = 0 ohm jumper	150 = 15 ohms	220 = 22 ohms	330 = 33 ohms	470 = 47 ohms	680 = 68 ohms
100 = 10 ohms	151 = 150 ohms	221 = 220 ohms	331 = 330 ohms	471 = 470 ohms	681 = 680 ohms
101 = 100 ohms	152 = 1.5k	222 = 2.2k	332 = 3.3k	472 = 4.7k	682 = 6.8k
102 = 1k	153 = 15k	223 = 22k	333 = 33k	473 = 47k	683 = 68k
103 = 10k	154 = 150k	224 = 220k	334 = 330k	474 = 470k	684 = 680k
104 = 100k	155 = 1.5 meg	225 = 2.2 meg	335 = 3.3 meg	475 = 4.7 meg*	685 = 6.8 meg*
105 = 1 meg					
106 = 10 meg*					
110 = 11 ohms	160 = 16 ohms	240 = 24 ohms	360 = 36 ohms	510 = 51 ohms	750 = 75 ohms
111 = 110 ohms	161 = 160 ohms	241 = 240 ohms	361 = 360 ohms	511 = 510 ohms	751 = 750 ohms
112 = 1.1k	162 = 1.6k	242 = 2.4k	362 = 3.6k	512 = 5.1k	752 = 7.5k
113 = 11k	163 = 16k	243 = 24k	363 = 36k	513 = 51k	753 = 75k
114 = 110k	164 = 160k	244 = 240k	364 = 360k	514 = 510k	754 = 750k
115 = 1.1 meg	165 = 1.6 meg	245 = 2.4 meg	365 = 3.6 meg*	515 = 5.1 meg*	755 = 7.5 meg*
120 = 12 ohms	180 = 18 ohms	270 = 27 ohms	390 = 39 ohms	560 = 56 ohms	820 = 82 ohms
121 = 120 ohms	181 = 180 ohms	271 = 270 ohms	391 = 390 ohms	561 = 560 ohms	821 = 820 ohms
122 = 1.2k	182 = 1.8k	272 = 2.7k	392 = 3.9k	562 = 5.6k	822 = 8.2k
123 = 12k	183 = 18k	273 = 27k	393 = 39k	563 = 56k	823 = 82k
124 = 120k	184 = 180k	274 = 270k	394 = 390k	564 = 560k	824 = 820k
125 = 1.2 meg	185 = 1.8 meg	275 = 2.7 meg	395 = 3.9 meg*	565 = 5.6 meg*	825 = 8.2 meg*
130 = 13 ohms	200 = 20 ohms	300 = 30 ohms	430 = 43 ohms	620 = 62 ohms	910 = 91 ohms
131 = 130 ohms	201 = 200 ohms	301 = 300 ohms	431 = 430 ohms	621 = 620 ohms	911 = 910 ohms
132 = 1.3k	202 = 2k	302 = 3k	432 = 4.3k	622 = 6.2k	912 = 9.1k
133 = 13k	203 = 20k	303 = 30k	433 = 43k	623 = 62k	913 = 91k
134 = 130k	204 = 200k	304 = 300k	434 = 430k	624 = 620k	914 = 910k
135 = 1.3 meg	205 = 2 meg	305 = 3 meg	435 = 4.3 meg*	625 = 6.2 meg*	915 = 9.1 meg*

All chip resistors are .10 watt, 5%, 0805 size 1.25mm (.050") x 2.0mm (.080")

Table 2. The CR-1 resistor kit assortment.

your local hobby shop. Prices range from \$2 to about \$4.50 for a wide variety of shapes and sizes. Finally, if you're having a problem persuading small SMD pieces to hold still during soldering, read the sidebar on how to build a

This kit contains 5 chip capacitors of every 10% value from 1pf to .33μf (67 values) plus a bonus of 5 additional chip capacitors in the 6 values of 1pf, 10pf, 100pf, 1000pf, .01μf, and .1μf. This is a total of 365 capacitors.

1R0 = 1pf NPO 100 = 10pf NPO 101 = 100pf NPO 102 = 1000pf X7R 103 = .01μf X7R 104 = .1μf X7R 25v*	1R8 = 1.8pf NPO 180 = 18pf NPO 181 = 180pf NPO 182 = 1800pf X7R 183 = .018μf X7R 184 = .18μf Z5U*	3R3 = 3.3pf NPO 330 = 33pf NPO 331 = 330pf NPO 332 = 3300pf X7R 333 = .033μf X7R 25v 334 = .33μf Z5U 25v*	5R6 = 5.6pf NPO 560 = 56pf NPO 561 = 560pf NPO 562 = 5600pf X7R 563 = .056μf X7R*
1R2 = 1.2pf NPO 120 = 12pf NPO 121 = 120pf NPO 122 = 1200pf X7R 123 = .012μf X7R 124 = .12μf Z5U*	2R2 = 2.2pf NPO 220 = 22pf NPO 221 = 220pf NPO 222 = 2200pf X7R 223 = .022μf X7R 224 = .22μf Z5U*	3R9 = 3.9pf NPO 390 = 39pf NPO 391 = 390pf NPO 392 = 3900pf X7R 393 = .039μf X7R 25v	6R8 = 6.8pf NPO 680 = 68pf NPO 681 = 680pf NPO 682 = 6800pf X7R 683 = .068μf X7R*
1R5 = 1.5pf NPO 150 = 15pf NPO 151 = 150pf NPO 152 = 1500pf X7R 153 = .015μf X7R 154 = .15μf Z5U*	2R7 = 2.7pf NPO 270 = 27pf NPO 271 = 270pf NPO 272 = 2700pf X7R 273 = .027μf X7R 274 = .27μf Z5U*	4R7 = 4.7pf NPO 470 = 47pf NPO 471 = 470pf NPO 472 = 4700pf X7R 473 = .047μf X7R*	8R2 = 8.2pf NPO 820 = 82pf NPO 821 = 820pf X7R 822 = 8200pf X7R 823 = .082μf X7R*

All chip capacitors are 50v (except those so marked above), 10%, 0805 size 1.25mm (.050") x 2.0mm (.080") EXCEPT * Which are 1206 size 1.6mm (.063") x 3.2mm (.126") and all Z5U which are 20% tolerance.

Table 3. The CC-1 capacitor kit assortment.

mini-SMD workstation. This clipboard-sized construction platform features a simple tool for holding individual SMDs firmly in place on the pc board while you work. The parts for this item will probably set you back about \$15, and

most of the materials can be purchased at—where else—the local mall!

Conclusion

As one industry trainer explained to me, the only real way to learn about SMD construction is to sit down and work with it. He suggested that attending classes and reading volumes of material may prove useful, but too much study can just as easily turn into an exercise in self-intimidation. I believe he's right! The sooner those of us in the RF business tool up and learn to work with SMDs in a comfortable and practical way, the sooner we can reap the obvious benefits these new products offer (some of us still remember how loud the old-timers howled when tubes went out and transistors came in). Toward that end, any builders with practical SMD construction tips are invited to submit them to the Quarterly to share with our readers. Together, perhaps we can muddle through this revolution with our eyesight and sanity intact!

More on surface-mount kits

As he did in our Winter 1995 issue, Senior Technical Editor Peter Bertini, K1ZJH continues his investigation of surface mount component kits. This time he looks at two offerings by Communications Specialists, Inc.

The Communications Specialists SMC Kits

While there are several good surface-mount capacitor prototype kits on the market, finding a companion chip resistor assortment is a challenge. I've encountered many chip resistor kits that only span a limited range of resistance values, say from 1.0 to 82 ohms. Thus, if you want to have most of the common 5 percent resistor values on hand, you must purchase several different kit assortments. While you do end up with many thousands of components at pennies apiece, the total cost is very high for the home or small service shop. Who really needs to have 100 10-meg resistors on hand?

Communications Specialists, Inc. offers two noteworthy surface-mount-component (SMC) kits that should be of great interest to small shops, design engineers, and radio amateurs. Another bonus (and a very large one in my opinion!) is that Communications Specialists sells "refill" quantities (minimum of five of each value for capacitors, for 10 of each value for resistors, with a reasonable \$10 minimum order). This lets you keep your assortment kit complete. The parts come on sections cut from

tape “strip” carriers used for automatic feeding in automated pc board assembly machines. The tape strips provide a convenient method for separating the different component values and for storage. There’s a sliding price scale depending on how many “strips” you order. Piece reels of up to 5,000 resistors are available. You don’t need to own a kit to order component strips. A special order form is available for these components.

Communications Specialists is best known for their extensive line of subaudible and audible tone signaling products. I suspect this new product line was created to assist two-way radio shops now servicing units that use surface mount technology.

The Communications Specialists CR-1 Chip Resistor Prototype Kit

The CR-1 resistor assortment contains 1,540 5-percent resistors. The kit contains each 5 percent value from 10 ohms through 10 megs. There are also an extra ten resistors included for each value of 10, 100, 1000, 10 k, 100 k, 1 meg, and 10 megs. Twenty “0” ohm jumpers also come with the kit. **Table 2** lists all the resistor values in the CR-1 kit. In the 0805 SMT packages, you’ll find 3.3 meg and lower values resistors rates at 1/10th of a watt (see **Figure 3**, size code line 1). The larger 1206 SMT package carries 3.6 to 10-meg resistors rated at 1/8th of a watt (see **Figure 3**, size code line 2).

Every resistor is marked with a three digit code showing its value. For example, a 10-meg resistor is marked 106. A magnifying glass sure helps here! Each tape reel strip of 10 resistors also has a printed label for easy identification. The presorted resistors come in a hinged plastic container with 24 compartments. Each compartment contains decade-related values. That is, the first compartment contains the values 0, 10, 100, 1000, etc., up to 10 megs. A parts listing for each compartment is affixed under the container lid. The price of this kit is \$49.95.

The Communications Specialists CC-1 Chip Capacitor Prototype Kit

This 365-piece capacitor kit contains five chip capacitors for each 10 percent value from 1 pF to 0.33 μ F—a total of 67 different values! A bonus of five extra capacitors is included for each of the six values of 1 pF, 10 pF, 100 pF, 1000 pF, 0.01 μ F, and 0.1 μ F. **Table 3** presents a complete list of capacitors. This kit covers a

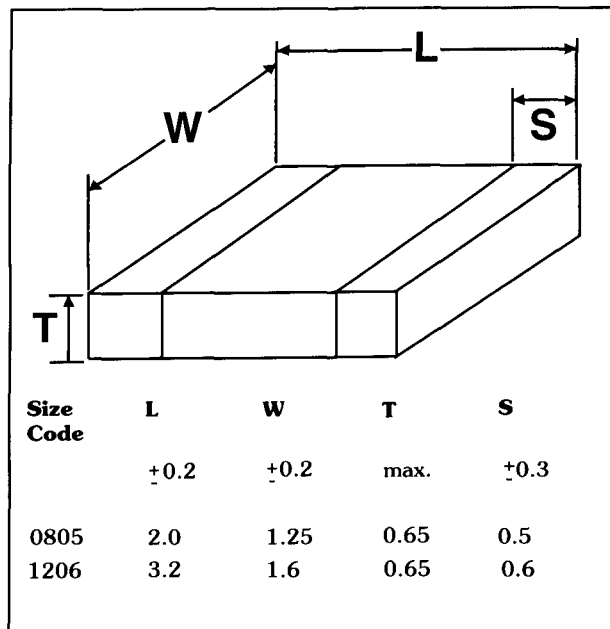


Figure 3. Length, width, thickness, and solder area data for 0805 and 1206 packages.

majority of the capacitor values needed for RF, audio, and general-purpose bypassing. Odd or special values can be obtained by piggy-backing capacitors.

All capacitors in the CC-1 are rated at 50 volts, except for five values listed below. Capacitor values from 1 to 820 pF are NPO temperature coefficient. These capacitors are 0805 SMT size (see **Figure 3**, size code line 1). Capacitor values from 1000 pF to 0.1 μ F are X7R temperature coefficient. Capacitor values of 0.1 μ F and larger are found in the 1206-size SMT packages (see **Figure 3**, size code line 2). They have a Z5U temperature coefficient and a 20-percent tolerance rating. Capacitors with values of 1.0 μ F, 0.033 μ F, 0.039 μ F, 0.1 μ F, AND 0.33 μ F are rated at 25 volts.

The CC-1 capacitor prototype comes in a 12-compartment hinged plastic box. The capacitors are shipped presorted in a similar “decade” values fashion as the resistor assortment. Unlike the resistor packages, the capacitor bodies aren’t marked with their individual values. They should be kept on the tape carriers for identification. Again, a parts list of the compartment contents accompanies each kit.

I’m very pleased with the CC-1 and CR-1 prototype kits. I couldn’t ask for more in a start-up resistor assortment, and the capacitor values are the best selection for a kit in this price class that I’ve seen to date. I appreciate being able to reorder whatever quantities are needed to keep my kits full—and at a fair price. Many retailers require subsequent minimum orders of 1,000 of a given value, making

restocking both expensive and wasteful. At \$49.95 each, the Communications Specialists SMC prototype kits are worth looking into.

If you wish to contact Communications Specialists about their SMC kits, you may write

to them at: Communications Specialists, Inc., 426 West Taft Avenue, Orange, California 92665-4296. Phone numbers are as follows: local, (714) 998-3021; fax, (714) 974-3420; order (800) 854-0547. ■

A Low-cost Mini-workstation for SMD Construction

When it comes to SMD construction, its no secret that human hands are too big to handle flea-sized leadless parts. Indeed, without the right tools, forcing a chip resistor to hold still while you solder it can prove an exercise in extreme frustration. Unfortunately, the right tools for this job—at least by industry standards—may cost from \$12,000 to \$15,000 per workstation. However, with a little improvisation, you can forego the high-price spread and get the job done for just a few bucks! Here's a very simple low-cost experimenter's SMD workstation that's guaranteed to ease your pain.

Description

The SMD mini-workstation shown in **Photo A** is built on a 10 x 12-inch piece of fiberboard liberated from a legal-sized clipboard. I glued an inexpensive mousepad—foam rubber side up—onto the lower area of the board to provide a non-skid workpad for pc boards. I then designed a special holding tool that applies pressure to SMD parts and keeps them in place for soldering.

The holding tool is like a tiny third hand. A small-diameter holding pin is mounted on the end of a square telescopic arm. I used square tubing for the telescopic arm to prevent the holding pin from rotating to the side. The telescoping arm is supported on an articulated mount that permits side-to-side and up-or-down movement—much like a record-player tone arm. This combined X,Y, and Z-axis mobility allows the holding pin to be positioned anywhere on the pc-board workpad. Once in place, the pin exerts a controlled downward force, pressing the SMD firmly against the pc board surface and immobilizing it. Downward pressure is generated in two ways—by force of gravity, and by the contraction of a rubber-band “bungie” attached to the arm near its mount. The force of the bungie dominates when the moment of the arm is short, and gravity dominates when the moment of the arm is long. Combined, these two vectors maintain a fairly uniform amount of pressure over the extension range of the instrument. Downward force must be regulated because too much pressure will inhibit free movement of

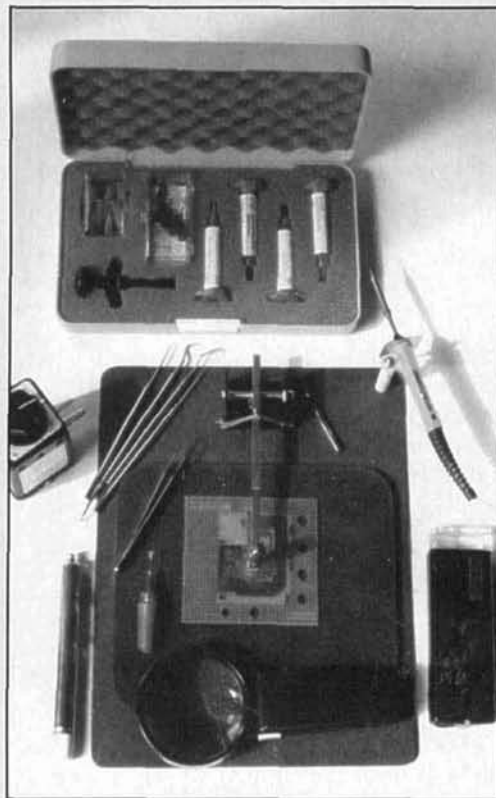


Photo A. Clipboard-sized SMD mini-workstation takes up little bench space and hangs on a wall hook when not in use.

the telescopic arm. It can also turn small SMD parts into a micro-sized tiddlywinks!

Nearly everything you need to build the workstation should be available locally at an average-sized shopping mall—the clipboard and mouse pad came from a discount department store, hardware came from a HWD superstore, and the K&S brass materials came from a hobby shop. Standard home shop tools were used to prepare materials for assembly. Many of the construction accessories I use with the workstation are low-cost items sold at RadioShack.

Arm assembly

Refer to **Figure 4** for dimension and assembly details. When soldering the round axle to

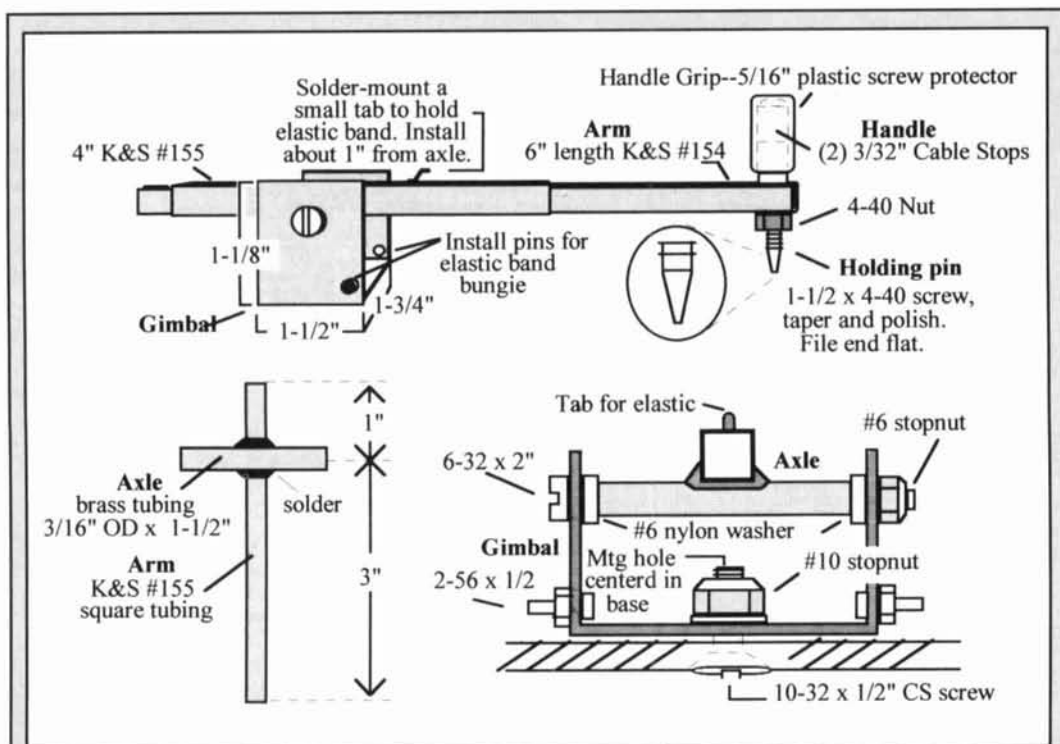


Figure 4. Construction details for SMD holding arm and pin.

the square extension arm, clamp both pieces in place to prevent movement. To ensure smooth telescopic action of the arm, carefully deburr both square tubes and polish the outer surface of the smaller one with steel wool. Test-slide the smaller tube into the larger, trying all possible mating combinations for smoothest extension (one way usually works better than the rest). Once this is determined, you can orient the holding pin and mount it at the outer end of the smaller tube.

The arm mounting gimbal is fabricated from sheet aluminum. This is drilled to pattern and bent into a U-shaped bracket using a vice or sheet metal-brake. Mount the gimbal at the top-center of the workstation board, as shown in **Photo A**. Tighten the base mounting screw so the gimbal turns freely, but without excessive sloppiness or jiggle (a stop nut is used to retain the adjustment). Next, mount the arm on its gimbal using the specified hardware. Tighten the stop nut on the mounting screw until the arm assembly moves up and down without excess sloppiness or drag. Apply a dry lubricant to the smaller section of the telescopic arm to ensure smooth operation. Finally, select a light-weight rubber band and install it using the arm tab and the holes provided on the gimbal. You may have to experiment with different length bands—or with different rigging—to obtain the ideal amount of downward pressure. When adjustments are complete, the telescoping arm and its holding pin should move freely

to any location on the pc workpad without binding or sticking.

Using the holding pin

When properly set up, the mini-workstation is easy to use. First, position your pc board in the center of the workpad. If you're using wire solder, it's recommended (but not essential) that you apply a small bead of flux paste to the appropriate pads with a controlled-flow applicator before mounting the part. If you're using solder paste, dispense a small quantity on each pad using a controlled-flow applicator. Once the part site is prepped, carefully position the SMD on its pads using a pointed-tip hand tweezer or a vacuum tweezer such as the ESP VACTweezer.™ Position the holding pin directly over the SMD, and gently lower it onto the part's midsection. If the device is an IC, be sure to check for pad alignment using an inspection magnifier. IC alignment needs to be exact, and you can make small adjustments easily using a dental probe when the holding pin is in place. Finally, apply heat, soldering each pin or tinned surface to its pad. The part should remain firmly seated throughout the operation. When working with static-sensitive devices, remember to ground the holding pin! You can do this do easily by attaching a ground lead to the axle portion of the extension arm.

To maintain your workstation's telescopic

arm, periodically remove, clean, and lubricate the smaller section of square tubing. Also, check gimbal and axle tension periodically—adjusting if necessary.

Conclusion

At first, the concept for this SMD mini-workstation seemed like a pretty quirky idea.

However, it has worked out well—proving vastly superior to the “toothpick and magnifying glass” methods familiar to many first-time SMD experimenters. In addition to gaining experience with my own workstation, I’ve farmed my prototypes out to others for informal beta testing. So far, the responses have been “thumbs up.” Good luck with yours, and let me know how it works!

PRODUCT INFORMATION

New AD421 DAC from Analog Devices, Inc.

Analog Devices, Inc. has introduced the AD421 loop-powered digital-to-analog converter (DAC) designed to meet the needs of smart transmitter manufacturers with industrial control applications. The 16-bit DAC sends 4–20 mA signals to a microcontroller to control a variety of digital processing functions. It offers a zero-scale 4 mA output current with $\pm 0.1\%$ offset error and a 20 mA full-scale output current with $\pm 0.2\%$ gain error. Full-scale settling time to $\pm 0.1\%$ occurs within 5 ms.

The AD421 includes an on-board voltage regulator which can provide +5 V, +3.3 V, or +3 V outputs, as well as on-board +1.25 V and +2.5 V precision reference voltages. The device also features a high-speed 2 Mb/s serial interface and a clock oscillator circuit, in addition to a programmable alarm current capability which allows the transmitter to send “out of range” currents to indicate a transducer fault.

The AD421 is fully-compatible with standard Highway Addressable Remote Transducer (HART®) protocol or other similar FSK serial communication methods.

The AD421 is available in 16-pin, 0.3 inch-wide plastic DIP, 16-lead, 0.3 inch-wide SOIC, and 16-lead, 5.3 mm-wide SSOP packages. The part is specified over the standard industrial temperature range of -40° to $+85^{\circ}\text{C}$, and costs \$6.95 in 1,000s. Delivery from stock.

For more information, contact Analog Devices, Inc., Ray Stata Technology Center, 804 Woburn Street, Wilmington, MA 01887; phone 617-937-1428; fax 617-821-4273.

New Converters from B&B Electronics

B&B Electronics Mfg. Co. has announced the release of four port-powered RS-232 to RS-422/485 converters. Each converter is packaged in a compact DB-9 hood. These units convert RS-232 TD and RD lines to balanced RS-422/485 signals. The pinouts of the 422LP9R and 485LP9R matches a SMPTE (video standard) compatible controlling device.

All of the converters are powered from the RS-232 handshake lines DTR and RTS (one

must be high). The RS-422/485 driver is enabled/disabled with RTS. The receiver is constantly enabled on RS-422 units. On RS-485 units, the receiver is disabled when the driver is enabled and is enabled when the driver is disabled. All of the converters have a female DB-9 connector on the RS-232 side. The 422LP9R and 485LP9R have a female DB-9 connector on the RS-422/485 side. The 422LP9TB and 485LP9TB have terminal blocks on the RS-422/485 side and can be externally powered with a 12 VDC supply. All are priced at \$59.95 each.

For more information, and to receive a free catalog of *Serial Communication Interface and Control Equipment*, contact B&B Electronics Manufacturing Co., 707 Dayton Rd., P.O. Box 1040, Ottawa, IL 61350; phone 815-433-5100 (8 am to 4:30 pm Central); 24-hour fax 815-434-7094; 24-hour BBS 815-434-2927; e-mail catrqst@bb-elec.com; Home Page <http://www.bb-elec.com>.

