HF MOBILE ANTENNAS

Methods to help you improve radiation efficiency

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In these days of miniaturization, HF mobile operation is more practical than ever before. Rigs are smaller, and DC inverter power supplies are virtually nonexistent. Are popular, small, antenna resonators a good choice also, or is too much given up in this crictical area?

Background

My early days of low-band HF mobile go back to the early sixties when tube equipment was standard, and there was a mystique surrounding the hardware required to get a station to function from one's car. A typical installation consisted of an AF-67 transmitter with 6146 final, a dynamotor (motor generator) to supply 250 and 650 volts, and a converter to receive 160 meters on a standard AM radio. I noticed that mobile antennas seemed to bring out regional biases — hams running mobile in Northern Ohio favored base-loaded whips as long as possible, while those in the greater Cincinnati area worked the top band with center-loaded whips and capacitive hats.

160-meter whip antenna

Several Cincinnati hams pooled their resoures to create a community mobile of sorts; the equipment, car, and effort were supplied by K8CRJ, K8IBQ, K8RRH, and WA8ADB (now NC0B). Our antenna construction was based initially on a Master Mobile 75-meter 5-foot whip and its matching resonator, which was 6 inches long and 1-3/4 inches in diameter. We discarded this no. 18 wire coil and modified its phenolic insulator to hold a 5-inch diameter plastic tube wound with 100+ feet of no. 16 close-spaced wire to resonate on 160. We added a 6-inch diameter capacitive hat that let us make minor adjustments to the antenna system's resonant frequency. The frequency wasn't easily changed once we had tuned it by removing turns from the coil. No one knew how efficient the antenna actually was, but it performed satisfactorily with daytime groundwave ranges of 50 to 75 miles to a base station.

For the next 20 years, my homemade mobile antennas evolved around variations of this same design. Discussion of HF mobile operation in *The ARRL Antenna Handbook* referred to maintaining the Q of the coil high, so I eventually abandoned the close-wound coil on a solid form. Even though the effect of plastic tubing on Q wasn't known, it was obvious that weather degraded coil operation severely. If the antenna coil got a little wet, the AF67 pi network started tuning backwards. The rig wouldn't load at all in a real downpour. If today's broadband fixed-tuned PAs had existed then, the transmitter would have barely functioned given the slightest bit of inclement weather.