New RF Antenna Measurement System From HP

Hewlett-Packard Company now has an integrated, fully automated RF antenna test system. The HP 85375 antenna test system measures, plots and analyzes antenna performance. It also performs pattern comparisons. Pattern plots generated by the test system illustrate the quality of a finished product and allow antenna manufacturers to demonstrate expected product performance, quality and reliability to their customers.

The HP 85375 operates via Windows™-based software and the network analyzer can be used independently to measure antenna impedance or make measurements on RF components.

The HP 85375A RF antenna measurement system is available from Hewlett-Packard for \$65,000. Delivery is estimated at eight weeks from receipt of the order.

For more information, contact Hewlett-Packard Company, Direct Marketing Organization, P.O. Box 58059, MS51L-SJ, Santa Clara, CA 95051-8059.

USING INEXPENSIVE DIGITAL PANEL METERS

Use inexpensive products to create your own high-performance projects

Often, various projects require some type of panel meter as an indicator. A good example is a general-purpose laboratory power supply. Meters can be a major part of the expense of such a project. Even inexpensive meters, of at least some reasonable quality, can be costly. However, there are a number of digital meters that can provide comparatively inexpensive solutions to metering needs. As a matter of fact, meter requirements for custom hand-held projects can be satisfied with a little creative use of available products. I'll review briefly the basic operation of common digital panel meters (DPM) and hand-held multimeters and provide a few ideas for low-cost digital meters for various project needs.

Currently, I'm building six lab power supplies. I need two panel meters for each because I want to measure both voltage and current simultaneously. The price of a typical 2-percent analog D'Arsonval meter (the common needle-type meter) is about \$50. So, just the meters for this project could cost as much as \$600. There are less expensive analog meters, but those are better suited for applications such as battery chargers where only a rough indication of the measured parameter is needed and where the meter must be very rugged. Very inexpensive meters are generally unsuitable for applications

where some degree of accuracy is needed.

Another suitable meter is the digital panel (DPM) type. The DPM is a good choice for many applications, and even the lowest-precision DPM is much more precise than the best analog meter. A number of general-purpose DPMs are offered by various manufacturers. About the least expensive are the Jewell line, available from Digi-Key. These are excellent meters, but even the lowest-priced unit is about \$34. That's certainly less costly than conventional analog meters, but it still represents a significant expense.

There are a number of other DPM alternatives, if you're willing to make a few modifications. One is a very inexpensive DPM available from various sources. I purchased several from Hosfelt at about \$8 each—model number PM-128, Hosfelt part number 39-177. Hosfelt also carries another DPM, part number 39-165, which is also strangely designated a model number PM-128. These two units are identical electrically, but the 39-165 doesn't have a mounting bezel and costs \$13. I couldn't find any other significant difference between the two. The 39-177 is the better buy, but the 39-165 is just as useful. Although these meters are adequate for many applications, they do require some modification before they can be used as

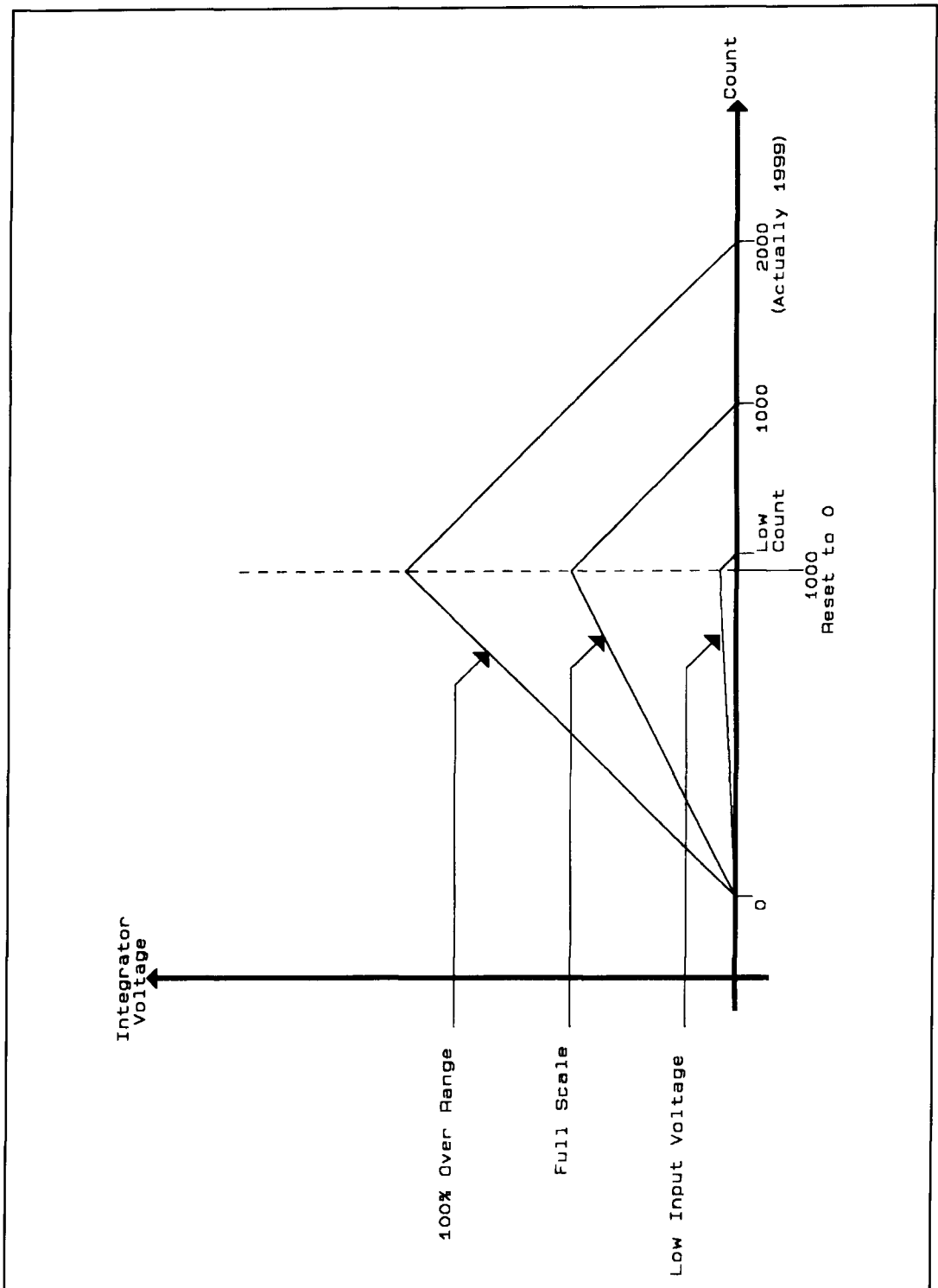


Figure 1. Dual-slope integrator waveform.

universal panel meters. Because I can save as much as \$400 to \$500 on my power-supply project, it's worth the time.

Some projects require a hand-held package with an appropriate meter. This type of project presents at least two questions—what type of

enclosure and what meter should I use? Then, how do I put it all together so it not only functions, but looks at least presentable? There are a number of inexpensive hand-held digital multi-meters that can be very useful as the starting point for these projects.

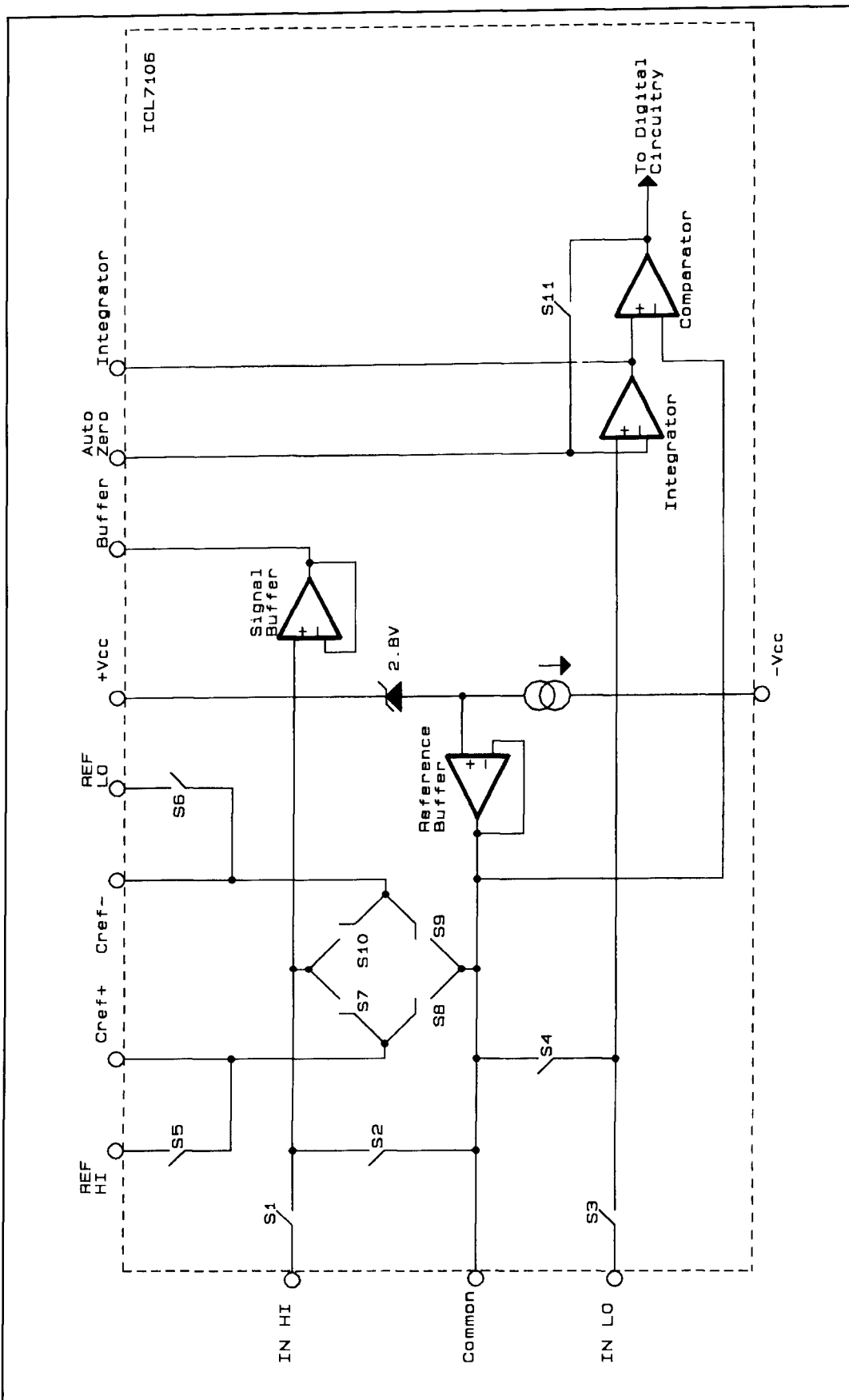


Figure 2. ICL7106 dual-slope analog-to-digital converter analog section.

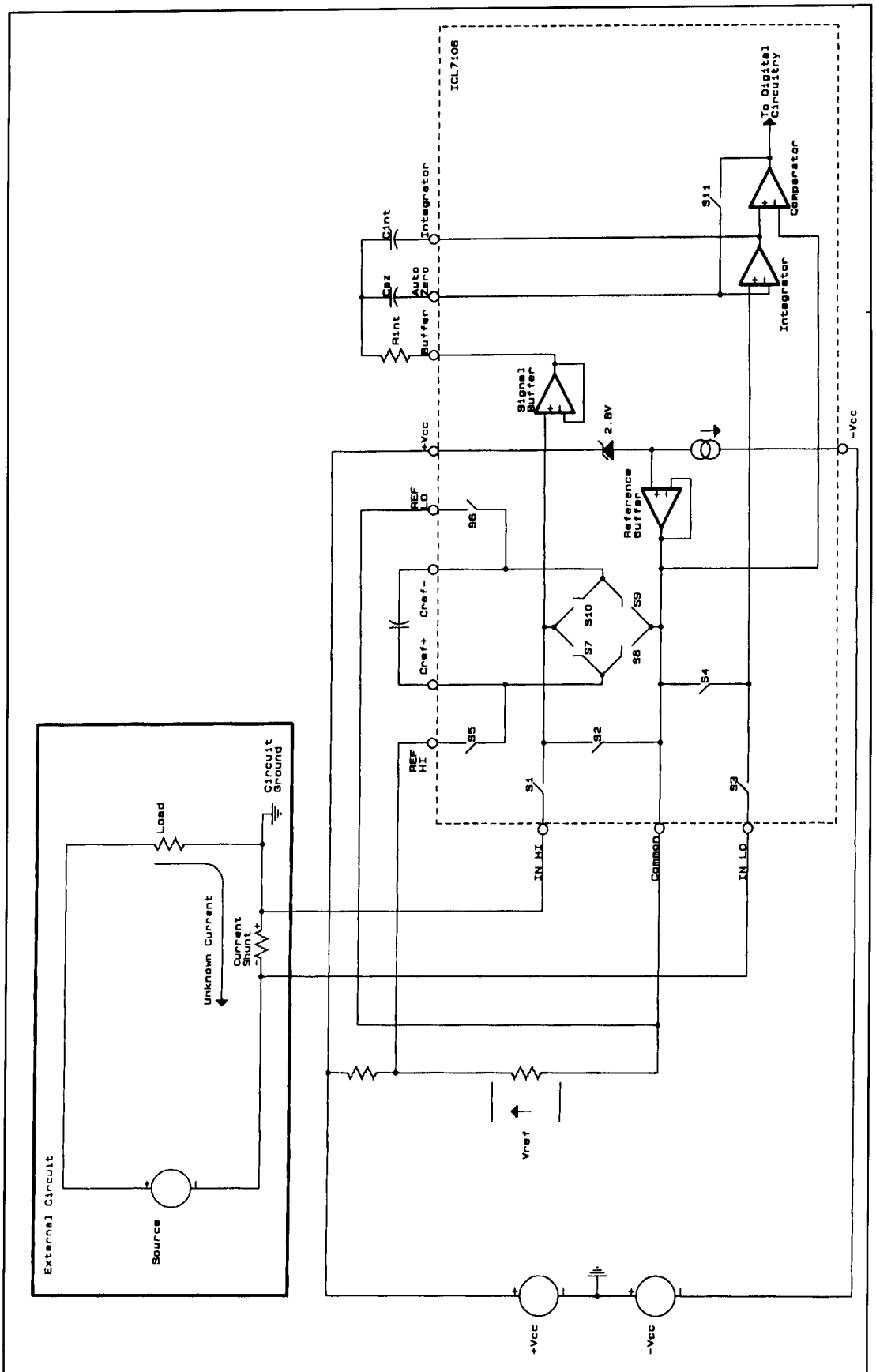


Figure 3. Typical current-sensing application.

The 39-177 or 39-165 meter is intended to be used only with its own battery power supply; in other words, the DPM battery can't be easily used for other circuitry. The reason the battery can't be used with other circuitry, or the DPM powered from some convenient power supply already available in a project, is because in these DPMs the negative input (the input noted as "GD" on the DPM pc board) has been connected to the DPM chip common terminal. When this is done, the DPM chip derives a positive and negative power supply with the common terminal as the common point between the two supplies, but this common point isn't centered between those two supplies. So the battery must "float" with respect to all other circuitry. Unfortunately, common of the DPM chip isn't really a "ground" terminal in the sense that it can be easily used as a ground for other circuitry. To make these inexpensive DPM devices useful as universal panel meters, they must be modified slightly to free the negative input terminal from the common terminal of the DPM chip.

Modification of these inexpensive DPMs and multimeters for use in specialty projects isn't as difficult as might be expected. Still, one must first understand how these devices operate. Many of the DPMs and inexpensive digital multimeters are based on the original Intersil ICL7106 voltmeter chip or an equivalent part. The ICL7106 is a classic dual-slope analog-to-digital converter with a 3 1/2-digit resolution. The ICL7126 is a low-power version of the ICL7106, and it may be found in various low-power instruments. However, the operation of these two parts is identical. If you understand the operation of the ICL7106, you'll be able to modify a number of digital meter products for your own needs. The explanation that follows is a very brief description of the dual-slope operation. If you'd like a more thorough explanation, look up the data sheet on the Intersil ICL7106 part and other dual-slope analog-to-digital converters.

In principle, the dual-slope conversion process is very simple. The term "slope" is used because in this procedure an unknown input voltage and a reference voltage are integrated in different parts of the process. This integration results in voltage ramps, or slopes, at the integrator output. There's one slope for the unknown integration and one for the reference integration. That's where the term "dual slope" originates. In the conversion process, the integrator is first reset to zero by some means. This is a rather sensitive operation as this zero setting will determine the accuracy of the overall digitizing process. This zero process is reviewed in more detail below in the description of the "auto-zero" phase of operation.

After the integrator is set to zero, the unknown voltage is applied to the integrator input for a specific length of time. However, the actual time isn't important. For example, assume that a clock is delivering pulses at some frequency. Then you may allow the unknown to be integrated for exactly 1000 clock cycles. You can use any number of cycles, but 1000 is consistent with the 3-1/2 digit DPMs. It's only important that the integration continue for precisely 1000 cycles, but the actual time that elapses in those 1000 cycles isn't important. Then, the unknown is removed from the integrator. The sign of the integrator output is observed and a precise reference voltage of the necessary sign to drive the integrator back toward zero is applied to the integrator input. That reference is integrated until the integrator output returns precisely to zero where it started originally. During the time that the reference is being integrated, the clock is counted to determine the number of clock pulses necessary to return the integrator to zero. The number of clock pulses counted during the reference integration is the digitized result of the conversion process.

This may be more clear if I present a complete conversion process with some real voltages. Let the reference voltage be 100 mV with either a +100 mV or -100 mV reference available. Also, let an input voltage to be measured be +100 mV. First, with the integrator at zero, the unknown is applied to the integrator input. The unknown is integrated for exactly 1000 counts of the clock, and is then disconnected from the integrator. At this point the integrator output is at some negative value (typical integrators are inverting). The fact that the integrator output is negative indicates that the sign of the unknown is positive. So far we have the sign of the input. +. Because the integrator output is negative, a negative reference is needed to drive the integrator back to zero. The negative reference is selected and connected to the integrator input. Actually, all the switching occurs in very much less than a clock cycle, so the switching is effectively instantaneous. At the instant the reference is connected to the integrator input, we begin counting clock pulses starting at zero. When the integrator output reaches zero, we stop counting the clock. What will the count be at that point in this example? Well, if the integrator was driven down to some level in 1000 counts with 100 mV applied, 1000 counts will also be required to drive the integrator back to zero with a 100 mV reference applied. The count will be exactly 1000. So now in addition to the polarity of the unknown, we also know that the value of the unknown is related to 1000 counts. Just how it's related will be shown a little later.

Figure 1 shows the integrator output for sev-

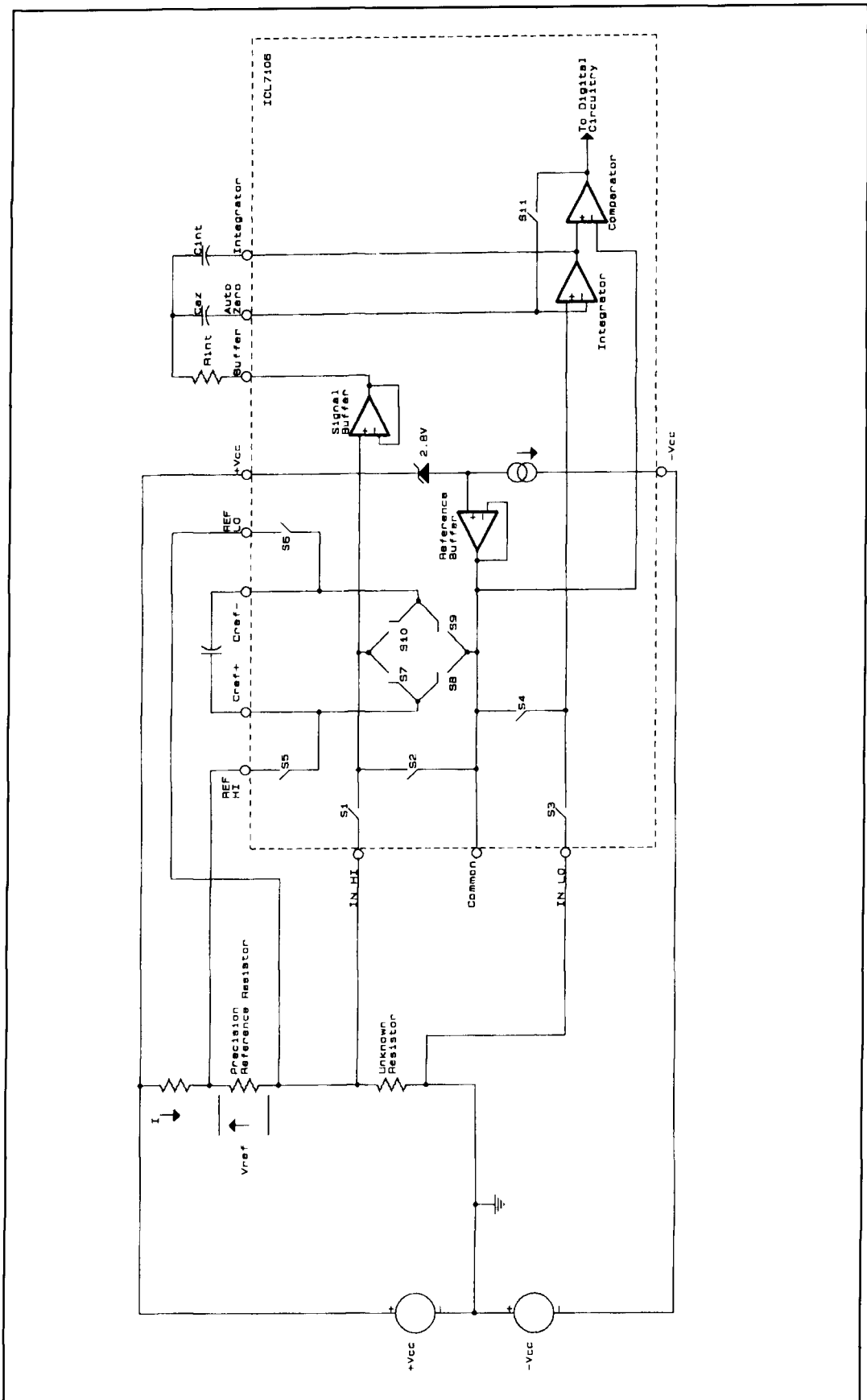


Figure 4. Example of a ratio-ohmic measurement.

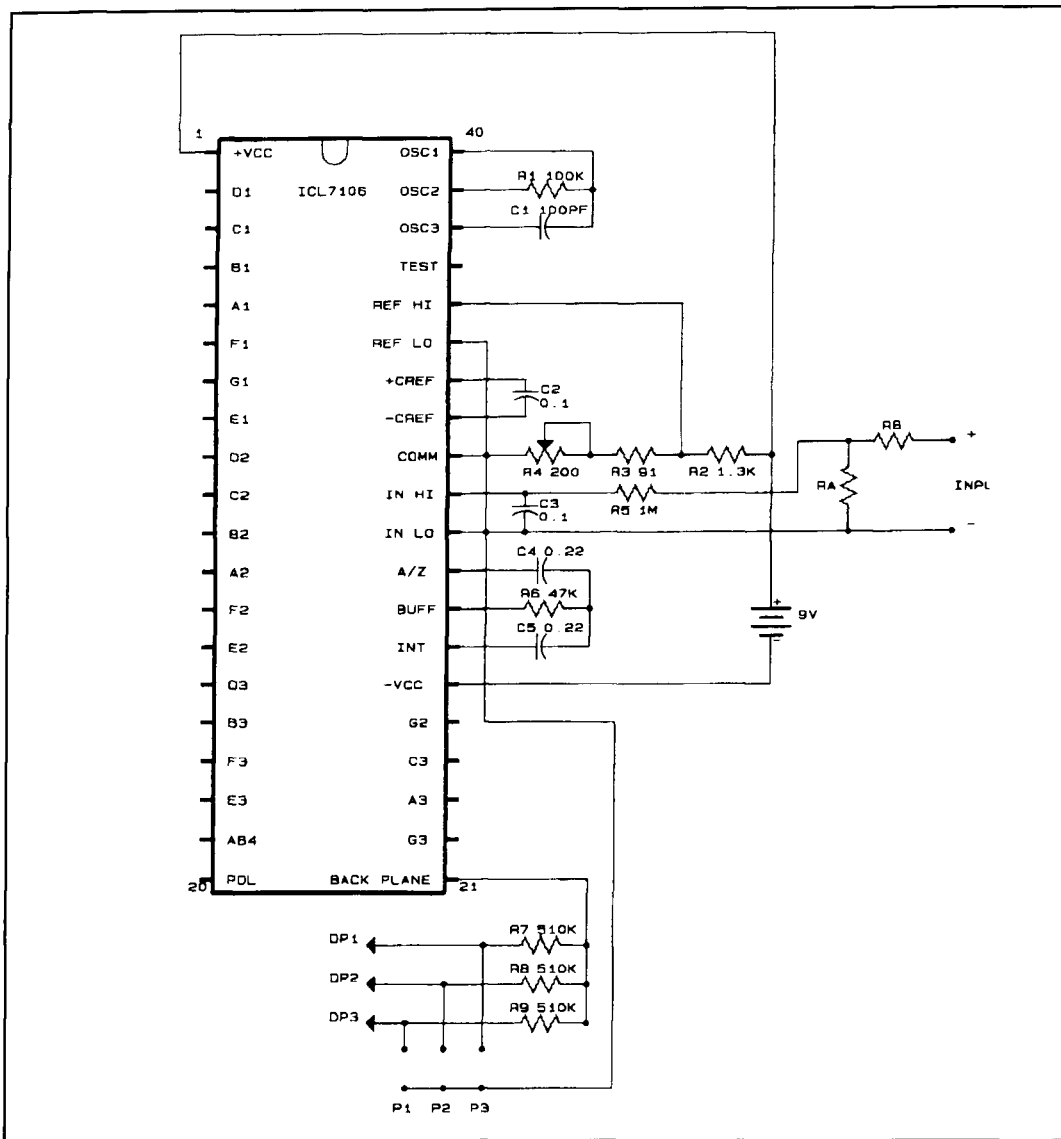


Figure 5. PM-128 analog section.

eral input voltages. The left-hand slope, the unknown integration phase, is constant in time and varies in slope with input voltage. The right-hand slope, the reference-integration phase, is constant in slope and of variable time.

Now, suppose that a +50 mV input is applied. In the 1000 counts of the unknown integration, the integrator output will reach only one-half the level it reached for a +100 mV input. Therefore, when the reference is integrated, only one-half the counts, or 500 counts, will be required to drive the integrator back to zero.

The result obtained from the dual-slope converter is the ratio of the reference-integration count to the unknown integration count. This ratio indicates the relative magnitude of the unknown input to the reference. In the case of the 100 mV input, the reference count was 1000 and the unknown count 1000. Therefore,

the unknown value is the reference value—100 mV, multiplied by the ratio of 1000/1000, or $100 \text{ mV} * 1.000$. In the case of the 50 mV input, the reference count was 500 and the unknown count 1000 for a ratio of 0.500. So the unknown voltage is the 100 mV reference voltage multiplied by 0.500, or 50 mV. If the input were 200 mV, the reference count would be 2000, the ratio would be 2.000, and the value of the unknown would be a factor of two greater than the 100 mV reference, or 200 mV.

If the input is negative, say -100 mV, the integrator output would end up at the same absolute level as for the +100 mV input, but positive instead of negative. Then the positive reference would be selected for the reference-integration cycle. All of the counting functions would remain the same for either positive or negative inputs.

The 1000-count point in the reference inte-

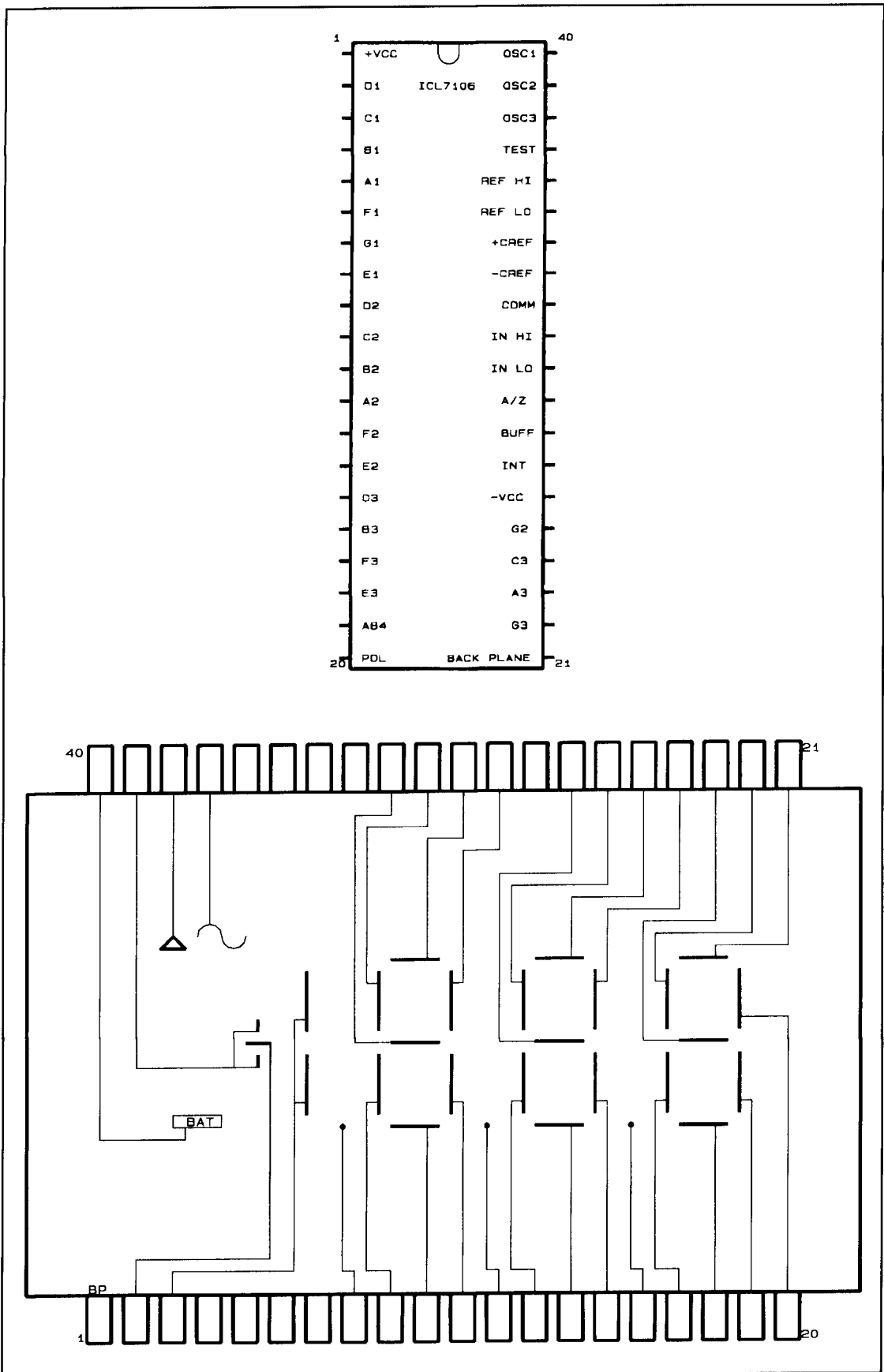


Figure 6. Pin-out of the ICL7106 converter and typical LCD displays.

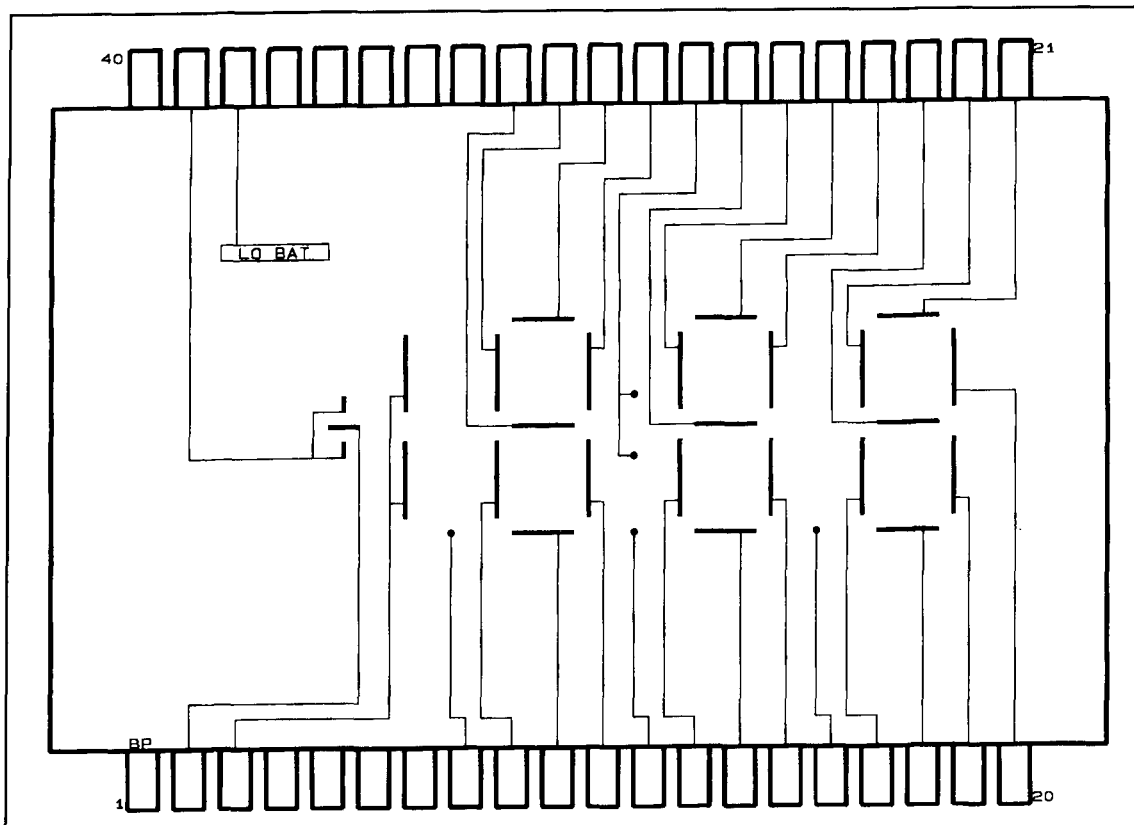


Figure 6. (continued).

gration is often termed the "full-scale" value. At this point, the unknown input is at the same voltage as the reference. Typically, the dual-slope converters are designed to accommodate a 100 percent over range, or an input that is twice the reference value with a resulting reference count of 2000 (actually 1999).

The 1000-count value for the unknown integration is a very convenient value for digital instruments using decimal displays. For example, with a 100 mV reference, 1000 counts corresponds directly to 100.0 mV, 100 μ V per count. So, if a 1000-count decade counter is used, the count in the counter at the end of the reference count interval may be used to drive a display directly without any additional computations. Of course, if a decade counter can count to 1000, it can also count to 1999. Therefore, a display with three full digits and a leading "1" has become a common DPM display. This is called a "3-1/2 digit" display.

If the dual-slope converter were to be used with a computer, it may be more convenient to use a binary counter, say 1024 counts, with a "binary" reference. For example, if a 102.4 mV reference were used with a 1024 binary counter, each count would correspond to 100 μ V just as with the decade system reviewed above, but with the value in binary code.

That's the basic operation of the dual-slope

analog-to-digital converter. Now let's see just how this is accomplished in the ICL7106 part. I'll only review the analog portion here as the digital portion is composed simply of counters, gates, and flip-flops. That's right, no processor at all! A block diagram of the analog section of the ICL7106 dual-slope converter is shown in **Figure 2**. This may seem rather confusing at first glance, but it's quite simple, and elegant. There are three operating phases in the conversion process: Auto Zero, Unknown Integrate, and Reference Integrate. The eleven switches shown are FET switches used to steer the signals.

During the Auto-Zero phase, switches 2, 4, 5, 6, and 11 are closed. Switches 2 and 4 connect the signal-buffer and integrator inputs to the common terminal. This defines an input zero-voltage condition. Switches 5 and 6 connect the reference capacitor to the reference supply. This charges the reference capacitor to the reference voltage. Switch 11 connects the comparator output to the integrator input. The purpose for this requires some explanation.

The integrator is simply a classic integrator—an operational amplifier with a capacitor in its feedback loop. The comparator is also an operational amplifier. The high gain of the comparator amplifier results in its output swinging between its output limits over a very

small input range. For example, if the voltage gain of the comparator amplifier is 100,000, the output will swing 5 volts for a 50 μV input. The important point to understand is that the comparator is a linear amplifier.

When switch 11 is closed, the output of the comparator is connected to the negative input of the integrator amplifier. This then forms a unity-gain amplifier configuration. Because the positive input of the integrator amplifier is connected to the common terminal, the comparator output is also at the same potential as the common terminal; that is, if the comparator and integrator amplifiers are perfect. And because switch 11 connects the comparator output to the integrator-amplifier negative input, that negative input is also at the potential of the common terminal. Because switch 2 connects the buffer amplifier input to the common terminal, the buffer output, which is the input to the integrator circuit, is also at the common-terminal potential, for a perfect buffer amplifier.

The buffer amplifier, the integrator amplifier, and the comparator amplifier aren't perfect amplifiers. They all exhibit an "offset" voltage. When the inputs are at zero, the output is at some nonzero level. That output level is equal to the offset voltage multiplied by the amplifier DC gain. Typically, the offset voltage of operational amplifiers can be many millivolts. Because a digitizing precision of 0.1 mV is desired, such offset levels are quite objectionable. It would be possible to incorporate manual zero controls to compensate for these offsets, but they would be inconvenient and dependent on such parameters as temperature and operating voltage. Alternatively, very high-performance amplifiers with very low offset voltages could be used, but that would be quite costly.

The auto-zero circuit

There's a much more convenient method of correcting for these offset voltages—the auto-zero circuit. Essentially, all the auto-zero circuit involves is the addition of the auto-zero capacitor *Caz* and switch 11 to the basic dual-slope converter. During the auto-zero phase, even though the buffer input is connected to common, its output voltage will be slightly above or below common due to its offset voltage. Also, even though the positive integrator-amplifier input is connected to common with switch 11 forming a unity-gain amplifier of the integrator and comparator amplifiers, the output voltage of the comparator, and the negative integrator-amplifier input due to the closure of switch 11, will be slightly above or below the common due to the offset voltages of the integrator and comparator amplifiers. Because *Caz* is connected

between the buffer output and the comparator output (and integrator input) during the auto-zero phase, some small voltage is stored on *Caz* that's equal to the combined offset voltage error of the buffer and the integrator. So, if switch 11 is opened and both the buffer input and the integrator-amplifier positive input (the integrator reference input) are connected to common, the comparator output will be precisely at zero because that was the output condition when the *Caz* capacitor was charged.

During the unknown integration phase, switches 1 and 3 are closed, and switches 5 and 6 may be allowed to remain closed to provide maximum time for charging the reference capacitor. All other switches are opened. Switch 1 connects the input high to the buffer amplifier, and switch 3 connects the input low to the integrator reference input. Now, if precisely 0.0000 volts is applied at the input, the voltage that appears between the buffer output and the integrator positive input—the combined offset error voltage—will be precisely the same as during the auto-zero phase. The voltage stored on the auto-zero capacitor compensates for this error voltage. For such a zero input, the effective integrator input is precisely zero, and the integrator output remains at a constant level; i.e., the integrator precisely integrates the zero-volt input even though there are very significant offset voltages in the various amplifiers.

The auto-zero feature is capable of correcting for very large offset errors. All that's required is that the offset voltage remain constant over one conversion cycle. The use of auto-zero allows very simple amplifiers to be used for the buffer, integrator and comparator. That's one reason why the dual-slope parts are very inexpensive.

Because switches 1 and 3 are closed during the unknown-integration phase, the unknown signal applied between the two input terminals is integrated for 1000 counts of the system clock. At the end of the unknown-integration phase, all switches are opened. The output level of the integrator is observed to determine the sign of the unknown and which polarity reference to apply. If the integrator output is negative, the input polarity was positive, and a negative reference is required to drive the integrator back to zero. Then switches 4, 8 and 10 are closed. Switches 4 and 8 connect the reference high terminal and the integrator reference to the common terminal, and switch 10 connects the reference low to the signal buffer input terminal. This results in a negative reference voltage being applied at the integrator input. Note that the voltage stored on the reference capacitor is the actual reference voltage. The clock is then counted as the integrator output ramps to zero due to the integration of the reference. When the integrator reaches zero, the comparator

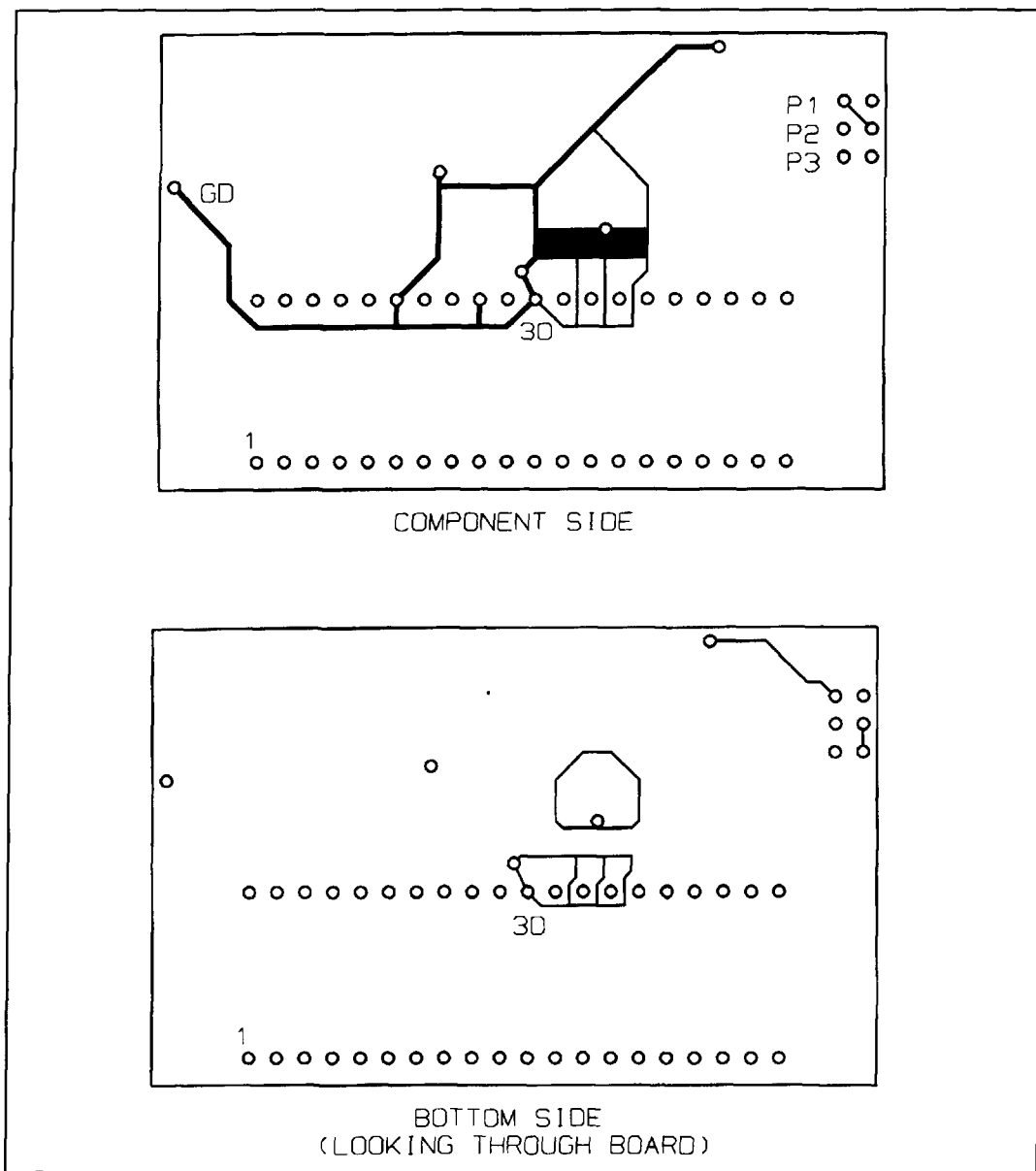


Figure 7. PM-128 common terminal circuit traces.

changes state and the counter is stopped. The count stored in the counter is the digital value of the unknown compared to the reference as discussed above.

If the integrator output is positive at the end of the unknown-integration phase, the input was negative, and a positive reference is required. Therefore, switches 4, 7, and 9 are closed to apply a positive reference to the input, and the integration and counting continues as described for a positive input.

About the only critical components in the dual-slope conversion system are the auto-zero capacitor and the integrator capacitor. However, even these don't need to be precision parts. The actual values aren't critical. The auto-zero capacitor must simply exhibit very

low leakage, so the reference voltage stored in that capacitor doesn't change during the conversion process. The integrator capacitor must exhibit low leakage as well, but it must also have very low dielectric absorption. Typical ceramic capacitors aren't generally suitable for the auto-zero and integrator capacitors of the dual-slope systems. Some type of low-loss film capacitor is preferred, such as a metalized polycarbonate or metalized polypropylene.

During each of the phases of operation, the signals being processed are isolated from the other signals by the various FET switches. It's important that the voltages be within the "common-mode" range of the device so the switches can properly isolate the different voltages, and the integrator can properly integrate the signals

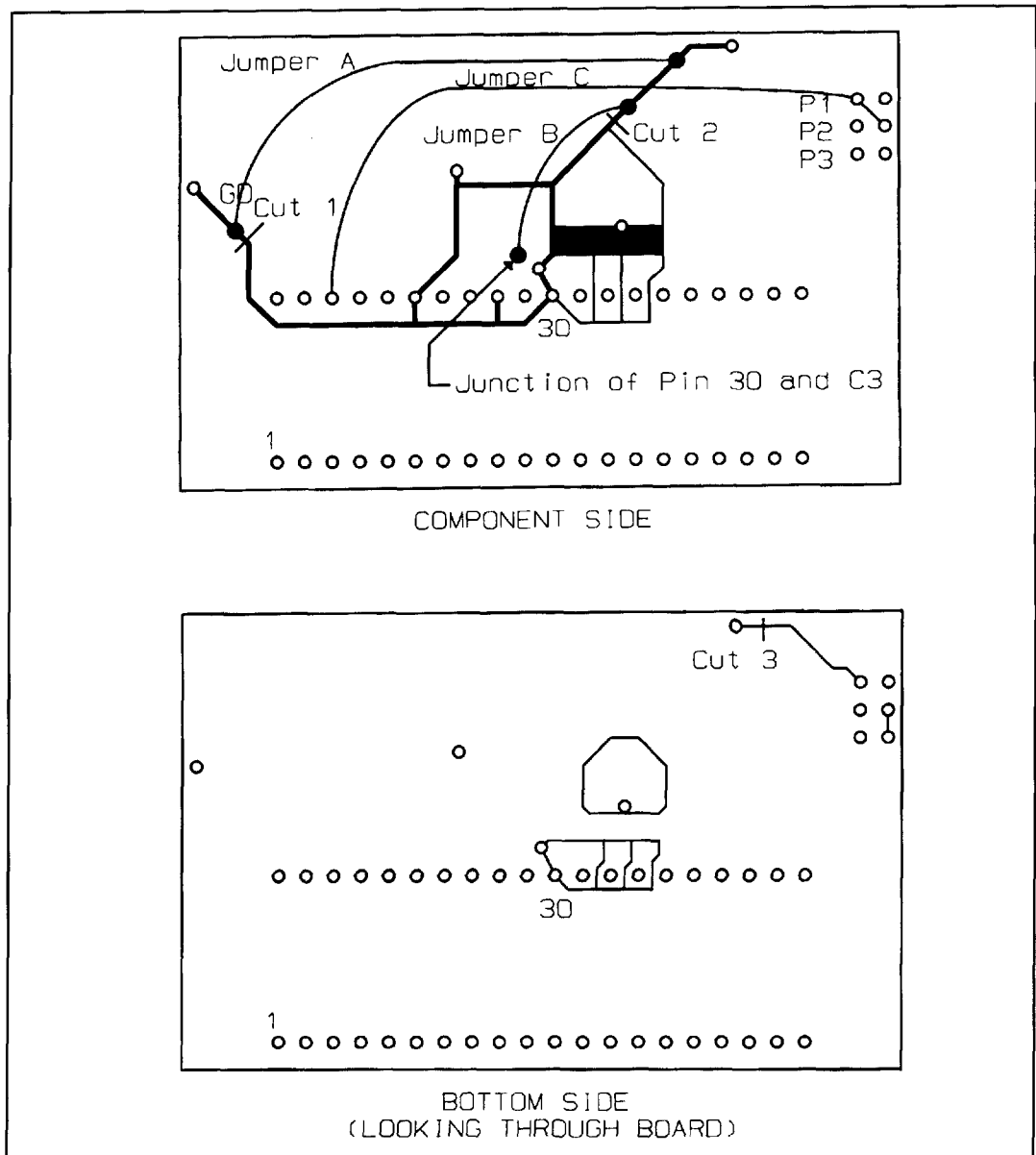


Figure 8. Cuts and jumpers for the "easy way" modification.

without saturating at either end of its range. In general, the range of the common-mode voltage of the input and the reference is from about a volt below the positive power-supply level to about a volt above the negative power-supply level. Note that the common terminal isn't a "ground" terminal in the normal sense. It's derived by a reference network in the ICL7106. A precision reference voltage is developed between the positive supply and the common terminal. The negative supply terminal will vary with power-supply voltage. So, you must be particularly careful how you use the common terminal.