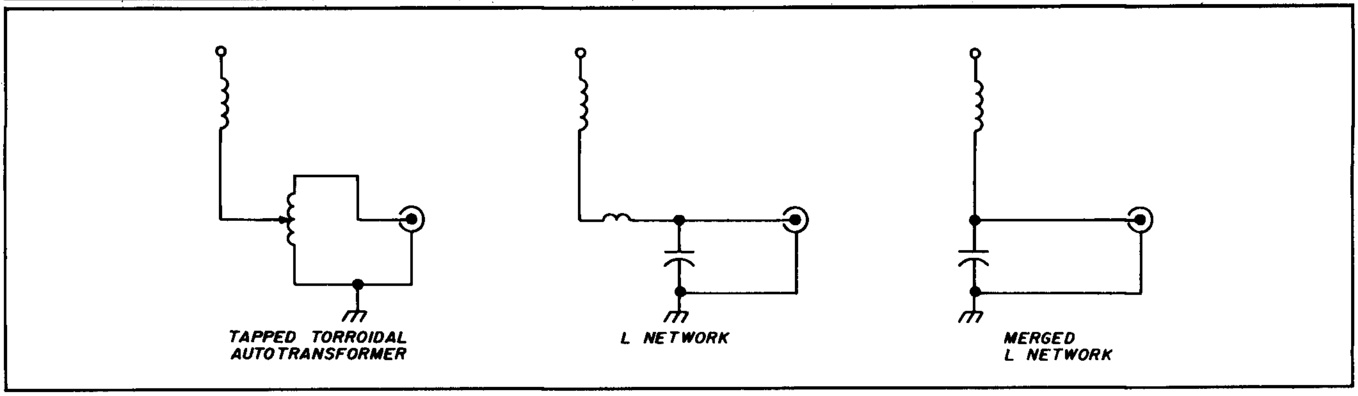
40-meter system

The original Master Mobile insulator was long enough to support half of a B&W 3033 10-inch coil made from six turns per inch of no. 12 wire. Because it was of ribbed construction rather than solid form design, this coil exhibited much less wind resistance than previous units. With a 3 to 6-foot base section and a 5-foot whip, the system resonated without additional top loading on 40 meters. It seemed desirable, however, to continue to use a capacitive hat, since what was advantageous on 160 would be an asset on 40 meters, too. Because my tendency was to assume that bigger was better, I built hats from 12 to 24 inches in diameter. The latter seemed to be the practical limit, especially since the consensus was that a hat should be kept out of the coil field, and that meant mounting it up the whip as much as 2 feet above the coil.

A side benefit of the open-air coil was a virtual lack of environmental effects. Rain didn't detune the coil, and it took a blinding snowstorm to pack it to the point where it wouldn't load.

A 5-foot whip let 5 inches of B&W coil resonate easily on 40 meters, even without a capacitive hat. This meant that I could make two resonators from one coil stock. Since resonance of a short, loaded antenna isn't a 50-ohm impedance, I chose an L network to provide a 50-ohm match. The added coil was simply an extra turn or two in the resonator, with an appropriate capacitor on the high impedance side of the network (across the coax feedpoint). That value was typically 470 pF on 7.2 MHz, 1200 pF on 3.8 MHz, and 2400 pF on 1.8 MHz, depending somewhat on the base

FIGURE 1



Matching options.

section length and mounting position (see **Figure 1**).

From a mechanical standpoint, this enhanced antenna with its large center loading coil and capacitive hat 2 feet up the whip put quite a physical stress on the bumper or deck mount, so I used a nylon guy line to keep things stable. However, I didn't use springs at the base because they allowed too much lateral sway.

Onward and upward

Once I had a well-developed 40-meter system using 5 inches of coil, I decided it was time to improve my design for 75 and 160 meters. Because 3-inch diameter no. 12 wire coils worked so well on 40, I chose 10 inches for 75 meters. Because it takes four times the inductance to tune a given whip when the frequency is halved, I knew that 10 inches of coil would require a longer whip or top loading. A 2-foot capacitive hat let me tune the antenna with less than 75 μH, even on the low end of the CW band at 3500 kHz. As with the 40-meter resonator, moisture had very little effect on the operation of the coil with six turns per inch spacing.

In 1984, world class mobile DXer KD0U asked if I would make him reproducible 40 and 75-meter resonators. He had 87 countries confirmed and was trying for mobile DXCC. His antenna had to be able to handle a solid-state Metron linear, which produced 600 watts output. Once the project was under way, we were asked by the Dayton Hamvention™ Antenna Forum to present quantitative data on our findings on the 40-meter version in 1985, and the 75 and 160-meter designs in 1986.

Although subjective evaluations of these antenna systems had been acceptable for over 20 years, we needed hard data to truly evaluate what progress had been made toward the goal of transmitting the strongest possible signal on low-band HF mobile.

Comparative and absolute measurements

There are two basic ways to measure antenna performance, comparative and absolute. On 7 MHz, the only method available was the comparative one; I didn't have access to a field-strength meter that would tune that high in frequency. Seventy-five meters was a different case because I could use a broadcast station's field-strength meter to measure absolute signal intensity.

We performed initial 7-MHz measurements in Denver at a large city park with room to make comparisons, using two mobile systems. One mobile was the transmit reference. The other, parked half a mile away, was the receive site. The reference system was a commercial 40-meter antenna with a bumper-mounted 5-foot base section. We tuned it to 7.2 MHz carefully, using a Bird wattmeter. Once it was adjusted for best possible match, we set the forward minus reflected power to 50 watts. We put a resonant antenna on the receiving end tuned for a perfect match at 7.2 MHz. We then inserted a laboratory-grade step attenuator into the receive coax line. Next, we set the received reference carrier from the commercial antenna for exactly S9, substituted a second commercial antenna for the first, and reset the receive S-meter to S9. Surprisingly, there was a difference of only 1/2 dB in favor of the second commercial antenna.