The ICL7106 provides a stable (but not precise) reference voltage developed between the positive supply terminal and the common ter-

terminal. This reference voltage is typically used to develop the measurement reference when these parts are used in DPM applications, such as the PM-128. An external reference may also be used. For a more detailed explanation of the use of the ICL7106 with an external reference or with dual power supplies, or for a more complete explanation of the common terminal, take a look at the ICL7106 data sheet.

The connection of the common terminal will depend on the type of power supply used for the meter and the type of input configuration desired. With a 9-volt battery, the battery would be connected between the power-supply pins. The common terminal will then be a type of derived ground reference for the DPM. Both the input and the reference voltages must be

referenced near the common terminal.

Typically with such battery operation, the input low and reference low terminals are connected to the common terminal. That's why the PM-128 DPMs are configured in that manner.

If power is supplied by positive and negative supplies with a common ground, such as ± 5 volt supplies, and if the internal reference voltage of the 7106 is to be used, the 7106 common terminal must not be connected to the supply-circuit ground. The input and reference may be connected either to the common terminal or to the power-supply ground because either of these is well within the common-mode range of the device. Generally, the circuit ground is the most convenient signal reference for the input voltage when dual supplies are used because the signals being measured will most likely be referenced to the circuit ground. However, the signal input and the reference input are true differential inputs, and may be connected directly to the point to be measured, and the input and the reference need not be connected to the same signal reference point.

Suppose that the DPM power is a ± 5 volt power supply with the common point of the supply grounded to our overall circuit ground (but not the DPM common). Also, suppose that you wish to use the internal reference voltage of the DPM chip as your reference. The chip reference voltage is developed between the positive supply, +5 volts, and the chip common terminal, not the circuit ground. Therefore, to develop a reference voltage for your DPM, you must add a resistive divider between positive supply and the chip common, perhaps to develop 100.0 mV between common and the divider output. Then you must connect the reference low terminal to the chip common and the reference high terminal to the divider output. Now suppose that you wish to accurately sense the voltage across a low-value resistor being used as a current shunt to measure a DC current. To obtain an accurate reading, you must measure right at the resistor. If you arbitrarily connect one of the measurement inputs to ground somewhere in the circuit and connect the other input to the resistor, you may get a false reading due to the voltage drop between the resistor and the point where your ground connection is made. To eliminate this problem, you must connect the input high and low terminals directly to the resistor.

The differential nature of the input and reference is very useful. For example, suppose that in the current measurement example above the resistor is in the current return path with the positive terminal of the resistor grounded to the circuit ground as shown in **Figure 3**. The voltage developed across the resistor will be negative, but you would like it to read positive. No problem. You simply connect the input high to

the resistor positive, i.e., circuit ground, and the input low to the resistor negative. Alternatively, you could have actually inverted the reference connections, but typically the input polarity is selected for the desired polarity indication just as when using a multimeter.

Another useful feature of the true differential signal and reference inputs is in making "ratio" measurements. As noted above, the dual-slope converter delivers a count ratio that expresses the unknown as the reference multiplied by that ratio. The reference doesn't need to be a voltage. For example it could be a "resistance." In **Figure 4**, a precision resistance is connected between the reference terminals and an unknown resistance is connected between the input terminals. The input low is connected to common, the input high and reference low are connected together, and the reference high is connected through a resistor to positive supply. As a result, some current flows through both the reference resistor and the unknown resistor. The actual value of the current isn't important. It's only important that the same current flow in both the reference and unknown resistors. The digital count result that the dual-slope converter provides is the ratio of the input voltage to the reference voltage. The reference voltage is the product of the current and the reference-resistor value, and the input voltage is the product of that same current and the unknown resistance. Therefore, the ratio of the input and reference voltages is simply the ratio of the unknown resistor to the reference resistor. Note again that the current need not be precise, or even known. The only requirement is that it be stable over the conversion cycle.

The ratio measurement property may be used for a number of applications. An ohmmeter is an obvious application. With proper selection of the reference resistor, the output count of the dual-slope converter will be directly the value of the unknown resistance. This ratio measurement for measuring resistance is often termed "ratio-ohmic" resistance measurement. It's interesting to note that if the reference and unknown resistor positions are exchanged, i.e., the reference resistor is placed at the signal input and the unknown at the reference input, the output reading will be the *conductance* of the unknown. There are countless other applications for the ratio feature. For example, the resistance of a resistive strain gauge could be measured and load, or weight, displayed directly. Or, a linear resistive temperature measurement element such as a platinum wire could be measured and absolute temperature displayed directly.

Well, now that I've discussed how the dual-slope DPMs function, I'll look briefly at a few actual devices. **Figure 5** shows the schematic of the analog part of the PM-128 (either one of

those from Hosfelt). The PM-128 uses a generic 7106 part, and the circuit design is taken directly out of the Intersil application notes for the ICL7106 dual-slope converter chip. Resistors RA (open) and RB (jumper) are included to provide a convenient place to install a voltage divider directly on the DPM pc board to allow scaling the meter range. Without a divider, the DPM full-scale voltage is 200 mV and the input impedance is almost infinite (>100 Megs anyway). If a divider is used, the input impedance will be equal to the sum of the two divider resistors.

The important point to note in **Figure 5** is that both the reference low and the input low are connected directly to the common terminal. That means that this part can't be used with a differential input with dual supplies where the supply common is the signal reference. However, that's precisely what I need to do in my power-supply applications. In order to allow differential input measurements, the input low terminal must be cut free of the common terminal. This is easier said than done, but not impossible, and well worth the savings that can be enjoyed with these inexpensive parts.

For reference, **Figure 6** shows the pin-out of the ICL7106 and the LCD displays used in the PM-128s. These are both more or less standard pin-outs—the enunciators of the LCD and their pin connections will be different from one unit to another.

Figure 7 shows the circuit traces associated with the common, input-low and reference-low terminals for the PM-128. To separate the input low from common, several cuts must be made to the circuit traces and several jumpers must be added. There are at least two methods that may be used—the easy way and the hard way. The easy way is the simplest, but it's not too elegant. The hard way provides a more professional result, but is much more difficult.

First, let's try the easy way. The input low pin, pin 30, must be separated from all connections except C3 and RA. The simplest approach to accomplish this is to unsolder pin 30 and the corresponding pin of C3 connected to pin 30, and pull both leads out of their pc board pads. Be very careful not to bend the pin 30 lead too violently, as it's very easy to break the lead right at the body of the package.

Remove the pc board from the display assembly by extracting the mounting screws. Some units have four screws and some five. Be particularly careful with the display. It's basically a couple of thin glass plates, and only the pc board holds the display into its bezel. The display will simply fall out of the bezel when the pc board is removed if one isn't careful. Be sure to place the screws in some type of container; they are quite small and are very easily

lost. These screws are critical to the proper operation of the display *connector*.

Now carefully remove C3 totally. This will provide some working room. Then unsolder pin 30—the pin that connects to the terminal of C3 nearest the 7106. Make sure you remove all the solder from both sides of the pc board and that the pin is totally free. Then, using a small flat jeweler's screwdriver or similar tool, *gently* pry pin 30 at the pc board surface bending the pin out until the tail of the pin is free of the board. Using a needle-nose plier, straighten out the pin somewhat. It's a good idea not to try to straighten the bend at the package body—just let the pin hang down at an angle. Finally, from a point about 1/16-inch from the package body, bend the pin to a nominal horizontal position and clip off the small tail (the part of the pin that was originally soldered into the pc board). This takes care of pin 30.

Next, place the outer lead of C3 back in its original pc board pad (the one farthest from the 7106), leaving the other lead of C3 free of the pc board. Bend the C3 leads so the free lead of C3 is in contact with the pin 30 lead. Solder the C3 lead and pin 30 together with the connection well above the pc board. Then solder the other C3 lead in the pc board. Pin 30 with its connection to C3 is now totally free of all other connections. Now connect pin 30 to the input low (labeled GD on the pc board) and to RA, the low end of the on-board divider network. To do so, make three cuts in the pc board traces and add three jumpers.

Figure 8 shows where to make the three cuts, two on the component side and one on the bottom side, and where to add three jumpers. When I make a pc board trace cut, I like to remove a short section of the trace, about 1/32 to 1/16 inch, just to make sure that the trace is severed and can't become reattached. I also scrape down into the pc board substrate material slightly to remove all of the adhesive and any trace remnant that may remain. Cut 1 isolates the input low (GD) pad; cuts 2 and 3 isolate the low end of RA. Jumper A connects the input low pad back to the low end of RA. Jumper B connects the junction of C3 and pin 30, the connection just made above the pc board, back to the low end of RA. Jumper C reconnects the decimal-point drive, but back to the OSC 3 pin rather than to the common terminal. Note: *Do not use the decimal-point drive as directed in the data sheet for the DM-128.* If you do, the decimal point will be permanently fixed on. The decimal-point drive is discussed in detail below.

The input is now floating and may be used as a totally differential input, as reviewed above. Just be sure when applying this modified unit that the input is within the common-mode range of the 7106. In other words, be sure the

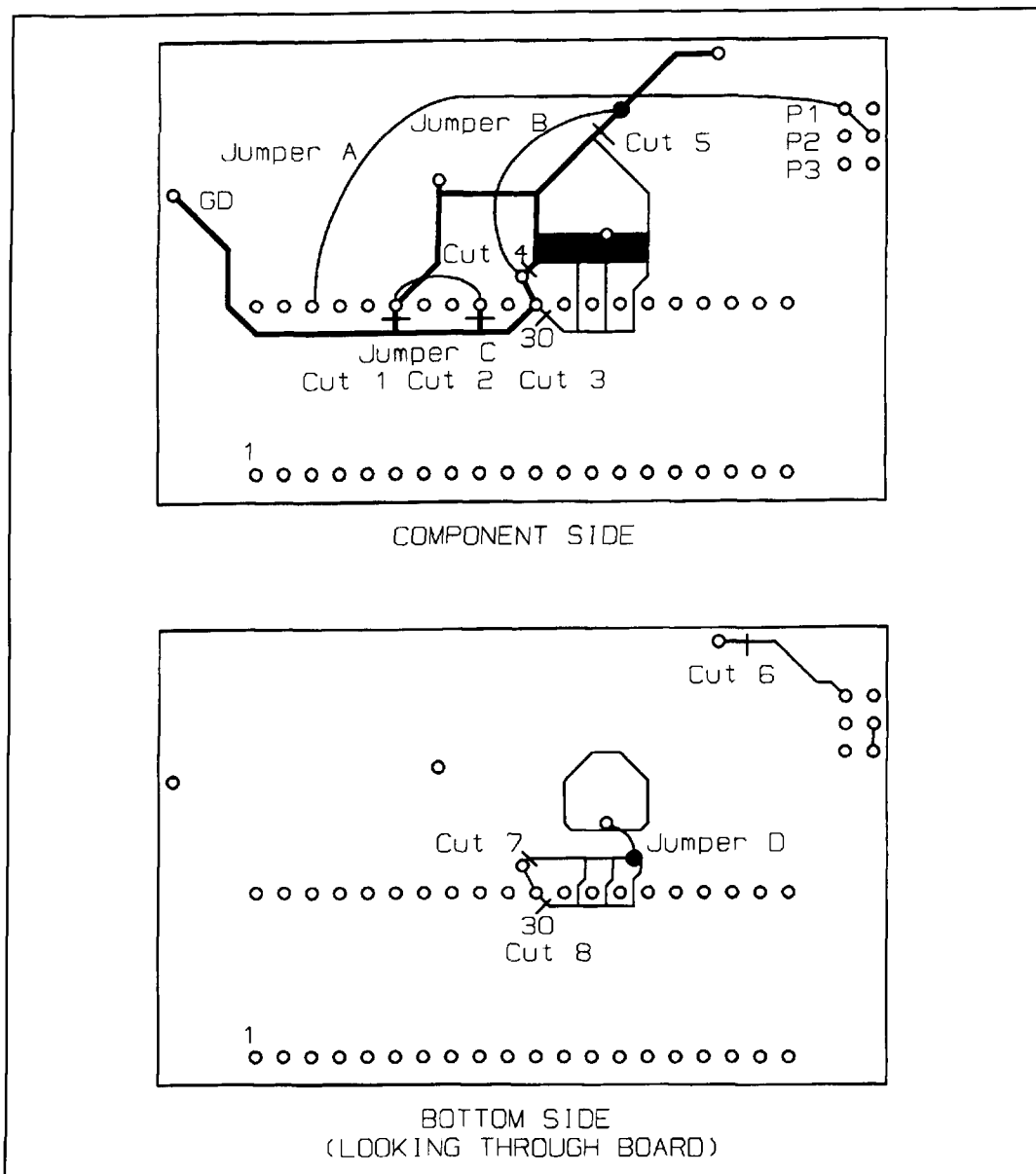


Figure 9. Cuts and jumpers for the "hard way" modification.

input is referenced to a point between at least 1 volt below the positive supply and 1 volt above the negative supply. Whatever you do, *do not* allow the input to float—you'll obtain very peculiar random results.

Now let's look at the hard way of isolating pin 30. Unfortunately, there are several connections made to pin 30 under the 7106 chip that must be broken. To proceed, remove the pc board from the unit. Then, without damaging the 7106, completely remove the chip. While this isn't a trivial operation, I've performed it on about a dozen of these meters and have found it a relatively simple task. The plated-through holes seem good in most cases, so desoldering isn't too difficult. I use a solder sucker and solder wick to clear the solder from both

sides of the board and from the hole. If you need to get to the pins on the top side of the board near the other components, simply remove the components that are in the way. Make a note of what you remove from where, and mark pin 1 of the 7106 on the pc board (pin 1 is nearest the input terminals on the pc board). One trick that may be useful for stubborn solder that just won't yield is to add a little fresh solder to the joint and then proceed. This adds a little new flux to the joint making the old solder flow much more freely. When you "think" you have all the pins free, go under the pc board with a needle-nose plier and wiggle each pin tail to make sure it's totally free. Those pins that aren't free can usually be released by touching the very tip of the lead

squeeze the leads flat and straight. Straightening the leads now will make reinstallation of the 7106 easier later.

With the 7106 off the pc board, you have access to the area of the board under the chip. You must make three cuts in this area. In total, eight cuts must be made—five on the top of the pc board and three on the bottom—and four jumpers must be added. The cuts and jumpers for the “hard way” are shown in **Figure 9**. After you’ve made the cuts under the 7106, you may reinstall the chip. Note Jumper C. You could put this jumper under the chip, but if you wanted to free the reference low pin later, you’d have to remove the chip again. To avoid this problem, simply put that jumper under the board and not under the chip. The group of traces under the pc board connected with Jumper D is a guard-ring structure around the reference and integrator pins. This guard isn’t too critical in this application, but because you’re adding other jumpers, you may as well reconnect this guard-ring structure back to the common terminal. Once all the cuts are made, all jumpers added, and the 7106 reinstalled, clean the pc board thoroughly with alcohol to remove all traces of solder-flux residue. If any flux residue remains around the input, reference, auto zero, or integrator pins, it could form a high-resistance conductive path that could compromise operation.

The final configuration achieved with either approach is shown in **Figure 10**. As was the objective with all this work, the input is now floating free with respect to the rest of the circuitry. This may seem like a lot of work for such a simple result, but I managed to modify a dozen or so units, the hard way, on a rainy Saturday afternoon. It takes about 15 minutes to a half hour or so once you get going. And, because I saved as much as \$400 to \$500 by doing these modifications, it was worth the time.

Reassembly

A few notes on reassembly. The connector used for connecting the display to the pc board is a conductive elastomer that conducts only through its thickness, not along its length. The mating surfaces must be clean and free of all foreign matter. Clean the board pads with alcohol, making sure that no lint remains. If the connector pieces were removed, clean the display contacts with alcohol before reinstalling the connectors. Make sure that the connectors are free of foreign matter.

Pressure is all that’s used to make contact between the pc board and display. That’s why the pc board mounting screws are so important. Unfortunately, I found that about half of the screw holes were striped in the DPMs I bought

(also, the pc board holes didn’t line up well with the holes in the housing). I filled the holes with epoxy and redrilled them. I also used a small rat-tail file to elongate the mounting holes in the pc board so the screws would fit properly. You may need to do the same. When you reassemble the pc board to the case, push the board down until it’s flush with the case and then install the screws. Do not try to pull the board down with the screw—you’ll simply strip out the hole. You don’t need much force to hold the pc board in place. Tighten the screws just enough to hold the pc board firmly in position. Don’t over tighten the screws—you’ll simply strip the plastic threads. If you do, simply fill the stripped holes with epoxy and redrill them.

You’re now almost ready to use the meter. The decimal point is a bit of a problem. The LCD is a somewhat peculiar part to drive. I won’t go into much detail here, but a very brief description may be useful. The LCD must be driven with AC signals. The common terminal of the LCD called the back plane is driven with a square wave. To hold a segment off, that segment is driven with the same square wave as the back plane drive. To turn a segment on, the segment is driven with a square wave that’s 180 degrees out of phase with the back plane drive. In either case, the segment sees no DC component. A DC component on a segment, even a very small DC level, will destroy the LCD segment by “burning” it permanently on (it really isn’t burned, the chemistry and metalization are permanently altered). In the PM-128, to activate a decimal point, a set of pads is provided which allow you to connect the decimal points to the 7106 common terminal. That will apply a DC component to the decimal point, and that decimal point will eventually be relegated to be permanently on. This isn’t good, but there’s a simple solution. If you’re going to use the PM-128 without the modifications discussed here, use a 0.1 μF capacitor instead of a jumper to activate the decimal points. The capacitor will block any harmful DC component, and the AC component available from the back plane drive is adequate to achieve an acceptable level of decimal-point drive. However, because the AC drive to the decimal point in this case is only half that for the other segments, the decimal point will have a noticeably lower density; that is, it will be more gray than black. If you wish to try an alternative drive for the decimal point, and LO BAT indicator if you use it, connect the decimal point to the OSC 3 output, pin 38 on the 7106, through a 0.01 μF capacitor. Even though the oscillator frequency is much higher than the back plane drive frequency, this connection results in a higher-level drive to the decimal point than

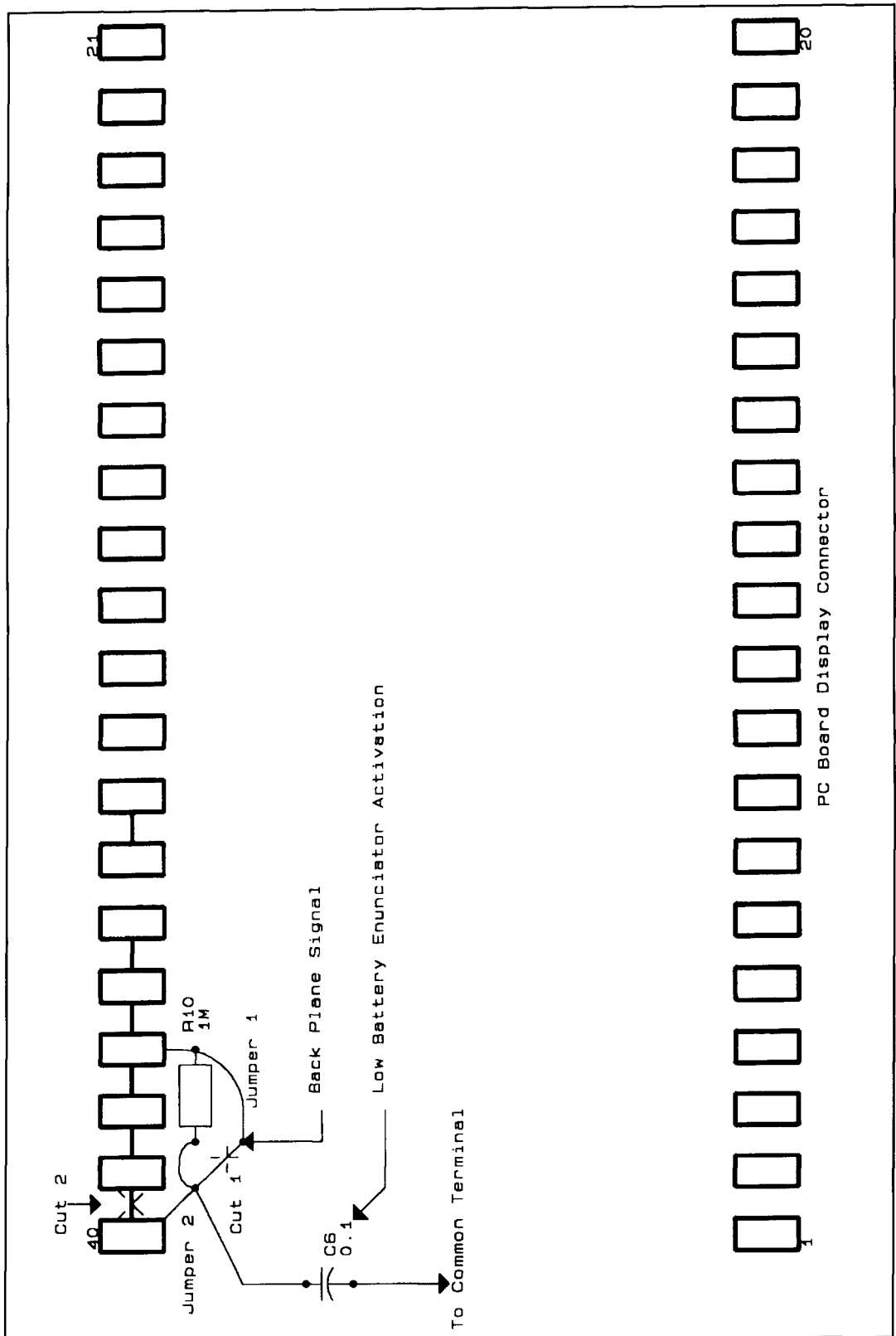


Figure 11. Cuts and jumpers for access to LO BAT display function.

simply using the back plane signal. The capacitor again is used to block any DC component.

One last note on the PM-128s. There are several enunciators included in the LCD that aren't

made available. These enunciators vary from unit to unit. For example, there's a "LO BAT" enunciator and a "+" display (but that's not typically of much value) on almost all the displays.

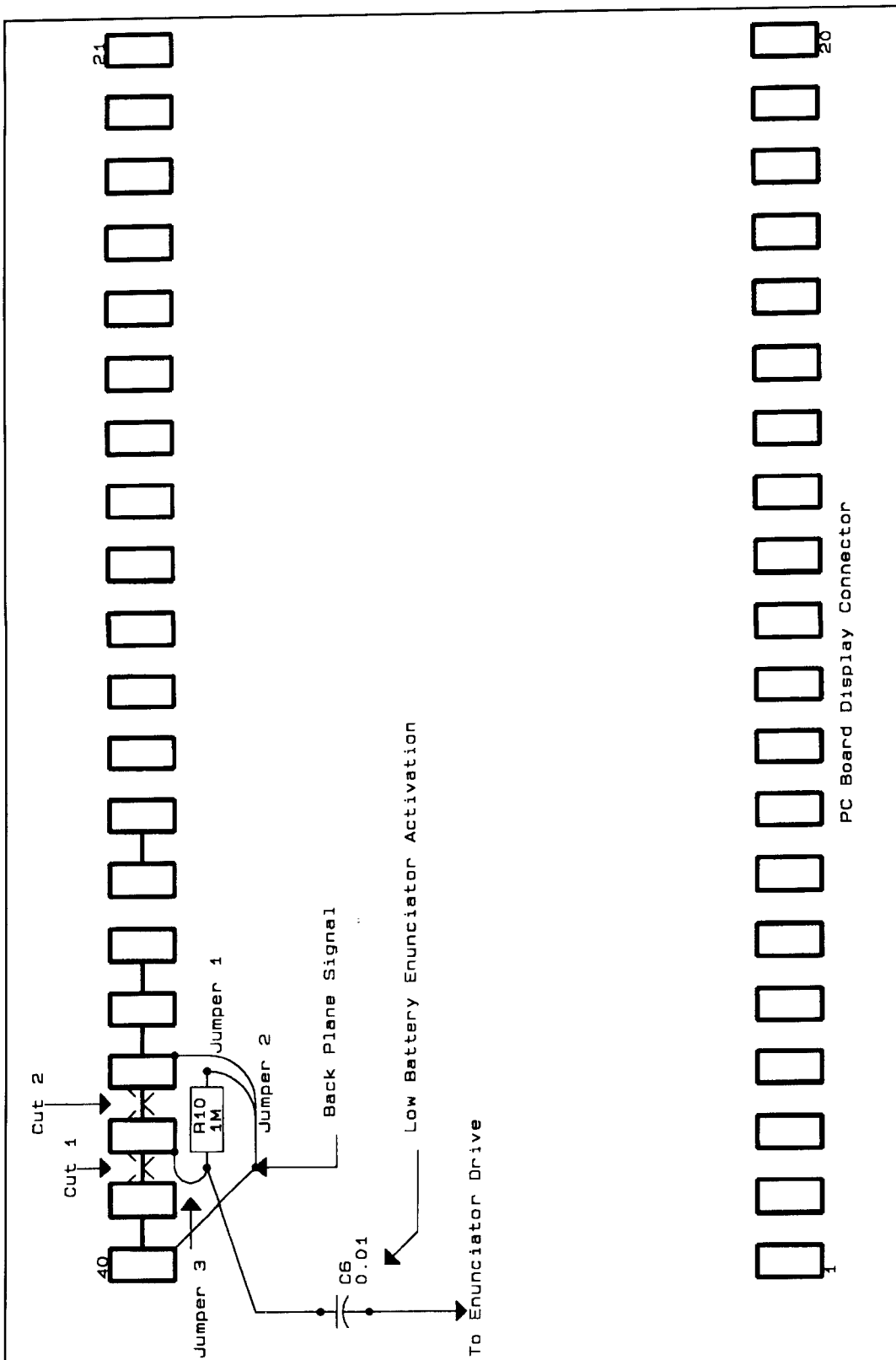


Figure 11. (continued).

and some include an AC display, ~, and some a colon between the second and third digits. If you're adventuresome, you can obtain access to these enunciators, for example the LO BAT

enunciator, for your projects. **Figure 11** shows where to make cuts at the LCD connector pads and where to add jumpers and a resistor. The modifications will most likely be different for

each different DPM. I added the resistor R10 next to R7. I put a loop in the resistor lead so I could connect a LO BAT drive signal easily. Be very careful not to get any excess solder on the display connector pad; make your connections to these pads at the very inner edge of the pad with an absolute minimum of solder. To activate the LO BAT indicator, simply connect a 0.01 μF capacitor from the resistor lead loop to the decimal-point drive terminal (OSC 3 signal, or COMM, whichever you chose to use). You'll need to provide your own external circuitry to activate the LO BAT indicator, as no provision is provided for this in the 7106 or the PM-128.

Suppose that your project is some type of hand-held, battery-operated instrument. Another of my projects is a Gauss Meter for measuring very small AC and DC magnetic fields. I want to make this instrument similar to a digital multimeter. Unfortunately, the enclosure options available for such a project are quite limited, and I must still use some type of DPM. Of course, the PM-128 or one of the Jewell units would be excellent choices, but there's an even better approach that will satisfy both the enclosure and meter needs. Once again, some modification of a standard product will be required.

If you look through the various parts catalogs, you'll find a number of inexpensive digital multimeters. These range in price from about \$15 to \$35. For instance, when I purchased the PM-128 DPMs from Hosfelt, I also bought a Suntek 1000 digital multimeter for about \$17. This unit is also based on an ICL7106-type part, although that's not the number on the converter part. But, in checking the pin-out and operation, it appears that the converter part used is essentially an ICL7106.

This instrument's display is a standard 3-1/2 digit type. The front panel is a thin plastic adhesive type that's very easily removed and replaced with a custom panel. The range switch provides 15 positions. So, for about \$17 I have a very pleasing, professional-looking hand-held package complete with a totally integrated 3-1/2 digit ADC and display, means for accommodating a 9-volt battery, a 15-position range switch, and a method for providing my own custom front panel with my specific labeling. There's no other way to get all those features for this price by purchasing separate parts such as an enclosure, a DPM, a range switch, etc. The cost of the parts purchased separately would be at least \$25. Consequently, the complete multimeter instrument is considerably less costly. With a little care, when the project is complete it will look like a commercial instrument—not something pieced together from various junkbox parts.

Of course a significant modification of the

basic instrument is needed for almost any custom application. Still, all the same work would be required even if such a commercial instrument weren't used as a starting point. In fact, it would even be cost effective to purchase an instrument such as the Suntek 1000 just for the A/D converter, the display, and the display connector. The price of those parts if purchased separately is likely much greater than the entire instrument. The fact that those parts already come in a nice package is a bonus.

So the next time you consider building a project like a hand-held VSWR meter, a power supply, a Q meter, or a frequency counter, look through the various parts catalogs to see if there's an inexpensive commercial product that will provide some of the elements you need. If you understand how the basic components work (like the dual-slope A/D converter), you'll be able to use those commercial products as the starting point for your project. This will save time and money, and will provide a finished product with a very professional appearance.

Closing remarks

The dual-slope analog-to-digital converter and specifically the ICL7106 is a very versatile part that can be used to provide good performance in a wide range of applications. For example, the 100 mV reference isn't a required value. Higher or lower values may be used. I have actually used a 10 mV reference in one application that provided a 10 μV resolution. But to do this, the integrator-component values must be changed to allow the integrator output to swing over its full range. Also, the true differential and floating nature of both the signal and reference inputs makes the part very versatile. This feature allows signals to be sensed right at the point of interest, eliminating errors that can occur from nuisance signals in the circuit (such as caused by ground loops). It also allows direct ratio measurements of two input signals, eliminating the need for various precision elements normally required to perform such a task.

The availability of inexpensive products based on dual-slope parts such as the ICL7106 makes it possible to build high-performance, professional projects at a comparatively low cost. If you wish to explore the possibilities of these devices further, get the data sheets on the various dual-slope parts so you thoroughly understand their operation and how to tailor them to your project needs. ■

REFERENCES

1. Hosfelt Electronics, 2700 Sunset Boulevard, Stubenville, Ohio 43592-1158. Phone: 800-524-6464 (voice) and 800-524-5414 (fax).
2. Digi-Key, 701 Brooks Avenue, South, P.O. Box 677, Thief River Falls, Minnesota 56701-0677. Phone: 800-344-4539 (voice) and 218-681-3380 (fax).
3. Intersil ICL7106 data sheet.

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Antennae Exotica—The Serpentine Stealth Vertical

By Nathan “Chip” Cohen, N1IR

2 LedgeWood Place
Belmont, MA 02178

Summary: An article describing a VHF/UHF fractal monopole antenna design. A Yagi design is discussed as well.

Spring 1996 issue, pages 79-83.

Please contact the author for additional information.

PRODUCT INFORMATION

New 1996 Product Catalog from AEA

Advanced Electronic Applications, Inc. (AEA) has mailed the new AEA 1996 Product Catalog. They introduced 16 new products throughout 1995 and the 1996 Catalog contains all the information and pictures for each of them plus the other AEA products including

data controllers, software, antenna analysts, remote radio controllers, and keyers.

If you would like to receive a catalog, send your name, callsign, and address to Advanced Electronic Applications, Inc., Attn: '96 Catalog, P.O. Box C-2160, Lynnwood, WA 98036; or fax 206-775-2340.

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SINGLE SIDEBAND SYSTEMS AND CIRCUITS

*A review of the second edition of this
popular book*

It would be hard to imagine walking into a technical library and not finding at least one well-worn copy of *Single Sideband Systems and Circuits* on the shelves. While most of the basic material contained in that venerable 1964 edition has withstood the test of time, technology has made vast strides in 23 years. In 1964, transistors were first appearing in low-level RF stages; today MOSFETs are vying for dominance in high-power RF designs. In 1964, microprocessors were unheard of. Integrated circuits were still in their infancy. Computer analysis of circuits and communications systems—a fact of life for today’s design engineer—was science fiction 23 years ago.

This book is written for practicing engineers; but, the writers deserve credit for using plain English whenever possible. This makes it both comprehensible and enjoyable reading for the average technically inclined individual. The seventeen chapters were edited by William E. Sabin and Edgar O. Schoenike (retired from the Advanced Technology and Engineering Department of Collins Avionics and Communications Division, Rockwell Corporation), and written by members of the engineering staff at the Collins Divisions of Rockwell. Sabin, W0IYH, is also a well-known and respected author of numerous amateur radio-related articles. Many of his receiver pieces are considered classics today.

Numerous circuit diagrams help to illustrate the design examples covered in the text. However, this is not a “cookbook” of practical circuits, as many component values are not

specified. Chapters deal with topics as diverse as “High Frequency Link Establishment,” “Digital Signal Processing,” and “Receiver Measurements and EMI Techniques.” Other chapters cover receiver, exciter and transceiver design, preselection, synthesizers, signal processing, solid-state power amplifiers, ultra-low distortion power amplifiers and high-power linear amplifiers. There’s even a chapter devoted to antenna matching techniques. Many other subjects are also covered in detail.

A 3.5-inch diskette containing public domain software developed by Rockwell engineers accompanies the book. The software runs under IBM DOS format. Programs for the analysis of cascaded noise figures and intercepts, Chebyshev bandpass filter design, and digital SSB receiver analysis are on the disk. Other useful programs are included for the design and analysis of PLLs and PLL filters. There is a program for the Fano method for broadband matching. There are also SPICE subcircuit files for three popular Collins mechanical filters.

Single Sideband Systems and Circuits is a fitting tribute commemorating the 50th anniversary of the founding of the Collins Radio Company. With any luck, we won’t have to wait another 20 years to see the third edition reach print. I’ve already reserved a place for it on my bookshelf!

The second edition of *Single Sideband Systems and Circuits* is published by McGraw Hill, Inc., New York, New York 10020. The book is priced at \$75, including software. To order a copy call: 1-800-2McGraw. ■

QUARTERLY COMPUTING

Software shortcuts

Years ago, I read a science-fiction short story in which a human space traveler crash-landed in a distant star system, on a planet populated by technologically backward but intelligent aliens. Our hero, a very lazy individual concerned about his own comfort, taught the natives the rudiments of technology so they could provide him with indoor plumbing, central heat, and refrigeration.

In fact, one could make a strong argument that human technology in general—and amateur radio in particular—represents encapsulated laziness. Why travel hundreds of miles to speak to someone in person, when wired or wireless communications can bring us in contact at the lift of a finger?

Sloth may hold a rightful place in the universe, after all. It does in this column, in which we'll examine a pair of potential software labor-savers that relate to amateur radio operations, and consider whether or not they meet our expectations.

PC diagnostics

Most radio amateurs own at least one test instrument—a multimeter—and take pride in knowing how to use it for basic troubleshooting. As we work our way upscale, we find VSWR meters, signal generators, oscilloscopes, and even an occasional spectrum analyzer.

Unfortunately, aside from using a multimeter to check power-supply voltages, none of these instruments can help us when the hamshack's personal computer malfunctions.

Troubleshooting a PC's hardware requires expensive and complex instruments—logic analyzers, microprocessor emulators, and pattern generators—more at home in a design lab than on a repair bench.

What makes a PC so hard to troubleshoot? In traditional amateur-radio equipment, we're accustomed to working with two-dimensional analog signals—for example, AGC or DC power-supply voltages that typically change slowly with time—that we can measure and display on a meter or oscilloscope.

In a PC, signals take on added dimensions. Instead of a single line, a pattern of voltages on a group of lines (a bus) carries information in the form of high and low voltages—binary ones and zeros. To make matters even more complex, the patterns change rapidly with time, at rates that approach the VHF bands. Worse, a group of lines in a bus can change their function and carry both addresses and data.

For example, modern PCs store working data in dynamic random-access memory (DRAM) integrated circuits, inside of which each memory cell consists of a leaky capacitor whose contents must undergo periodic refreshment to maintain data. A few thousand electrons consti-



AMIDIAG Ver 4.58A, System Information, (C)1992-1994 American Megatrends Inc.

Port Address	Type	Owner	Status	Properties
1F8-1F7	ISA	HDD controller	Nonsharing	
200-207	ISA	Game port	Nonsharing	
220-22F	ISA	Sound card	Nonsharing	
2F8-2FF	ISA	COM2	Nonsharing	16558 type
330-331	ISA	Sound card	Nonsharing	
378-37A	ISA	LPT1	Nonsharing	Extended LPT
388	ISA	Sound card	Nonsharing	
3C8-3CF	ISA	UCA adapter	Nonsharing	
3D0-3DF	ISA	UCA adapter	Nonsharing	
3E8-3EF	ISA	COM3	Nonsharing	16558 type
3F0-3F5	ISA	Floppy controller	Nonsharing	
3F6	ISA	HDD controller	Nonsharing	
3F7	ISA	Floppy controller	Nonsharing	

Menu- Next-<N> Previous-<O> Print-<P> <I> <I>

Figure 1. AMI Diagnostics' SysInfo utility can pinpoint I/O addresses currently in use and locate spares available for adding new hardware to a PC.

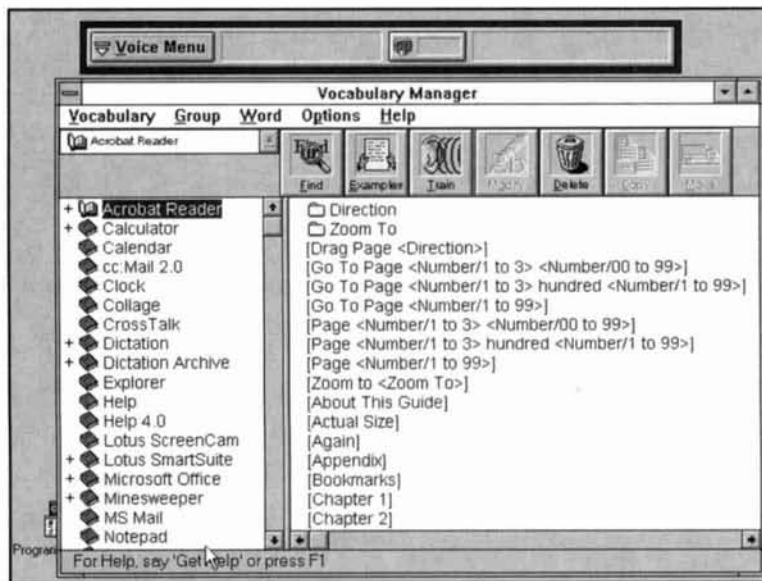


Figure 2. DragonDictate for Windows recognizes application-specific words that control Windows software, in this case a portion of the controls for Adobe Acrobat, a document reader.

tute the difference between a stored logic one and a zero; that's a far cry from the untold billions of electrons per second that make the trip from cathode to plate in an old-time transmitting tube!

Pattern sensitivity complicates PC memory testing. In a defective DRAM IC, a logic one can affect the contents of a neighboring memory cell, altering a stored zero to a one. Thus, it's important to test memory using various combinations of ones and zeros, and not just a single all-one or all-zero pattern—that adds another dimension of test complexity.

So far, we've only considered memory tests. A modern PC also includes I/O ports, hard and floppy disk drives, a video-display board, cache memory, and auxiliary I/O. Fortunately, you can troubleshoot a PC without owning a bench full of equipment.

By way of example, American Megatrends, Inc., of Norcross, Georgia offers AMIDIag, a DOS-based diagnostic-software package that can test your PC's memory and virtually all of its components, from floppy-disk drive to cache memory. At a list price of \$99.95, AMIDIag rates as an inexpensive insurance policy and an alternative to an expensively loaded test bench. In addition to offering hardware tests, the AMI Diagnostics package also includes a clutch of utilities that can help you prepare your PC for installation of new hardware and software components. For example, Creative Labs' Sound Blaster 16 add-in sound card can use one of four user-selected blocks of I/O port addresses. As **Figure 1** illustrates, you can use AMIDIag's Sysinfo utility to check for I/O port addresses

already in use and select another block for the Sound Blaster.

AMI includes a copy of McAfee Associates' Scan computer-virus detector (release 9.30, version 117), but due to production cycles the version included carries a March 1995 file-creation date. While this otherwise-excellent utility can sniff out older viruses, you're better off obtaining a more recent version from a BBS.

Rounding out AMI's extras, Config offers developers and systems administrators a potentially helpful tool kit for creating and updating configuration logs and hardware setups. You can add digitized photos of motherboards and link the (X,Y) coordinates of components to AMI's diagnostics, enabling a technician to pinpoint a defective memory IC.

In practice, using a diagnostics package requires some preparation and a dash of skepticism. AMIDIag requires you to disable any memory-resident routines or memory-management software before you run diagnostics. Also, AMIDIag won't report SCSI (Small-Computer Systems Interface) peripherals unless your PC is running a hardware-specific ASPI driver that supports the SCSI controller.

In general, all diagnostic software can occasionally mislead a user by incorrectly identifying interrupts and addresses in use, and by overlooking or misidentifying add-in boards introduced since the software was developed. To its credit, AMI regularly releases updates of its diagnostics—version 5 should be available when this review appears in print.

DragonDictate

For about the price of a new ham radio transceiver, you can own a piece of futurist technology that's here today and nothing short of amazing. I refer to DragonDictate for Windows, a voice-recognition system that works via your IBM PC's sound card and converts spoken words to text on screen. In addition, DragonDictate can also control many Windows programs via the spoken word.

Among the many intriguing possibilities DragonDictate offers for amateur radio applications, a few come to mind immediately: contest logging, recording a CW transmission (a boost for anyone who can copy high-speed CW and speak the characters faster than he or she can write), and control of a radio transceiver via a Windows program and an RS-232 link. In addition, DragonDictate could form the nucleus of a club project aimed at helping prospective or current radio amateurs who have suffered disabling injuries.

Also, anyone who regularly uses a computer and suffers from carpal-tunnel syndrome or repetitive-strain injuries can use DragonDictate

to alleviate symptoms. Of course, it's imperative to correct whatever condition caused the problem in the first place, but using voice-recognition software may speed healing by reducing the strain on afflicted joints and nerves.

What makes DragonDictate work? Spoken words consist of phonemes, or subwords, that are analogous to the dots and dashes we string together to form a Morse code character. Over 50 phonemes exist, which allow creation of an enormous number of words. DragonDictate's software uses a PC's sound card hardware to process phonemes into code and then compares it with encoded words stored in a dictionary.

Because phonemes tend to occur in certain combinations, DragonDictate narrows its search by predicting which phonemes are candidates to occur next. The closest-match word then appears in the application, with a list of also-ran and comes-close candidate words appearing in an adjacent window.

If DragonDictate's first choice isn't what you intended, you can select a closer match from the list, edit an existing entry in the list or type a new entry. You can also invoke Spell Mode, which uses the international phonetic alphabet (called "alpha-bravo" words by Dragon Systems) that's familiar to radio amateurs (e.g., "key" is spelled as "kilo echo yankee"). If DragonDictate consistently fails to recognize a word, you can select a training mode that will reinforce recognition of both the correct and the incorrect words.

DragonDictate's designers have incorporated phrase-recognition routines that reinforce the program's utility as a dictation tool. Examples include recognition and entry of ZIP codes, telephone numbers, and salutations. You can enter numbers in natural format (e.g., "one hundred and twenty-five") in addition to single digits (e.g., "one", "two", "five"), and you can also add your own frequently-used phrases. In addition, you can create "dictation macros", or short phrases that substitute for several words, that are analogous to radio's Q signals (e.g., QRT, QSL, QSY, etc.).

As a controller, DragonDictate allows you to activate applications that run under Windows 3.1x and Windows 95 simply by speaking the names of menus and commands, field names in dialog boxes, and control-button names found in windows and dialogue boxes. You can launch and close programs, and also control the position of a mouse within an application.

Figure 2 shows a portion of the command list for Adobe Acrobat, a universal document-reader package.

My review copy of DragonDictate for Windows arrived on a single CD-ROM disc (floppy-disk installation kits are also available) accompanied by a quick-reference card, a 230-

Most amateurs are surprised to learn they hold and unused field strength meter-dared gas W. R. neither. With a telescope entire attached tool one connector and necessitated turned to high, its nearer is helpful and many situations. Some small indicators sold for CB use even have a special check for just such an entire.

Most amateurs are surprised to learn they own an unused field strength indicator—their swr meter. With a te telescoping antenna attached to one connector and the sensitivity control turned to high, this meter is helpful in many situations. Some small indicators sold for CB use even have a special jack for just such an antenna.

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Most amateurs are surprised to learn they own an unused field strength indicator—their SWR meter. With a telescoping antenna attached to one connector and the sensitivity control turned to high, this meter is helpful in many situations. Some small indicators sold for CB use even have a special jack for just such an antenna.

Table 1. DragonDictate's accuracy improves with training. Here are five successive readings of the first paragraph of R.P. Haviland's article entitled "Instruments for Antenna Design Development and Maintenance, Part 4" that appeared in *Communications Quarterly*, Winter 1996. Errors noted in each reading were corrected in subsequent readings. In the first reading, the software finds "entire" as closest match for "antenna."

page user's manual that benefits from a comprehensive index and clear writing, and a Shure SM10A microphone.

Depending upon the size and shape of your head, you may have to spend a few minutes adjusting the microphone and headband for correct and comfortable positioning.

Dragon Systems notes that voice-recognition accuracy depends on several factors, including room noise, mike position, and the sound card itself. Dragon certifies software operation with certain cards (the SoundBlaster 16 Value Edition and the M-ACPA DSP-based sound card), but notes that the SB16 Vibra card doesn't

work with the software. I used a SoundBlaster AWE-32 and experienced no problems.

To run the software, you'll need an IBM-compatible PC that's equipped with at least a 486/66MHz CPU and a minimum of from 12 to 16 MB of RAM, depending on which version of DragonDictate you order. While all three versions include a 120,000 backup dictionary in a disk file, the \$395 Personal, \$695 Classic and \$1695 Power Editions maintain vocabularies in RAM of 10,000, 30,000, and 60,000 words, respectively. Profession- and language-specific add-on vocabulary modules are also available.

When first started, DragonDictate for Windows runs a microphone-calibration routine that attempts to maximize the software's acoustic signal-to-noise ratio, and then presents you with a cleverly written tutorial that shows the basics of dictation and software control.

I found that DragonDictate works amazingly well, and that its accuracy improves with practice. My first few dictation efforts resembled "Beat" poetry, and the software initially didn't recognize many common amateur-radio terms. **Table 1** illustrates how DragonDictate's accuracy improves with training. I read the same paragraph five times, correcting errors as needed.

To simulate Field Day contact-logging operation, I switched a VHF receiver to a busy local 2-meter repeater and tuned in an AM-radio talk show at moderate volume. While I noted an occasional errors, DragonDictate continued to work well. For operation under extremely noisy background conditions, it would be worthwhile

to investigate using a World War II-vintage pilot's throat-contact microphone equipped with a suitable interface circuit to drive the SoundBlaster.

Like most "labor-saving" devices, voice-recognition software requires some expenditure of effort to obtain best results. For DragonDictate for Windows, that translates to expending some time and patience in training the software. Based on my admittedly subjective impressions, DragonDictate should easily achieve accuracy rates at least as high as—and probably higher than—most optical-character recognition (OCR) software, another labor-saver. And that's very good, indeed.

Purchasing information

Where to buy products mentioned in this column:

You can purchase AMI Diagnostics from most software suppliers or directly from American Megatrends, Inc. Write to them at 6145-F Northbelt Parkway, Norcross, Georgia 30071, or phone 1-800-U-BUY-AMI or 1-770-263-8181.

Order DragonDictate for Windows from Dragon Systems, Inc., 320 Nevada Street, Newton, Massachusetts 02160. You can also reach them by phone at 1-800-TALKTYP or 1-617-965-5200, or via E-mail at info@dragon.com (Internet: <http://www.dragonsys.com>). ■

PRODUCT INFORMATION

HP Using World Wide Web

Hewlett-Packard Company is using the World Wide Web to pioneer new ways of communicating with its worldwide test-and-measurement customers.

By offering a separate directory within HP's Web home page, Access HP, HP's Test and Measurement Organization (TMO) gives its global customers instant access to information about HP test-and-measurement products and services. Some TMO information is available in five languages, with most information expected to be available in multiple languages in the future.

The information available through the World Wide Web includes interactive lists of sales offices, service centers and call centers; a history of Hewlett-Packard's test-and-measure-

ment business; and the ability to order hard copies of the test-and-measurement product catalog on-line. Also available is the Test & Measurement On-line quarterly newsletter, a Product Information Area, and an interactive index that allows customers to search for application notes, view abstracts and order hard copies of notes. The newest addition to the Web is the availability of TMO product data sheets. Data sheets are listed by model as well as product type and contain a color photo, product summary, a list of feature specifications, and ordering information.

The TMO directory can be accessed via HP's home page at <http://www.tmo.hp.com>.

For more information, contact Hewlett-Packard Company, Direct Marketing Organization, P.O. Box 58059, MS51L-SJ, Santa Clara, CA 95051-8059.

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SETI MADE SIMPLE

What can **we** do?

There are many things that excite me about the times in which we live. One is that I have been privileged to witness a perceptual revolution. Just 50 years ago, every credible authority maintained that mankind is alone among the stars—the sole sentient species in the vast cosmos. Today, the overwhelming preponderance of scientific thinking holds that we are not. How quickly we have completed the Copernican revolution!

In these pages, we'll explore the pertinent cosmological evidence that leads most knowledgeable scientists to envision a universe teeming with life. We'll see why many astrophysicists believe that the best evidence of extra-solar civilizations is to be found in the microwave spectrum. If these lines of thinking are correct, it is you, the radio amateurs and microwave experimenters of planet Earth, who have the best chance of detecting such evidence. I'll lay out a strategy for amateur SETI—a Search for Extra-Terrestrial Intelligence involving several thousand hobbyists that can rival any government search ever proposed and denied funding. Finally, I'll list the equipment requirements for you to join the team: the microwave, computer, and digital signal processing (DSP) hardware and software that would make a planet like our own visible from across the galaxy, and which is today within your grasp.