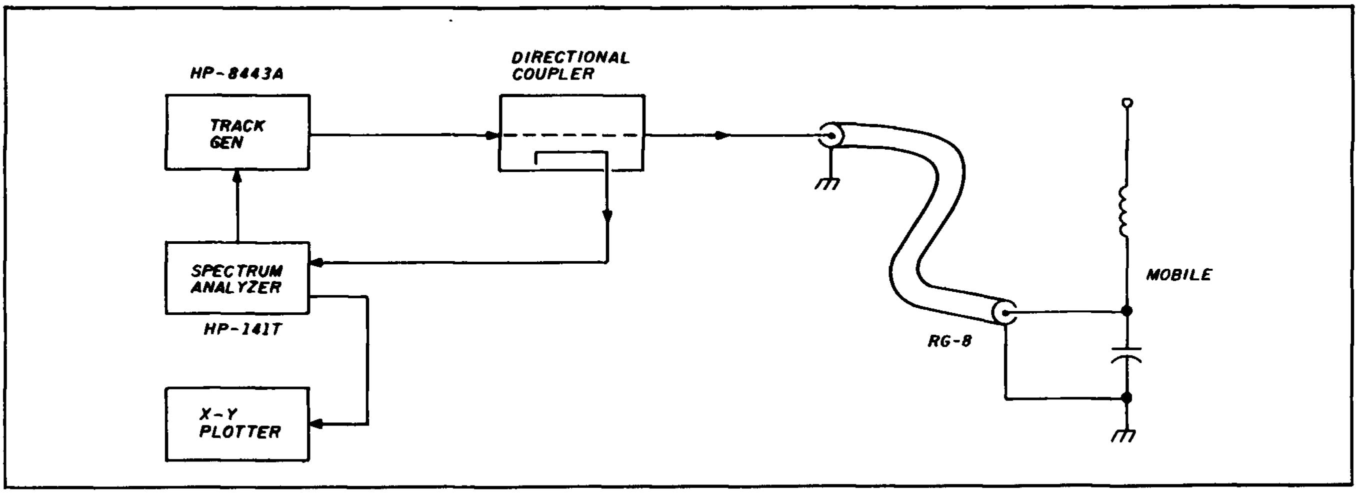
We continued by mounting a homemade antenna (now called the SE-40) in place of the commercial reference, and tuning it to 7.2 MHz. We measured its radiated signal both with and without a 24-inch capacitive hat. Without the hat, the signal registered 5 dB greater than the reference. With the capacitive hat attached and coil requirements reduced by about 40 percent, the signal was 6 dB stronger than the reference. With this much more signal radiated, it wasn't surprising that its coil ran very cool — barely above ambient. We also noted that a 40-percent reduction in coil size (and therefore coil loss) increased the signal only an additional 1 dB.

This implies that ground losses were now predominant in limiting radiation efficiency. We also found that the usable bandwidth of the antenna system with the hat was significantly greater than without; we investigated this later at the lab.

Tests on 3.8 MHz

We moved our testing to 3.8 MHz, again setting up a commercial antenna to radiate a signal with 50 watts of power. We adjusted the received carrier to S9 and recorded the attenuator setting. Then we removed the commercial antenna and substituted a homebrew antenna (SE-75) with 10 inches of open-air coil, a 5-foot whip, and 2-foot diameter capacitive hat mounted 2 feet above the coil. Its measured signal was 4 dB above reference. In this case the hat was necessary to resonate a 5-foot whip with the inductance available. To resonate without a hat required an 8-foot whip,

FIGURE 2



Instrumentation for measuring antenna bandwidth.

which measured 5 dB above reference, but was an impractical mechanical choice. As before, the B&W coil ran near ambient, while the commercial antenna got quite hot after a couple minutes of 50-watt carrier.