Each of these topics is worthy of an article, so my comments will, of necessity, be cursory. For those interested in pursuing this subject further, abundant literature exists, much of which is available through The SETI League.

So, who is SETI?

Not too many years ago, when I wrote about a previous amateur breakthrough, people would

ask: "Who is OSCAR?" The present acronym represents the *Search for Extra-Terrestrial Intelligence*. It was coined in the 1960s to describe the use of radiotelescopes to seek out electromagnetic signals of possible intelligent origin, emanating from beyond our planet. Dozens of such searches have been conducted over the past 35 years, with some interesting results, none yet conclusive. On the other hand, not only have we not yet scratched the surface, we haven't even found the itch. We *have* surveyed several thousand stars, for brief periods of time, at limited frequencies. But with an estimated two hundred billion stars in our galaxy, and perhaps a hundred billion other galaxies, we have a long way to go before we can start drawing any conclusions.

In fact, logic and probability theory suggest that we should *not* have yet succeeded in receiving intelligent signals. SETI pioneer Dr. Frank Drake, who conducted the first search in 1960, now estimates that there are perhaps 10,000 advanced civilizations in the Milky Way Galaxy.¹ That makes each star we survey a 20 million-to-one long-shot. To have found the elusive needle in the cosmic haystack by now, would be equivalent to walking into the Library of Congress blindfolded, selecting one book at random, and getting home to find that we had checked out *Macbeth*. If we try, and fail, does that mean that *Macbeth* does not exist? The data is incomplete.

Then again, our elected leaders are hardly averse to drawing conclusions from incomplete data, and acting upon them precipitously. NASA once had a modestly funded SETI effort, which consumed about a tenth of a percent of the agency's budget. Both a targeted search of likely candidate stars and an overall sky survey were initiated in October 1992 (significantly, the 500th anniversary of Columbus'

first voyage of discovery). Absent immediate results, NASA's funding was suspended by Congress just one year later, and both searches were curtailed. The SETI League, SETI Institute, Planetary Society, and other organizations are now trying to privatize those efforts.

The SETI League was founded in 1994 as a membership supported, non-profit [501(c)(3)] scientific and educational corporation. Our charter involves organizing and conducting an electromagnetic search of the skies, to spot signals of possible intelligent origin. This search will involve thousands of radio amateurs, microwave hobbyists, and DSP experimenters around the world, working in concert to accomplish the seemingly impossible. In other words, we seek to do what hams have always done!

Cosmic evolution

Current thinking, as first theorized by George Gamow, holds that the universe began as a single, extremely dense point in space-time, which exploded perhaps 9 to 18 billion years ago, and has been expanding and cooling ever since. Gamow's evidence in support of this theory was the consistent red-shift (decreasing frequency Doppler shift) that Edwin Hubble had measured in distant galaxies. Fred Hoyle derisively dubbed that universal birth the Big Bang, and the name stuck. Gamow's theory further predicted that the Big Bang should have left a residue of microwave radiation, which was indeed first measured by Arno Penzias and Robert Wilson in 1965. The so-called Three Kelvin (3K) Background Radiation has been reaffirmed countless times, and stands as the best evidence to date of an expanding universe.

Our uncertainty as the exact age of the universe stems from our inability (thus far) to precisely measure the Hubble Constant, which relates to the rate of expansion of the universe. Since measurements from (appropriately) the Hubble Space Telescope bring us a new estimate every few weeks, I've taken to calling this number the Hubble Variable! We do know that our planet is on the order of four and a half billion years old. Thus, the Earth appears to be only half to one fourth the age of the universe. This is significant, because it suggests that our planet (and the star around which it revolves) are youngsters—relatively new arrivals on the cosmic scene.

Our rather ordinary star is but one of perhaps two hundred billion in its galaxy (which we call the Milky Way), and perhaps a tenth of those stars appear to be of similar size, heat, and composition to our Sun. Although we can not detect planetary systems optically,² they evidence themselves in several other ways, and everywhere we have looked for planets, we

have detected what we believe to be indications of their presence. It is theorized that the formation of planets is an essential process by which a rotating star dissipates some of its angular momentum. So planetary formation appears commonplace, and we can assume that each of the sun-like stars in our galaxy has its own retinue of planets. Because the stuff from which our planet is made is hardly unique to Earth, but common throughout the cosmos, we can expect at least some of those hundreds of billions to have a rocky crust, liquid oceans, puffy clouds, and nitrogen skies. What *Star Trek* calls "M-class planets."

Finally, our galaxy is one of perhaps a hundred billion such star groups in the universe. Now there's no reason to expect the laws of physics, or chemistry, to be different in those other galaxies, from the ones we observe on Earth. Which leads us to image the existence of countless billions of Earth-like planets circling Sun-like stars. And remember, most of these planets are older than our homeland, and have had more time to spawn their particular versions of life.

The emergence of life

Perhaps the most amazing aspect of our existence is that *life evolved from non-living things!* Not just any non-living things, mind you, but a specific group of complex organic molecules called amino acids. Of course, we have no way of knowing that life on other planets is necessarily "organic" as we use the term, but let's assume for just a moment that it is. (If we're wrong, this suggests the existence of more, not less, life than I am supposing.)

One of the most important contributions of radio astronomy is its ability to discern the composition of its target objects. Not just stars (which we know to burn primarily hydrogen into helium); radio telescopes can measure the composition of interstellar gasses and molecular dust clouds as well.

The presence of abundant interstellar hydrogen was first detected by Harvard University graduate student Harold Ewen and his advisor Edward Purcell, in 1952, by measuring its 21-cm microwave emissions.³ In 1963, a group at MIT's Lincoln Laboratory first detected the characteristic 18-cm emission of interstellar hydroxyl ions. We shall learn shortly about the significance to SETI of these two spectral emission lines. Less well known, but even more important for discussions involving the origin of life, is that dozens of complex molecules, many organic, have also been detected in the interstellar medium. A partial list includes: cyanogen, ammonia, water, formaldehyde, carbon monoxide, hydrogen cyanide, cyanoacety-

lene, methyl alcohol, formic acid, carbon monosulfide, silicon oxide, carbonyl sulfide, acetonitrile, isocyanic acid, methylacetylene, hydrogen isocyanide, acetaldehyde, methyleneimine, deuterium cyanide—the interstellar medium is anything but an empty void. It's a veritable chemistry set.

But can it spawn life? Nobel chemist and SETI pioneer Melvin Calvin believed so. At Berkeley in 1951, he sparked a mixture of carbon dioxide, hydrogen, and water with an energy burst from a cyclotron, and produced organic chemicals—some of which are known to be precursors of life. In 1955, another graduate student, Stanley Miller, working with his advisor Harold Urey at the University of Chicago, restructured the Calvin experiment with an even more startling result. Using several of the precursors from the above list, they produced a wide variety of amino acids!

If solar systems indeed condense out of the interstellar medium, then the chemicals of life may be found on countless planets. Necessary energy sources (lightning, volcanism, whatever) are readily available. Building amino acids appears relatively easy. In fact, “alien” amino acids have already been found in meteorite fragments,⁴ so we know they are commonplace in the cosmos, by no means unique to Earth. The clincher is that, using an electron microscope, Hans Dieter Pflug has detected what appear to be micro-organisms within meteorites! They're only fossilized bacteria, but they certainly present us with our most promising evidence of the existence of alien life.

Now it's a long way from bacteria to thinking beings capable of harnessing electromagnetic communications (and hence detection by our radiotelescopes). On the other hand though, the number of potential life sites in the universe is truly mind-boggling. If we take the Milky Way to be typical, there are on the order of a million billion billion “good” suns among the galaxies. Should intelligent life not have evolved on planets orbiting a good many of those suns? If an infinite number of monkeys sits down at an infinite number of typewriters, one of them is bound to write out the whole *Encyclopedia Galactica*.

How to search

We don't know for certain that all species eventually develop electromagnetic communications, but it's a safe bet some do. Photons are, after all, the fastest space ships we can imagine. Radio communication is cheap, and quick, and easy to learn. If we can figure it out, the assumption of mediocrity suggests, then so can more advanced civilizations, who may have been around millions, perhaps billions, of years

longer than ourselves. Okay, so maybe a given technologically advanced civilization adopted, and then abandoned radio communications a billion years ago. No matter. If they are a billion light years distant, their photons are just now reaching us, and are in fact falling silently on our heads even as we speak.

The greatest obstacle to interstellar communication is naturally occurring noise. Galactic, cosmic, quantum, and synchrotron noise sources span the spectrum, but they aren't uniform. The quietest part of the sky, the 1 to 10 GHz microwave window, is a logical starting point, and by no means geocentric. But we're taking an incredible bandwidth here. Can we narrow the search spectrum?

Most SETI scientists think we can. Toward the bottom of the microwave window are two rather strong spectral radiation lines, emanating from hydrogen and hydroxyl, among the most abundant substances in interstellar space. It has long been suggested that between these two markers falls a natural, universal communications band.

Significantly, hydrogen and hydroxyl are the disassociation products of water. Although we needn't limit our search to water-based life, it's interesting to speculate that others might recognize an additional significance to these two frequencies. Dr. Bernard M. Oliver, retired vice president of engineering for Hewlett-Packard Company, headed NASA's SETI office until it was closed, and was senior technical advisor for the SETI League until his death last November. It was Oliver who, in a 1971 study,⁵ first suggested scanning the cosmos between the hydrogen and hydroxyl lines. He coined the rather poetic term for this proposed communications band. “Where shall we seek out our kind?” Oliver asked. “At the water hole, where species have always gathered.”

Other frequency bands than the water hole, and other technologies than microwave, are certainly worthy of SETI consideration. In fact, a good deal of attention is being paid to Optical SETI, by optical astronomers who, after all, do have a 400 year head start on their radio counterparts. But since radio waves are what the ham community knows best, it is here that I propose concentrating our amateur SETI efforts.

The water hole extends from roughly 1420 to 1660 MHz, a bandwidth of 240 MHz.

Monitoring it at, let us say, 10-Hz resolution, we have 24 million channels to scan.

Consequently, much SETI research has been devoted to developing mega-channel real time spectrum analyzers. This can be approached as a digital signal processing project, an area in which hams are emerging as the technological innovators. The AMSAT/TAPR DSP-93 project, for example, may not be capable of scan-

ning the entire water hole in real time, but it can certainly cover audio bandwidths, at reasonable resolution, with astounding sensitivity. Given the appropriate accompanying software, there's no reason not to believe such DSPs capable of recognizing very weak coherent signals coming out of our microwave receivers.

The late NASA SETI study had two complementary components: a targeted search and an all-sky survey. The former, involving parking on likely candidate stars for long periods of time, is well suited to large, steerable dishes with their narrow beamwidths and high sensitivities. If we guess right as to which stars are likely candidates, the targeted search will provide us with the greatest likelihood of immediate success. But because we only know of a limited number of relatively nearby candidate stars, concentrating our search in their direction may cause us to miss an equally good star of which we happen to be unaware.

An all-sky survey, on the other hand, makes no *a priori* assumptions as to the most likely direction to explore. The sky survey attempts to sweep out the entire sky that can be seen from a given location. No antenna tracking is required, because it is sky, rather than individual stars, which we seek to survey. Therefore, we can use our antennas in drift scan mode, as Grote Reber did when he invented the radiotelescope,⁶ by aiming in a north/south line, letting the Earth turn the antennas, and varying only their elevation.

Since large antennas are quite narrow, the sky survey is better performed with dishes of moderate size. Of course, smaller antennas have less gain, so to achieve reasonable sensitivities, they need to scan for extremely long periods of time. The sky survey approach, it would seem, is ideally suited to the community of radio amateurs and microwave experimenters. This is the area in which I feel hams can make their most significant SETI contributions.

Why to search

Any endeavor that commits significant resources must promise substantial benefits, if it is to be justified. In this section, more philosophical than technological, I'd like to quote the rationale given by some of the SETI pioneers. Their comments are gleaned from the references that appear at the end of this article.

"We believe such a coordinated search program is well justified on its scientific merits. It will also have important subsidiary benefits for radio astronomy in general. It is a scientific activity that seems likely to garner substantial public support.

"You find out who you are. It's a

basic question. Are there beings in some sense like you, elsewhere in the universe, or are we the only ones around? It touches deeply into myth, folklore, religion, mythology; and every human culture in some way or another has wondered about that kind of question. It's one of the most basic questions there is."

—**Dr. Carl Sagan, Duncan
Professor of Astronomy, Cornell
University**

"...a vast body of knowledge will have accumulated over the aeons, and this knowledge is accessible to any race whose technological prowess qualifies it.

"I have termed this body of knowledge our galactic heritage, and I believe that access to it would truly be the most important event in the recorded history of man. The galactic heritage could include a large body of science that we have yet to discover—answers to questions that we haven't even thought of...

"But more important, I think, would be the societal benefits. We will be in touch with races that have achieved longevity. The galactic community would have already distilled out of its member cultures the political systems, the social forms, and the morality most conducive to survival, not for just a few generations, but for billions of years. We might learn how other races solved their pollution problems, their ecological problems, and how they have shouldered the responsibility for genetic evolution in a compassionate society."

—**Dr. Bernard M. Oliver, former
Vice President of Engineering,
Hewlett-Packard Company;
Senior Technical Advisor, SETI
Institute**

"There are few questions that more excite the curiosity, the imagination and the exploratory bent of modern man than the one posed in this study: Are we humans alone in this vast universe? The question is usually expressed in terms of other possible intelligent beings, on other planets. The philosopher in me would want to believe that if there are other intelligent beings, they are also free, and will use that freedom

to try to find us. The basic problem to which this study is addressed is similar: Will we use our freedom to find them? What priority should this search have for modern man, everywhere?

"I must now mention God—otherwise quite properly unmentioned in these scientific studies—and must go a step further and pose the question: Can a religious person, or even more, a theologian, possibly be legitimately involved in, even be excited by these discussions of the possibility of other intelligent and free creatures out there?

"As a theologian, I would say that this proposed search for extraterrestrial intelligence (SETI) is also a search of knowing and understanding God through His works—especially those works that most reflect Him. Finding others than ourselves would mean knowing Him better."

—**Father Theodore M. Hesburgh, C.S.C., President Emeritus, University of Notre Dame**

"...the lesson we have learned from all our previous searching is that the greatest discovery is not a simple one to make. If there were once cockeyed optimists in the SETI endeavor, there aren't any now. In a way, I am glad. The priceless benefits of knowledge and experience that will accrue from interstellar contact should not come too easily. To appreciate them, we should expect to devote a substantial portion of our resources, our assets, our intellectual vigor, and our patience. We should be willing to sweat and crawl and wait.

"The goal is not beyond us. It is within our grasp."

—**Dr. Frank Drake, Professor of Astronomy and Astrophysics, University of California, Santa Cruz; President, SETI Institute**

"I think the SETI enterprise can best be understood as a kind of exercise in the archeology of the future. We are well aware of the archeology of the past. We find a site, a tumulus, or a ruin, and we take a spade and dig into the ground—and if we are lucky, we discover Ur of the Chaldees or something marvelous.

"Now we never thought that we could examine the same thing in reverse time. But in fact, in a way, we can. We know that it is possible that some other civilization, who wants to, can bring us in. Of course it will be their past, but our future, which we are investigating to some degree. Even though they are made of different chemistry, even though they have never seen our star, even though they have nothing biological in common with us, if they have radio astronomy and the kind of technology we are imagining, they have very much in common with us: the development of culture which is unmatched in all the 10 billion species or more that have come to the face of the Earth.

"So that is the story. Maybe the spade will turn up a good site one day. We hope it will. It's just a question of being patient. When you've got the spade, and you know the future is there, it seems very wrong not to dig."

—**Dr. Philip Morrison, Professor Emeritus of Physics, Massachusetts Institute of Technology**

What can we do?

The beauty of SETI is that there's something for everyone—enough work to spread around. And if we succeed, it will not be the individual, but all of humankind, to whom the glory will accrue. What I intend to show you here is that, should we succeed, it will be due not to any individual effort, but to the cooperative efforts of thousands of dedicated amateurs.

Consider that the average ham moonbounce or TVRO dish has a beamwidth on the order of three degrees. Let's put that dish on a transit mount, and let the Earth be our antenna rotor. Now the dish will be rotating at 15 degrees per hour, which means a given star will be within its beamwidth for at least twelve minutes. Given existing amateur DSP technology, and employing a few tricks, twelve minutes is enough time to roughly scan about 14.4 kHz of spectrum, at 10-Hz resolution (which I consider consistent with the frequency stability of amateur microwave local oscillators). But the water hole is 240 MHz wide, which means to cover our assigned swath of sky at all water hole frequencies, we need to be listening for 16,667 days. That's a little over 46 years.

Well, perhaps a dedicated experimenter will be willing to devote 46 years of his life to

studying the sky. Tycho Brahe did. But a 46-year search at a single antenna elevation will only survey a three degree wide swath of sky. To cover the range of declinations from southern to northern horizon, we need to conduct 60 such surveys, which brings the time dimension of the effort up to about 2760 years. And that only covers the one hemisphere of sky we can see from our QTH; a complete sky survey may demand we spend as long searching from Earth's other hemisphere as well. So a dedicated amateur can complete one full sweep of the water hole in just under six millennia!

On the other hand, 5220 experimenters can do that same sky survey in just one year. Which is why it becomes important to make SETI a broad-based effort. And where but in the amateur radio service are we as likely to find several thousand dish-equipped experimenters, scattered around the globe, with the means to communicate, hence coordinate their efforts? I submit that the problem might have been tailor-made for us.

What do you need to join the search? Here's the list:

- 1) a three-to-five meter parabolic reflector with surface smoothness adequate for TVRO, or 23 cm moonbounce;⁷
- 2) a low-noise preamp that covers the 1.4 to 1.7-GHz range;
- 3) a downconverter (in the manner of the popular Rick Campbell/Jim Davey No Tune Transverter Boards) to shift the water hole down to a suitable IF;
- 4) IF amplifiers, filters, and a square law detector that will derive audio from that IF;
- 5) a digital signal processor, such as a computer sound card;
- 6) spectrum analysis software, and a home computer on which to run it.

That which you don't build can be purchased at a cost on a par with a typical OSCAR station. Several hundred stations are already so equipped. By the turn of the century, it's possible several thousand will be, and then—well, who knows?

I expect some kind of coordination to be required, and that's where The SETI League comes in. We are a tax-exempt, nonprofit scientific and educational organization devoted to keeping the search alive. Our mission involves research, economics, and more than a little politics. We will encourage restoration of NASA's SETI funding if possible, help to privatize the effort if necessary, coordinate the efforts of a wide range of SETI amateurs and professionals, and educate the public as to the possible benefits of the search. We also stand prepared to assign particular amateurs specific search decli-

nations to assure full sky coverage, and will act as a clearinghouse for information and results. I'm sure once one suspicious signal is detected, everybody will want to know where to point his or her dish to help confirm it! The information superhighway will certainly help, and we're already a presence there. If you happen to have World Wide Web access, I invite you to browse our home page. It's hypertext linked to numerous other related Web sites. The Uniform Resource Locator (a Web address) is <http://seti1.setileague.org/homepg.html>.

A broad membership base will make it possible to put amateur SETI on track. It will also enable us to keep our membership on track with SETI-related information through a quarterly newsletter, and journal articles such as this one. We hope to promote the best hardware and software schemes to come out of the ham community, and will design, prototype, and evaluate various detection and signal analysis technologies. For further information on joining the SETI League, call 1(800) TAU-SETI, or e-mail to info@setileague.org. In the immortal words of Rick Blaine, "If that call comes, and you don't answer, you'll regret it. Maybe not today, maybe not tomorrow. But soon, and for the rest of your life."

Conclusions

It's my belief that radio amateurs and microwave experimenters, with our limited equipment but high level of dedication, have every bit as much likelihood of success as do operators of the world's great radiotelescopes, in detecting extraterrestrial signals of possible intelligent origin. It is, after all, amateur optical astronomers who have first detected the majority of comets, and radio amateurs who have pioneered most all of modern telecommunications technology. And that which the scientific establishment has in the past regarded as impossible, dedicated radio amateurs will doubtless accept as just another challenge to be met.

I like to view the SETI problem as an equation with four degrees of freedom: sensitivity, frequency coverage, sky coverage, and time. The amateur quest that I propose will of necessity be weak in the first variable, moderate in the second, but extremely strong in the third and fourth. Using readily available technology, a few thousand dedicated amateurs around the world can, in twenty year's time, repeatedly scan all 4π steradians of sky, over the entire water hole, to 10-Hz resolution, at sensitivities that rival NASA's late JPL All Sky Survey.

The Targeted Search aspect of the High Resolution Microwave Survey is another matter. Abandoned by NASA due to lack of funding, it has resurfaced as Project Phoenix, under

SETI Institute sponsorship. Phoenix started observations from a 64-meter dish at Australia's Parkes Observatory on February 2, 1995, and has already surveyed about 200 sun-like stars within 150 light years of Earth, at astounding sensitivities, from 1.2 to 3 GHz. The two efforts are, of course, complementary; just as the Targeted Search was resurrected as Project Phoenix, so we hope will amateur SETI give life to the All Sky Survey.

If we do the search, and do it right, a generation from now we'll either know for certain that we are not alone in the universe, or perhaps be forced to reluctantly conclude that we are. Either possibility boggles the imagination. So join us in seeking the ultimate DX. Maybe it's only SWL, but it's the rarest grid square of them all! ■

ARTICLE NOTES

1. Drake bases this estimate on his personal solution for the Drake Equation, an elegant tool for quantifying our ignorance, which he developed in 1961 as the agenda for the world's first SETI conference. Today the Drake Equation is a classic, to be found in nearly every astronomy textbook that addresses the question of alien life.
2. Trying to optically view a planet orbiting a star is a little like trying to spot a firefly perched on the rim of a searchlight.
3. The following year Purcell was awarded the Nobel Prize for this and other accomplishments. Ewen had the distinction of writing what is probably history's briefest doctoral dissertation—a scant dozen pages.
4. Could these samples have originated on Earth, resulting perhaps from contamination in the laboratory? A fair question. Amino acids come in two varieties: clockwise ("right-handed") and counterclockwise ("left-handed"). All life on Earth is composed exclusively of left-handed amino acids. But, meteor fragments have been found that contain right-handed amino acids, so we assume they are of extraterrestrial origin.
5. That study, part of a summer faculty fellowship program at Stanford University, brought together some of the leading minds in radio astronomy to puzzle the problem of interstellar communications. The group's most tangible result, the Project Cyclops report, remains one of the most important SETI publications to date. The SETI League and SETI Institute will be jointly reprinting "The Cyclops Report" in the summer of 1996.
6. Reber, an electrical engineer and radio amateur (W9GFZ), built the first true radiotelescope in his backyard in Wheaton, Illinois in 1937. Although lacking in formal astronomical training, he is today recognized as the patriarch of a new discipline. His 10-meter diameter dish (somewhat larger than the size that I propose for amateur SETI), on a transit mount, generated the first radio map of the Milky Way. Reber measured radiation levels millions of times in excess of what then favored theories predicted. His controversial measurements have subsequently been borne out repeatedly. Reber ultimately retired to Tasmania, apparently preferring to be, rather than merely work, DX.

7. If you don't want to dedicate your dish full time to the SETI effort, no problem. A water hole feed certainly doesn't preclude installing other feeds at the focal point as well. You can practice what's come to be known as Parasitic SETI, letting your water hole receiver scan while your dish goes about its daily business of EME, or TV, or whatever.

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PRODUCT INFORMATION

New Low-Loss RG-8U-Type Coax from Belden

Belden Wire & Cable Company has introduced their Part Number 9913F, a low-loss RG-8U-type coaxial cable. This new cable is a high-flex version of Belden's 9913 coax.

High-Flex 9913F is a 50-ohm cable suitable for high-power RF transmission. The 50-ohm impedance has the ability to offer maximum voltage withstand and optimum power transfer, opening the door to a variety of power transmission applications. Unlike conventional RF transmission cables with solid center conductors, Belden High-Flex 9913F features a 10 AWG stranded bare copper center conductor that provides improved flexibility and flex life.

The cable also utilizes a Belflex™ jacket that offers cut and abrasion resistance over a range of temperature extremes. The 9913F also utilizes gas-injected foam polyethylene insulation technology which offers better water-migration resistance. The Belden 9913F also features a foil/braid shield for 100% coverage. The foil is Belden's Duobond II®, which is a laminated foil/film/foil shield bonded directly to the foam insulation. The braid is a 90%-coverage, tinned copper braid shield.

To obtain additional information on Belden High-Flex 9913F cables or other Belden cables, contact Belden Wire & Cable Company, P.O. Box 1980, Richmond, IN 47375; or call 1-800-BELDEN-4.

Compiled by Peter Bertini, K1ZJH
Senior Technical Editor

Short Stacks and Miniaturized Antennas

Despite the fact that this was a record-breaking a winter for many in the midwest and northeast, spring has come again. What do hams thoughts turn to when spring returns? Antennas! Here are some designs to get you thinking. K1ZJH

Build a Short-stack for 2-meter SSB

This pair of "baby-boomers" will give your 2-meter SSB signal a successful launch without hanging over the neighbor's fence!

Rick Littlefield, K1BQT

Computer-modeled Yagis on long booms have a great track record for delivering pinpoint gain. However, computers are equally useful for designing short antennas for stacked arrays. In some applications, a short stack may be preferable to a single antenna with a long boom. One advantage is purely mechanical—short booms present a shorter moment to the mast. This places less stress on gearing and breaking mech-

anisms and, usually means you can use a smaller rotor. Also, according to the 1/2 boom-length rule, you can space a short array closer to other antennas on the same mast without introducing unacceptable interaction. Another advantage, at least for casual operating, is the antenna's azimuth pattern. An array with a broad main lobe and smooth off-axis response will frequently enable you to pick up contacts a sharper antenna would miss. Also, the stack's added capture area may pay off in improved weak-station reception. The main reason I became attracted to this type of antenna is because it more readily adapts to lightweight rooftop installations using TV hardware.

Design

The building-block for my rooftop array is a 5-element log-tapered Yagi developed with K6STI's Yagi Analyzer (YA) program. For the uninitiated, YA is an abbreviated form of YO (Yagi Optimizer) offered as bundled software in recent editions of *The ARRL Antenna Book*. Although more limited in scope than larger design programs, YA provides aspiring antenna builders with a user-friendly introduction to PC-based design.

When using YA, you must first choose from a listing of premodeled antennas in the program's antenna menu. Once you've selected the element and boom configuration that *most closely* matches your requirements, you can customize it—adding or removing elements and adjusting other key parameters to create a new design. If necessary, you can also scale it to another band. My Yagi, which I nicknamed the *SSB Shorty*, evolved from YA's 602-08H file. This code number signifies that the model antenna has 6 elements on 2 meters, and is mounted on a 8-foot heavy-duty boom. Because I wanted my boom to measure 6 feet in length or less, I removed one director from the 602-08H model to shorten it. According to YA, this configuration would use a 65-inch boom and yield 9.05 dBd gain in free-space (this is only 0.9 dBd less than the original 8-foot version, but with some resulting loss of front-to-back ratio). Staking a second identical antenna above the first would then increase gain by 2 to 3 dBd, for a total array gain approaching 12 dBd. A single-boom design would have to be nearly 15 feet long to equal this performance in forward gain!

In addition to shortening the 602-08H model by one element, I used the design features in YA to change the antenna's resonant frequency to 144.5 MHz, to readjust element length for

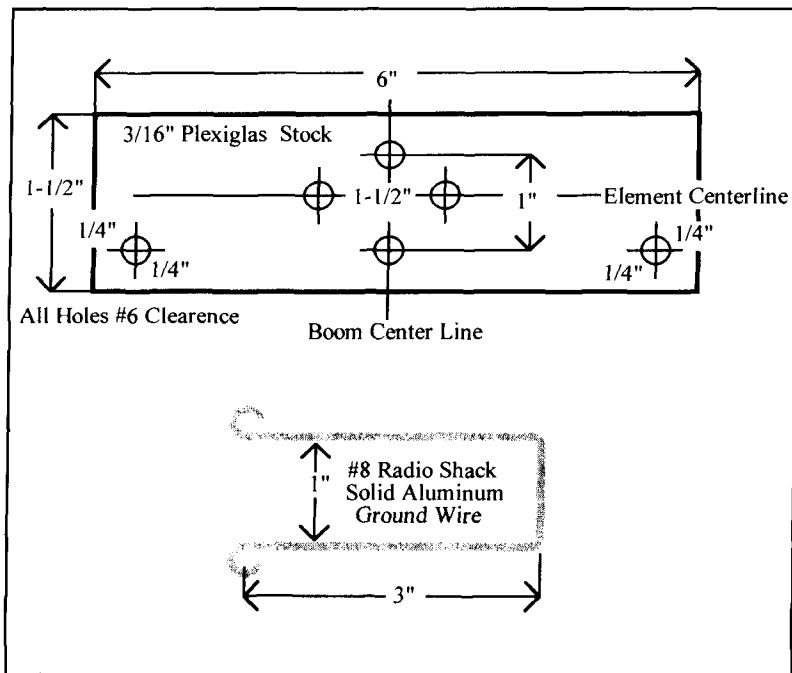


Figure 1. Driven element drilling template and hairpin inductor details.

my aluminum stock, and to estimate dimensions for a driven-element matching system. YA offers hairpin, gamma, and T-match options. I chose the hairpin because I've had good luck replicating antennas using this match without need for providing adjustable tuning.

Construction

For my particular application, I wanted these antennas to be very light. (My chimney-mounted mast already supports two small 6-meter beams spaced 12 feet apart, and slipping a pair of 2-meter Yagis in between these would be pushing the envelope.) The lightest boom stock I could find was 1-inch thin-wall shower-curtain rod at a local hardware store. This stock crushes easily, and I recommend using heavier material if you plan to tower-mount your antennas. I made the elements using scraps of 5/16-inch diameter thin-wall left over from other projects. If you wish to substitute other stock, enter the new element diameter into YA's *taper* data-file to obtain corrected lengths.

When working with YA, it's important to remember that element-length computations assume a nonconductive boom. Any element mounted through a metallic boom must be corrected for boom diameter by a formula provided in the YA manual. Because the four parasitic elements in this antenna were mounted through a 1-inch aluminum boom, they had to be corrected—a task that required some high-school algebra, a pocket calculator, and about five minutes to execute. The driven element is mounted on an insulating center block and requires no boom correction. Final element dimensions, after factoring in all corrections and final tune-up adjustments, are provided in **Table 1**. If you follow these dimensions exactly, no additional tuning should be needed.

The driven-element center block was made from 3/16-inch Plexiglas.™ A drilling template is provided in **Figure 1**. Antenna construction details are similar to those used for my 6-meter ultra-light stack (see "A Featherweight 6-meter Beam," "Tech Notes," Summer 1995). Each parasitic element was drilled at the center and locked firmly into its mounting hole using a no. 6 sheet metal screw. The driven-element center insulator was mounted through the boom using 1-1/2-inch no. 6 machine screws. Each element half was then secured on a no. 6 stud, along with the element's hairpin match inductor. My first prototype hairpin was adjustable; but I replaced this with a fixed hairpin made from no. 8 solid aluminum wire later on, once I found the optimum length. If lightweight tubing is used for the boom, add some form of reinforcement at the mounting point to prevent the U-bolt from crushing the boom. A detailed assembly drawing for the entire antenna is provided in **Figure 2**.

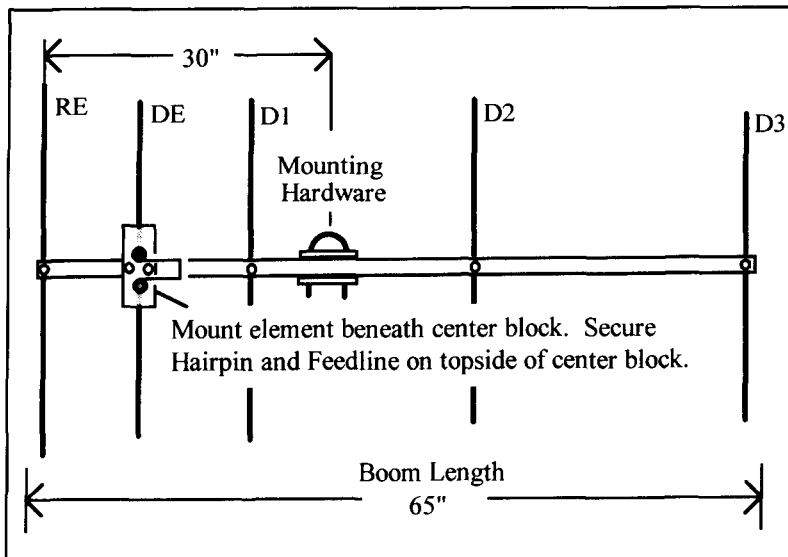


Figure 2. Assembly drawing for the SSB Shorby stacking antenna.

Be sure to use only stainless steel hardware for fasteners, and sandwich the aluminum hairpin with flat washers when mounting.

Tune up

When my first prototype antenna was assembled and ready for testing, I used one electrical wavelength of 50-ohm line to connect my MFJ-259 Analyzer to the driven element. The one-wavelength feed ensured that the VSWR and the resistance readings on the analyzer would reflect the actual conditions at the antenna terminals. I also installed two ferrite sleeves at the feedpoint to act as a choke balun (FB-43-6301 or equivalent is recommended). This step is very important—without it, the feedline will radiate, interact with the elements, and make tune up impossible.

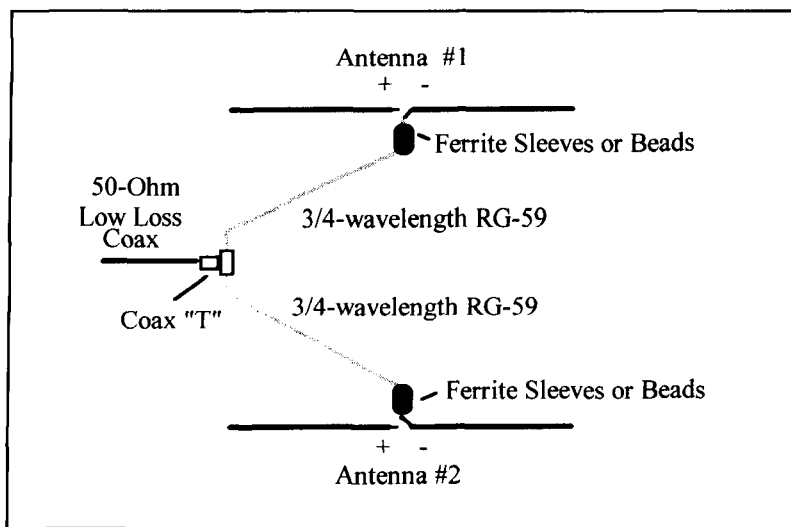


Figure 3. Phasing and matching for a stacked pair of antennas.

Despite various attempts, I've never been totally successful at modeling an accurate hairpin match at VHF using a computer. However, in fairness to the program, it is important to remember that virtually *all* antenna-matching algorithms have zones of inaccuracy where they don't predict as well. In addition, most driven-element matching systems have undefined sources of parasitic capacitance and inductance that designers fail to recognize and enter. For these reasons, the YA manual advises builders to make their prototype-antenna matching systems adjustable because additional tuning will probably be needed. These adjustments aren't difficult to make—especially if you have a VSWR analyzer or network analyzer available to help you.

Toward this end, I began my tune up by

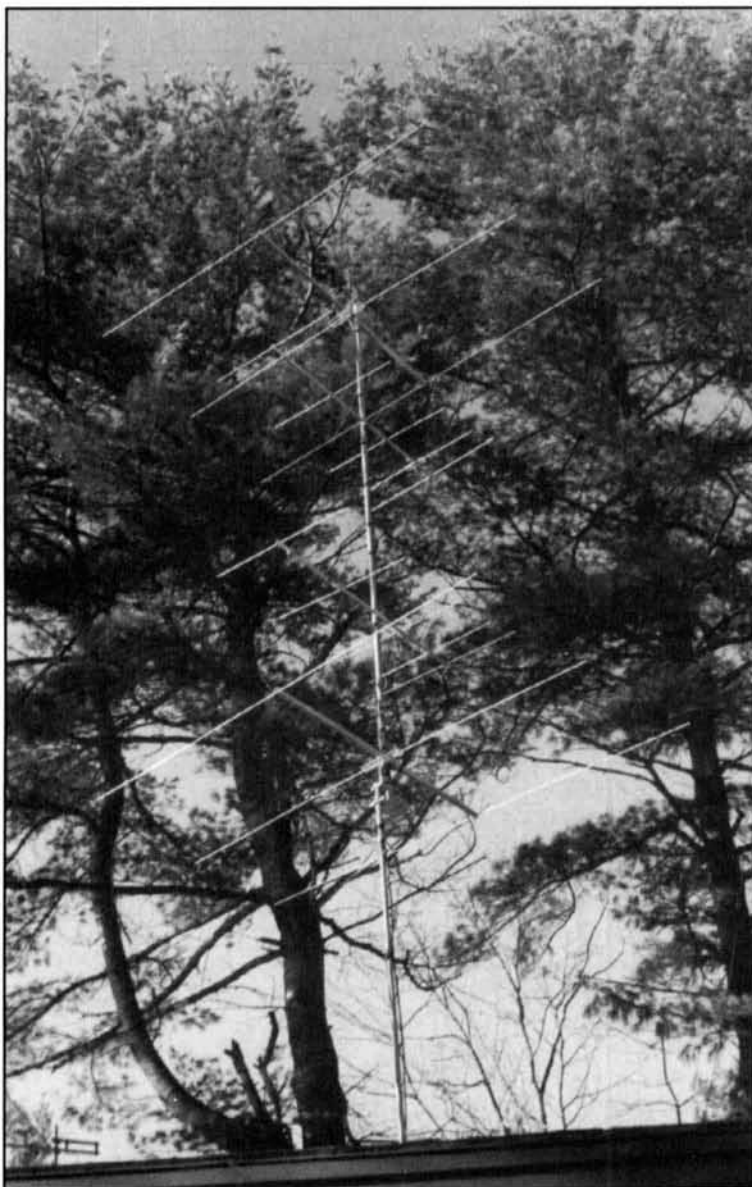


Photo A. The *SSB Shorty* stacking antenna the chimney-mounted mast.

	Position	Length
Ref	0"	41-1/4"
DE	7"	17-7/8" each (2 required)*
D1	9-1/8"	37"
D2	41-1/2"	36-1/4"
D3	64"	36-1/4"

* Flatten each DE section on one end, drill no. 6 clearance hole 3/16".

Table 1. Element position and length for the 144.5-MHz *SSB Shorty*.

manipulating the driven element length and hairpin inductance for minimum VSWR. Doing this, I obtained 1.5:1 at the design frequency. I then made very *minor* corrections to the directors and obtained a flat 1:1 match. This is where YA really delivered the goods—the program correctly predicted each parasitic element length to within 1/8 inch. My greatest sources of error were the original measurements I made when cutting the tubing!

Because the *SSB Shorty* was to be used in a stacked array, my next task was to build a carbon copy of the first antenna. This gave me an opportunity to check out the measurement and construction details I'd recorded. Happily, antenna number two worked perfectly on the first try with no tune up whatsoever.

To interconnect my stack, I installed two 3/4-electrical wavelength sections of foam RG-59 to serve as transmission-line transformers and phasing lines (Figure 3). Two ferrite sleeves were installed at each feedpoint to prevent radiation from occurring on the outside surface of the coax shield. This simple matching technique provided a dead-flat 1:1 VSWR at the feed system's 50-ohm termination point at Fr. I then mounted the stack between my pair of short-boom 6-meter beams with approximately 1/2-wavelength spacing above and below (see Photo A). This yielded slightly under 1-wavelength of space between the 2-meter beams—plenty of separation to ensure adequate gain.

Testing and On-air Performance

The free-space azimuth plot for a single *SSB Shorty* is depicted in Figure 4. To check the pattern of my array, I pointed the antenna toward a point source delivering a S9+10 dB signal to my IC-211. As I rotated the array off-axis, this signal dropped nearly into the noise off each side, then rebounded to S4 off the back. I later referenced the S9+10 and S4 readings using a HP-8640B signal generator, and found the difference to be just over 15 dB. This

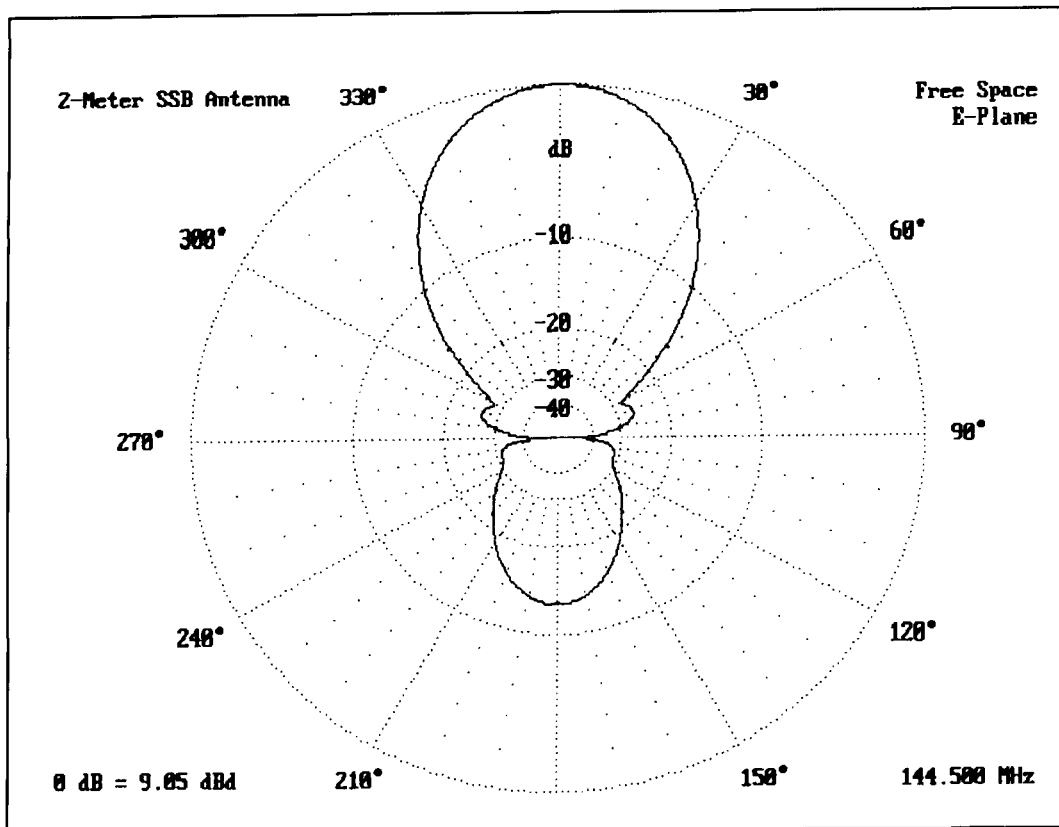


Figure 4. Free space plot in dBd for a single SSB Shorty stacking antenna.

would indicate that the “real-world” F/B performance of the array is slightly better than the 13 dB YA predicted for a single antenna in Figure 4.

As far as on-air contacts go, the antenna appears to be doing its job. The off-air signal source for my front-to-back test was generously supplied by Harv, WIHXO, who was also my first contact using the new array. Harv is located approximately 50 miles away. Given that my top antenna was only 35 feet above the ground and my output power 10 watts, our S9+ QSO was encouraging. My second contact was with veteran VHFer Ron Klimas, WZ1V, who lives well over 100 miles to the south in Bristol, Connecticut. Although both stations were well equipped, both contacts were made mid-winter on a relatively “dead” band.

Conclusion

When seeking antenna solutions, it’s always fun—and wise—to look at the alternatives. I’m certain that the short-stack approach to antenna building won’t appeal to everyone. However, it did work for me—providing excellent performance in an antenna system that’s compatible with my rooftop hardware and operating style. If you lack the space to swing a long boom or prefer a more inclusive pattern, a short stack might also work for you!

Miniaturized Antennas

Mike Traffie, N1HXA

Miniaturization has brought about many changes. Today’s high-performance, HF transceiver is smaller than the typical power meter of yesteryear. Two-meter transceivers have become HTs that fit in the palm of your hand. Are similar advancements ahead for antennas?

My search for an antenna array began with this question in mind. This sought for array should perform as well, or nearly as well, as existing designs, but would also be:

- small and light
- sturdy and durable
- simple and straightforward
- multi-bandable
- legal limit capable
- affordable

A review of existing designs revealed that, for the most part, conventional rotatable beams are based on straight dipole or loop elements spaced along a boom or support. This technique yields significant performance benefits such as power gain and directivity. At frequencies of 14 MHz and up, this provides a manageable, high-performance array. However at lower frequencies, a full-sized array becomes very impractical and expensive. Coils and other loading techniques can be used, but each intro-

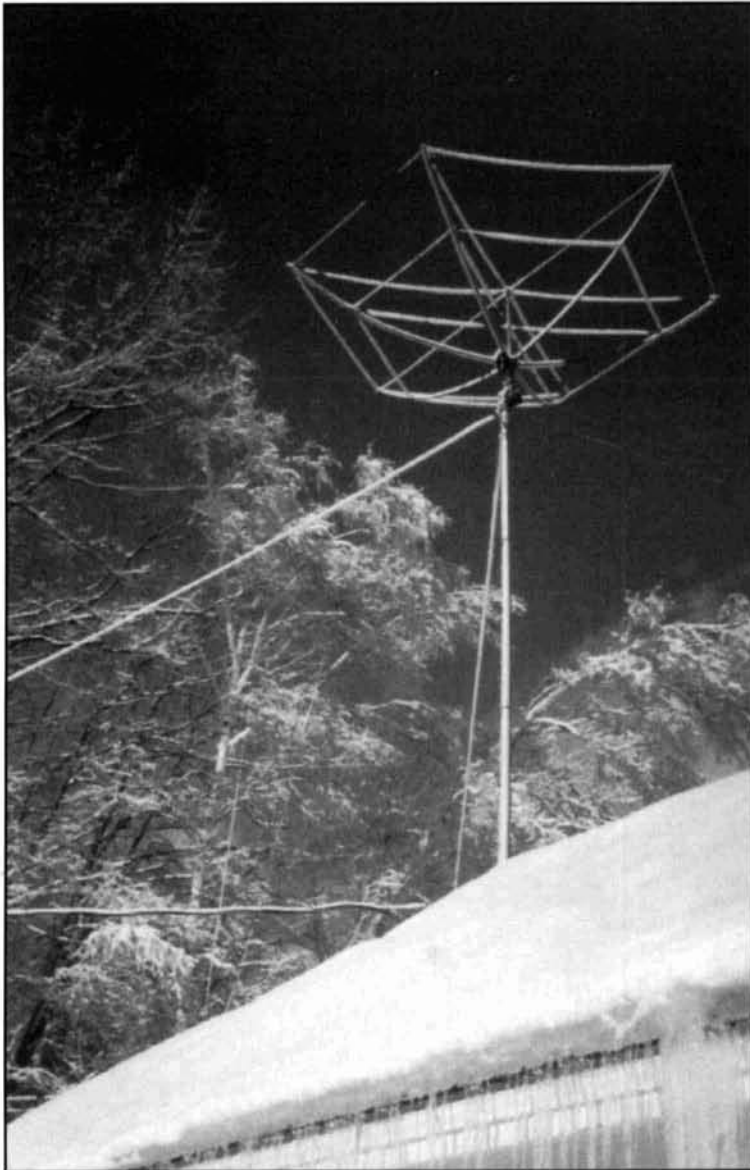


Photo A. A 17/12-meter hex array.

duces its own added cost and complexity. The result is a compromise antenna. I wondered if it was possible to construct a full-size array that didn't suffer from any of the usual penalties of size reduction.

The Snowflake

The snowflake came to mind. It is a planar crystalline structure that forms from the center outward and is shaped by intense controlled fields.^{1,2} What would happen when a dipole element is folded to the apex angle of the snowflake (60 degrees) instead of the usual 180 degrees of a straight dipole? Would this configuration work for a beam? Some colleagues and I ran a series of tests and found:

- A differently configured, concentrated field is formed in the apex of the "W"-shaped dipole element.

- A mirror image element can be tuned as a parasitic for gain and directivity, even if there's no physical boom ("spacing" comes from the antenna's shape).

- Element folding reduces the array's size and provides the necessary coupling for proper current balance in the array without any additional parts.

Quantitative tests showed that:

- Overall antenna performance improved with size reduction.

- Input impedance is in the same range as conventional designs (25+ ohms).

- VSWR bandwidth remains quite broad with this configuration.

The Hexagonal Array

The result of these experiments is the hex array (see **Photo A**). At first the hexagonal configuration seemed odd for an antenna—or at least odd for a "real" antenna. "Odd" quickly changed to "unique" when I realized this configuration yielded the sort of size reduction and performance level for which I'd been looking. When I found that additional monobanders could be added inside the existing arms, the adjectives neat, compact, and even awesome and fabulous came to mind. Admittedly, thoughts of can't be, won't work, and impossible also tempered my awe with doubts. However, the results speak for themselves.

The hex array is a half-size beam without a boom. No loading or matching devices are required. You don't need a balun to direct feed the antenna with 50-ohm coax (a slightly tipped pattern results, so a coiled choke can be used). When direct-fed with 50-ohm line as a monobander, VSWR is 1.4 to 2.0:1 over the operating bandwidth of the array (for more VSWR measurements, see **Table 1**). For closer matching, a simple series-section transformer can be constructed of 75-ohm coax. When multi-banded, the array can be fed with a single feedline. A "stacked" array of monobanders for 20-17-12 meters is about 3 feet high, weighs a little over 10 pounds, and requires a 9+ foot turning radius. These were some of the pluses; the big question remained, "how does the hex array perform?"