We made all tests using the same base section, appropriate coil, and accompanying whip. Additional measurements were later made with K7AYC and N0EYK to determine the effect of increasing base section length. Though it may not be completely obvious, you can change the length below the coil of the center-loaded antenna without changing its resonant frequency significantly. Feed impedance changes somewhat, necessitating a modest change in the shunt capacitor for a 1:1 match, but the length below the coil is rather removed from resonance effects. This is because the reactance of a short whip is very high, and the large inductance needed to cancel this reactance predominates.

We assembled a test setup identical to that used earlier, and repeated our measurements. We varied base section length in increments of 16 inches with both the commercial antenna and open-air coil SE-40 and SE-75. All antennas showed the same 1-dB improvement in radiated signal with a 16-inch increase in base length. Compare this to switching from a 5-foot whip and hat to an 8-foot whip to pick up 1 dB, and it becomes obvious where to add additional length. It was only practical to go to a second 16-inch extension; the system became unwieldy beyond that and would be practical only in a fixed mobile/portable environment. One thing became obvious: a 7-1/2 foot base section, 18-inch 75-meter coil/insulator assembly, and 5-foot whip with 24-inch capacitive hat looks impressive going down the highway! While I've never mobiled using more than a 6-foot base section and the aforementioned antenna assembly, a typical comment at gas stations is: "What you got there, satellite TV?"

Swept VSWR measurements

The next series of measurements we made on our antennas was swept VSWR. Because we're in the filter business, a tracking generator/spectrum analyzer is usual laboratory equipment. By adding a Mini Circuits directional coupler and a length of RG-8, we could run a cable to a parked mobile (see **Figure 2**) and take large amounts of data on antenna bandwidth quickly. We plotted the output with an XY recorder for analysis.

FIGURE 3

RETURN LOSS	VSWR
0dB	∞
6dB	3:1
10dB	1.9:1
14dB	1.5:1
20dB	1.2:1
26dB	1.1:1
32dB	1.05:1
40dB	1.02:1

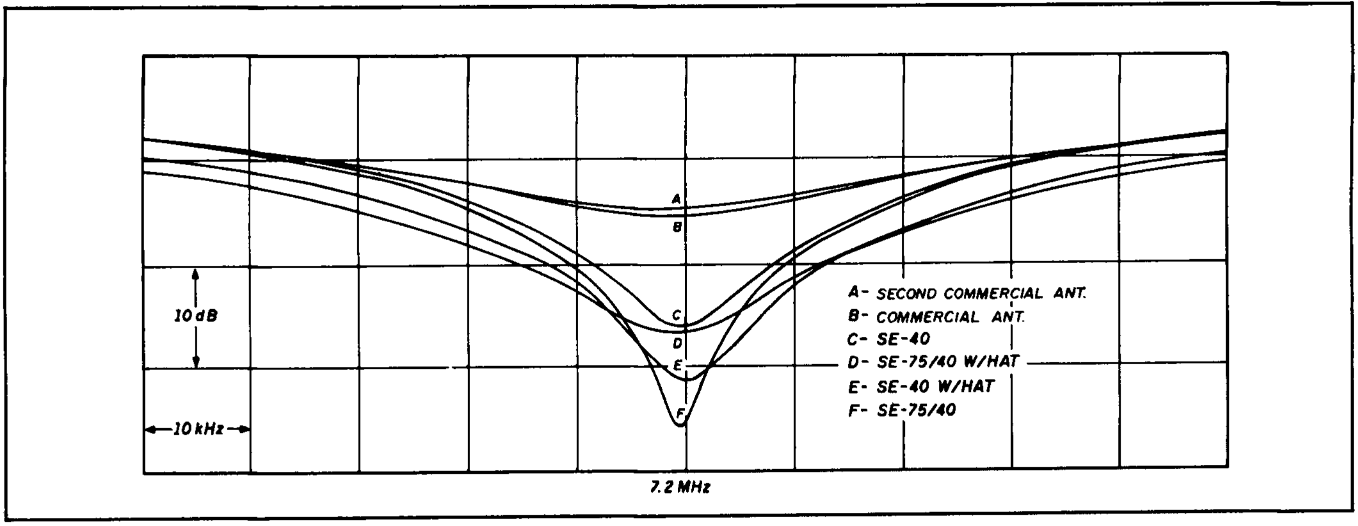
Return loss as a function of VSWR.