Performance Tests

I considered scale modeling for performance evaluation. However, this approach was set aside because of the many possibilities for error. Actually, antennas often perform much differently in the real world than they do in a controlled environment.

Numerous computer models were done. The first showed a negative gain. Another showed no F/B. Others showed some gain and

12 meters: Design f = 24.9 MHz	
Frequency	VSWR
24.7	1.7-
24.8	1.7
24.9	1.65
24.95	1.65
25.0	1.75
17 meters: Design f = 18.1 MHz	
Frequency	VSWR
17.975	2.0
18.000	1.6
18.050	1.3
18.100	1.2
18.150	1.2
18.200	1.2+
18.300	1.2
20 meters: Design F = 14.200 MHz	
Frequency	VSWR
14.150	2.0
14.175	1.9
14.200	1.7
14.250	1.6
14.300	1.6
14.350	1.6
14.400	1.7
14.450	1.9+

VSWR measured at antenna on 40-foot tower.

- Direct fed without matching network.
- Design frequencies as noted.
- Single feedline.
- Not tuned for best match with 50 ohm.

Table 1. VSWR measurements for multiband hex array for 20-17-12 meters.

mediocre F/B. Obviously, substantial discrepancies existed. Our performance question was left without a real answer.

A full-size 3-element Yagi-Uda was built on a 1/3 wavelength beam. Computer models and range tests of this antenna were in close agreement, so it was used as a reference antenna in our performance evaluation tests.

Range testing showed that the 3-element Yagi-Uda had the edge gainwise, when both were tuned for best gain. With this tuning, the hex array had a substantially better front-to-rear ratio. When both were tuned for F/R, performance differences were slight and azimuth patterns were very similar. I didn't perform range tests with a 2-element quad at this time.

"On-the-air" comparisons showed the hex array's performance was very similar to a 2-element quad or 3-element Yagi-Uda. Many

stations reported little or no detectable difference. During certain weak signal conditions, the large arrays would "hear" better and were less affected by QSB. Under other conditions (i.e., differing angles of arrival, etc.), the hex consistently performed better and was less affected by QSB than the other arrays.

The hex array is a "quiet" antenna. This may be due to the tight coupling of the high-density fields. This quietness was especially noticeable on "long-haul" QSOs to the South Pole, where the quad and hex were very close performance-wise. Both worked well at relatively low heights. Overall, these comparisons showed that each of the three antenna types has its own "personality." Each also has a distinct performance advantage at times.

The hex array is a simple design, but as yet there are no guidelines to predict dimensions for differing element types, sizes, tapers, etc. An antenna built from the basic formulas* works quite well, but the hex array's full potential is realized through fine tuning. With the right combination of element lengths and tip spacing, the array provides amazing performance for its size. The beams are made with adjustable elements so the array can be tuned for broadbandness, or optimized for a band portion, with minimal effort.

These experiments, and those of others, lead me to conclude that full-size performance really is possible in a half-size array. This antenna has met, and in some respects, exceeded my expectations. This is especially true on 40 meters, where a small 35-pound hex array makes good performance possible in my modest installation. For me, a large 200± pound array, 3-element Yagi-Uda is out of the question. This array, which now covers 40-17-12 meters, is approximately the same size and weight as my conventional trapped tribander for 20-15-10 meters. The hex array has a slightly larger turning radius, but is a little lighter.

While sturdiness and durability are prime factors in a fixed installation, weight, portability, and ease of assembly become important factors for temporary or emergency setups. I've built some "featherweight" 10-meter HEX-

$$DE \approx \frac{6160 - 6190}{f} \quad \text{and} \quad Ref \approx \frac{6262}{f}$$

$$DE_{TIPSACE} \approx \frac{102}{f} \quad \text{and} \quad Ref_{TIPSACE} \approx \frac{65}{f}$$

$$Overall_{TIPSACE} \approx \frac{145}{f}$$

*Basic formulas: These formulas are for the lower end of the desired operating bandwidth using no. 14 bare copper. As with other antennas, many factors enter in such as existing conditions, intended objective, and so on. Generally speaking, tip spacings aren't especially critical.

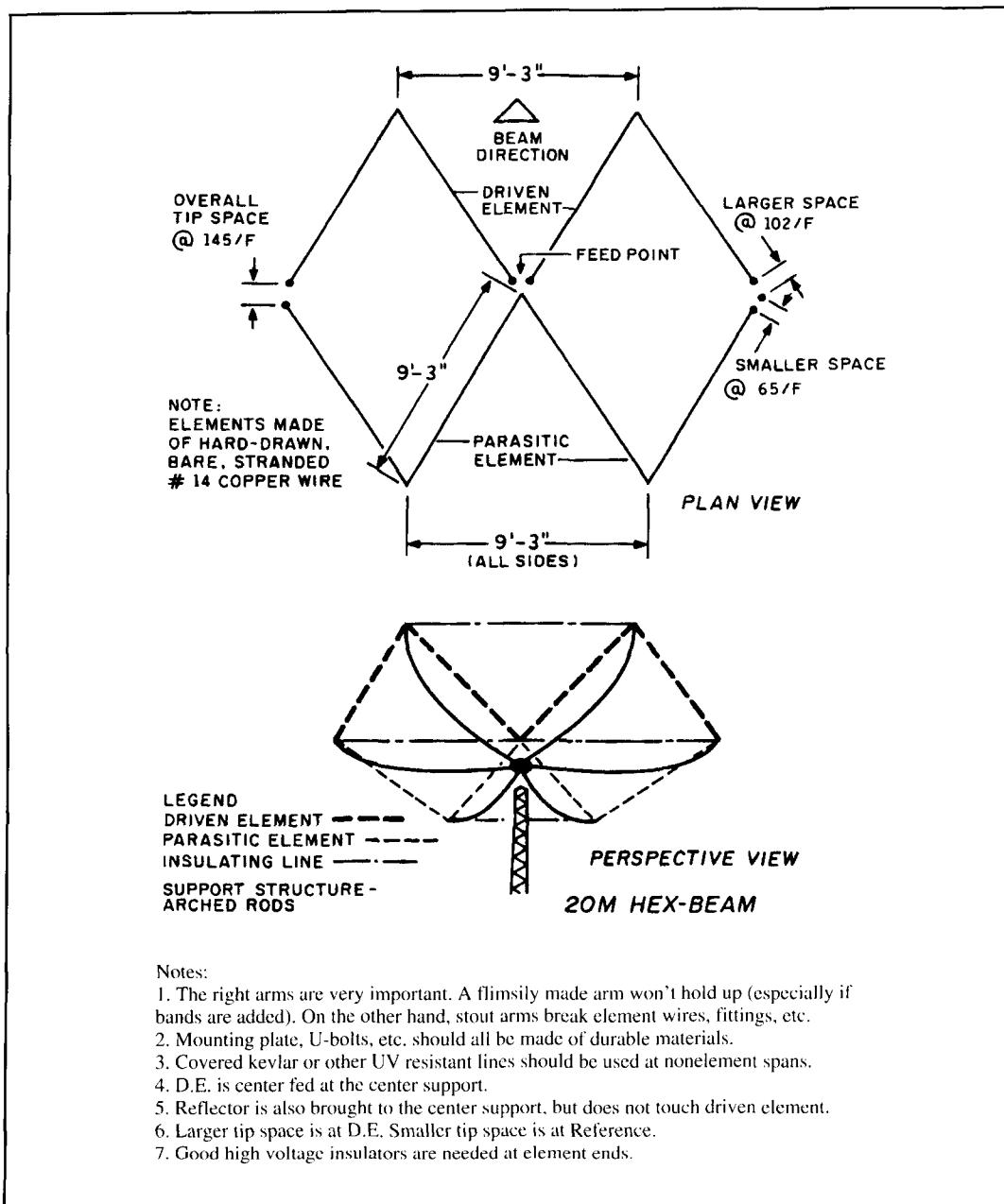


Figure 1. Guidelines for hex array experimentation.

BEAMs™ to address these needs. This 20-ounce version has worked out well when 10 meters is open. Work is now in progress on a collapsible, lightweight array for 20 meters.

Conclusion

This is a brief overview of my experiments with reduced-size antennas. As mentioned, this array's that performance actually improved with size reduction. This was especially true in the area of F/R ratio. I'm convinced that smaller, of itself, doesn't mean inferior and wonder what more can be done with small antennas.

Extensive "build-it" information is beyond the scope of this article. However, the sketch in

Figure 1 should serve as a guideline for experimentation. The interested reader is referred to a previous article written with experimenters in mind.³ Note that shorter D.E. lengths provided here give higher levels of performance.

While it's possible to build a hex array using materials on hand, proper components and techniques are more important with a wire beam than most any other type of array. Wire beams are often cobbled together, only to last less than a single season. This has given the impression that wire beams aren't practical. Many performance improvements and construction refinements have been made since the first article was written. It is my hope that this

compact design, which doesn't suffer from the asymmetric loadings of a quad, when coupled with new products and building techniques, would change that view. I'd enjoy hearing from others who try this concept.

Because many of the right parts are difficult and/or expensive to acquire (especially in small quantities), I've put together a basic raw materials kit for the 20-meter kit. This makes a sturdy array, which can be multibanded later. Completed arrays are also available.**

Acknowledgements

While writing this article, my thoughts have often turned to those who have made it possible. Thanks especially to Gary, KA1DW, Dave, G0DAB, and Roger, G4RUW, with whom the first conclusive performance tests were run.

**For more information send SASE to: Mike Traffic, 421 Jones Hill Road, Ashby, Massachusetts 01431.

Sons, Carl, N1IFU, Jon, KB1BSV, and Tim, KB1BSU, have worked shoulder-to-shoulder with me. The rest of my family and many other friends have also contributed in their own way. Hams from around the world have provided reports and suggestions. Mr. Howard Johnson is to be acknowledged for pointing out the "sparks" that led to the snowflake design—*The Holy Bible*, Job 38:22 ". . . treasures of the snow;" and W.A. Bently and W.J. Humphreys, *Snow Crystals*, Dover Publications, New York, 1962. Thanks to all. ■

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1. Conversations with Howard Johnson, inventor of the permanent magnet motor. See Howard R. Johnson, Steven P. Davis, Dr. Gerhard H. Bayer, *Discovering Magnetism*, copyright 1994, Howard R. Johnson.
2. Conversations with Albert Wuori, former Division Chief, Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.
3. M.I. Traffic, "The HEX-BEAM," *Electric Radio Magazine*, September 1994. (Back issues available for \$3.25 ppd U.S. from Barry Wiseman, Editor, P.O. Box 57, Hesperus, Colorado 81326.

PRODUCT INFORMATION

New Hewlett-Packard Benchtop Analyzers

Hewlett-Packard Company now offers 500K of acquisition memory, Ethernet LAN connectivity and software-performance analysis in a benchtop logic analyzer. The three models in the HP 1670 series offer software developers 64K of acquisition memory with an option to increase to 500K. Deep acquisition memory lets software designers see long periods of code execution.

Ethernet LAN capability eliminates the difficulty of verifying logic-analyzer data against design information. When benchtop logic analyzers are used as stand-alone instruments, they have no direct connection to the computing environment. This forces designers to lay a hardcopy printout of logic-analyzer data next to the computer screen to make side-by-side comparisons between their hardware simulations and their logic-analyzer data. The addition of Ethernet LAN capability eliminates this inefficiency and provides two additional benefits. First, it allows logic-analyzer users to consult more easily with others when troubleshooting a problem; and second, an X Window interface, lets users who have separate lab and office areas choose where they work.

The addition of a 290Mb hard-disk drive and the Ethernet LAN allows design teams to use

the HP software analyzer. They can compare a code trace from a microprocessor with the original high-level-language program, such as C++. The HP software analyzer helps designers of low-level software pinpoint bugs more quickly by using data collected in the logic analyzer to highlight lines in the source code.

The HP 1660C series for hardware designers includes a 290Mb hard-disk drive, an optional Ethernet LAN connection and support for the HP software analyzer.

Eight models, with varying channel counts to suit users' needs, offer 500 MHz timing with five modes of timing analysis and 100 MHz state analysis. The CS models are equipped with a two-channel 1-GSa/s oscilloscope.

To protect current users' investments and provide security for expanding needs, HP offers several upgrade options for its benchtop logic analyzers. With the exception of the HP 1664A, current owners of HP 1660A series logic analyzers can upgrade to the new C or CS models. The 1660C models can be upgraded to CS (integrated oscilloscope) models. Also, most models can be upgraded to a higher channel count.

For more information, contact Hewlett-Packard Company, Direct Marketing Organization, P.O. Box 58059, MS51L-SJ, Santa Clara, CA 95051-8059.

TECHNICAL CONVERSATIONS

Charles Kitchen, NITEV, received yet another letter on his article "Regenerative Receivers" (Communications Quarterly, Fall 1995).

Dear Mr. Kitchen:

I read with great interest your piece, "Regenerative Receivers: Past and Present" in the current *Communications Quarterly*. Congratulations on an excellent article! I have built a number of regenerative receivers over the years with excellent results and believe, as do you, that this technology is underrated and deserving of future development.

I'm beginning to assemble the parts in order to build the high-performance JFET shortwave receiver.

Again, I was pleased to see your article and look forward to building the receiver.

**Bob St. John, W9DWT
Williamston, Michigan**

Peter Bertini's editorial "Thank you Mr. Morgan," in our Fall 1995 issue also received more attention.

Dear Mr. Bertini:

Originally I did not see your editorial referring to Alfred Morgan, but I picked it up when I saw Alan Douglas' letter to you about Morgan's series of books ("Technical Conversations, Winter 1996). I too was a fan of his when I was younger. I should have known better, but I did not realize that he was a popular as it seems he was.

I still have my copies of *The Boys First*, *Second*, and *Third Books of Radio and Electronics*. My parents gave them to me for my tenth birthday because I was constantly taking out the library copies. I have lost, given away, and otherwise disposed of many other books, but I still keep and treasure Mr. Morgan's books. After I read your editorial, I went down to the radio room to look through them again. There they were, in between *Troubleshooting Analog Circuits* by Robert Pease, *Discrete-Time Signal Processing* by Oppenheim, and Schafer's *Physics of Semiconductor Devices*. If my parents had only known.

My parents love to tell the story of my father going to the local electronics shop to buy me one of those big 1.5 volt cells. My mother made

a big fuss saying that it was not worth it, what was a nine-year-old going to do with such a battery. Now I have my own pair of boys and although they are not as passionate about electronics as I was (and I cannot seem to get them to read Alfred Morgan) they can hold their own. Now if I could only get them hooked on ham radio.

Thanks for bringing back good memories.

**Jim Stewart, VE3SRJ
Etobicoke, Ontario**

Pete's article on surplus test equipment also brought a response.

Dear Mr. Bertini:

After reading your editorial (Winter 1996) I feel reassured to hear that there are people like me with shacks containing plenty of surplus test equipment and just a few radios. Over the past ten years or so, I have been "collecting" signal generators, 'scopes, voltmeters, and a couple of HP spectrum analyzers with various RF plug-ins, etc.

I always enjoy reading the magazine.

Jacques Audet, VE2AZX

CORRECTIONS

Missing References

In the *Winter 1996* installment of "Quarterly Devices: The MRF-255 RF Power Field-Effect Transistor and Digi-Key's Panasonic Multilayer Ceramic Chip Capacitor Kits," the references were accidentally omitted. They are printed below for your convenience.

REFERENCES

1. Rick Littlefield, K1BQT, "A Compact 75-Meter Monoband Transceiver," *Ham Radio*, November 1985, pages 13-27.
2. Norm Dye and Helge Granberg, *Radio Frequency Transistors—Principles and Practical Applications*, Butterworth-Heinemann, 1993.
3. *Digi-Key Catalog*, 701 Brooks Avenue, South, P.O. Box 677, Thief River Falls, Minnesota 56701-0677; phone 1-800-344-4539.

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SL-11A	•	•	7	11	2 ⁵ / ₈ x 7 ⁵ / ₈ x 9 ³ / ₄	12
SL-11R	•	•	7	11	2 ⁵ / ₈ x 7 x 9 ³ / ₄	12
SL-11R-MC	•	•	7	11	5 ³ / ₄ x 7 ¹ / ₄ x 9 ³ / ₄	13
SL-11R-GE	•	•	7	11	5 ³ / ₄ x 7 x 9 ³ / ₄	13
SL-11R-RA	•	•	7	11	4 ³ / ₄ x 7 x 9 ³ / ₄	13
SL-11R-EFJ	•	•	7	11	5 ¹ / ₈ x 7 ¹ / ₄ x 9 ³ / ₄	13
SL-11MG	•	•	7	11	5 ¹ / ₈ x 7 ¹ / ₈ x 9 ³ / ₄	13
SL-15R	•	•	12	15	2 ⁵ / ₈ x 7 x 9 ³ / ₄	13
SL-15R-GE	•	•	12	15	5 ¹ / ₈ x 7 ⁵ / ₈ x 9 ³ / ₄	14
SL-15R-RA	•	•	12	15	4 ³ / ₄ x 7 ¹ / ₄ x 9 ³ / ₄	14
SL-15R-EFJ	•	•	12	15	5 ¹ / ₈ x 7 ¹ / ₈ x 9 ³ / ₄	14

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RS-4L	•	3	4	3 ¹ / ₂ x 6 ¹ / ₈ x 7 ¹ / ₄	6
RS-5L	•	4	5	3 ¹ / ₂ x 6 ¹ / ₈ x 7 ¹ / ₄	7

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RM-35A	25	35	5 ¹ / ₄ x 19 x 12 ¹ / ₂	38
RM-50A	37	50	5 ¹ / ₄ x 19 x 12 ¹ / ₂	50
RM-60A	50	55	7 x 19 x 12 ¹ / ₂	60
• Separate Volt and Amp Meters				
RM-12M	9	12	5 ¹ / ₄ x 19 x 8 ¹ / ₄	16
RM-35M	25	35	5 ¹ / ₄ x 19 x 12 ¹ / ₂	38
RM-50M	37	50	5 ¹ / ₄ x 19 x 12 ¹ / ₂	50
RM-60M	50	55	7 x 19 x 12 ¹ / ₂	60

RS-A SERIES



MODEL RS-7A

MODEL	Colors		Continuous Duty [Amps]	ICS* [Amps]	Size [IN] H x W x D	Shipping Wt. [lbs]
	Gray	Black				
RS-3A	•	•	2.5	3	3 x 4 ³ / ₄ x 5 ³ / ₄	4
RS-4A	•	•	3	4	3 ³ / ₄ x 6 ¹ / ₂ x 9	5
RS-5A	•	•	4	5	3 ¹ / ₂ x 6 ¹ / ₈ x 7 ¹ / ₄	7
RS-7A	•	•	5	7	3 ³ / ₄ x 6 ¹ / ₂ x 9	9
RS-7B	•	•	5	7	4 x 7 ¹ / ₂ x 10 ³ / ₄	10
RS-10A	•	•	7.5	10	4 x 7 ¹ / ₂ x 10 ³ / ₄	11
RS-12A	•	•	9	12	4 ¹ / ₂ x 8 x 9	13
RS-12B	•	•	9	12	4 x 7 ¹ / ₂ x 10 ³ / ₄	13
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RS-35A	•	•	25	35	5 x 11 x 11	27
RS-50A	•	•	37	50	6 x 13 ³ / ₄ x 11	46
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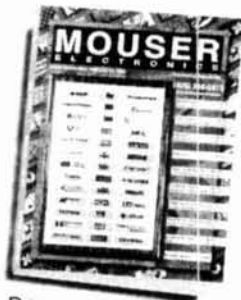
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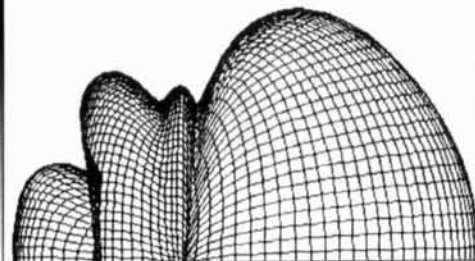
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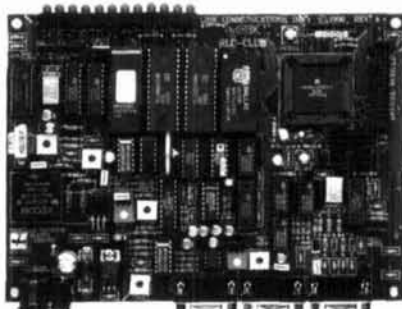
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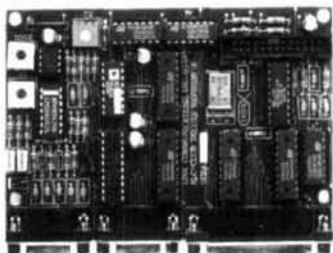
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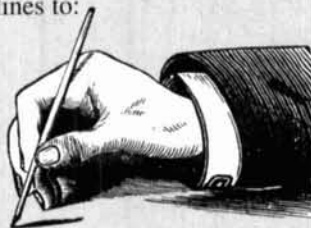
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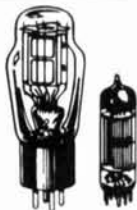
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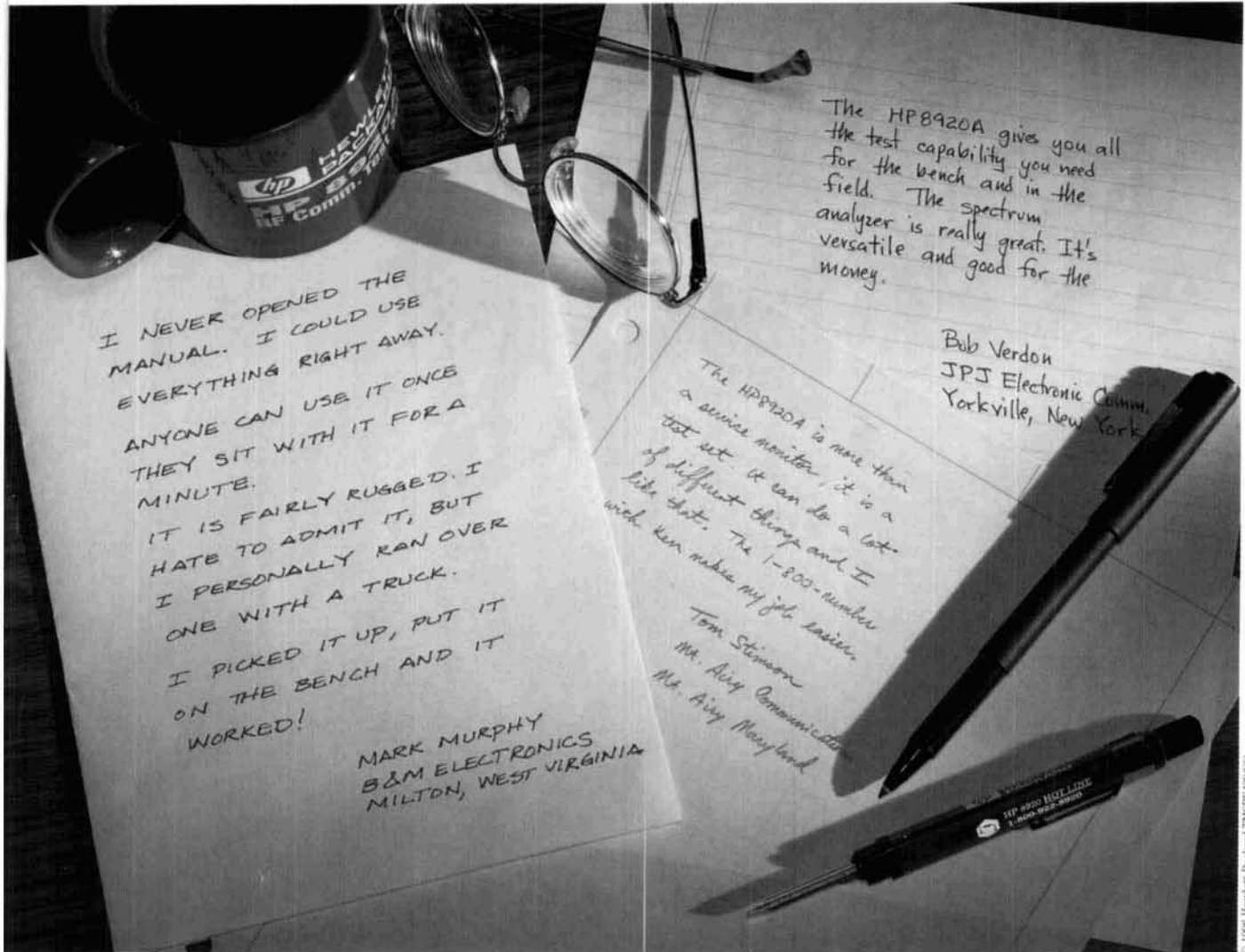
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