With the test equipment set up to measure return loss, we attached a precision 50-ohm termination to the bridge output port, and measured a return loss of over 40 dB. An open circuit set the infinite VSWR reference line, and 25, 75, and 100-ohm terminations were attached to verify operation. All functioned as expected, so we connected the coax from the mobile. We also attached a 50-ohm termination on the car end, and measured over 35-dB return loss. We then attached the antennas, tuned them, and swept them for return loss.

Since the homemade antenna could be adjusted to nearly 1:1 by selecting the base shunt capacitor, it could always be adjusted for 25 to 30-dB return loss. We set the commercial antenna for the best match using its whip length tuning. On 40 meters it could be reduced to just a 15-dB return loss, or 1.4:1 VSWR. The 75-meter match was similar; it reached 14-dB return loss, or 1.5:1 VSWR. Of course you could add a capacitor across the coax with the commercial system, too. When we did this, the best match could be brought down to a 25-dB return loss and a VSWR better than 1.2:1, as shown in **Figure 3**.

After observing bandwidth plots, we noted that the best match at one particular frequency didn't necessarily give the widest bandwidth at a specified VSWR limit of, say, 1.7:1. If you do a lot of frequency changing, you might want to

FIGURE 4



Bandwidth measurements for six antenna configurations.

tune an antenna for the most power output over a measured bandwidth.

When tuned for lowest spot frequency VSWR, an SE-75 system showed a bandwidth of 10 kHz with a 1.7:1 VSWR limit. Retuning for a better average match increased this 1.7:1 bandwidth to 15 kHz, though the match at resonance was worse. The commercial antenna's 1.7:1 bandwidth (without added capacitor) was 7 kHz.

Adding a capacitive hat on an SE-40 also improved the usable bandwidth. There was a typical increase on 40 meters from 50 kHz to 75 kHz at 1.7:1. By comparison, the commercial unit showed about 35-kHz bandwidth. (See **Figure 4**.)

In 1985, a ham at the Dayton Hamvention™ bought one of these 40-meter antennas, and he and his friend rushed out to the parking lot to compare signals — one with a SE-40 and the other a commercial unit. They happened to have identical rigs, parked about 100 feet apart. About an hour later the gentleman returned to inform me that he and his friend had been on the air getting comparative reports, and the new antenna definitely was running about an S unit stronger.

Additional measurements

We took the next step in the measurement process in 1986 with a field-strength meter. K7AYC and I made measurements in a remote area of Arapahoe County near Denver using increments of 1/4 to 1 mile. With 100 watts of power as reference, we calibrated the field-strength meter and adjusted it for maximum readings at 1/4-mile points. We recorded test data on both 75 and 160 meters because this instrument tuned from 500 kHz to 5 MHz.

We used ground conductivity charts in the *ITT Reference Data for Radio Engineers* to calculate the theoretical groundwave signal for a 1000-watt broadcast station with a quarter-wave antenna and 120 quarter-wave radials. Then we compared this data with actual measurements made on 1600 kHz from a local broadcast station's construction permit proof of performance. Its measured signal strength in mV/meter at 1 mile correlated well with theoretical calculations for average terrain in Colorado. However, unlike the measurements of power and antenna current that a broadcast station makes, field-strength readings are much more variable and inaccurate. We weren't looking for 2-percent accuracy in field-strength values, but a general idea of what level of efficiency was obtainable with an optimized mobile antenna. Field-strength measurements vary with the weather, the season, and the water table. One local station had such difficulty maintaining its pattern that it was forced to move its antenna towers farther away from a grove of cottonwood trees that ran along a creek. The trees' sap content would change periodically and distort the licensed pattern out of FCC specifications. So much for antenna operation being an exactly predictable science!

TABLE 1

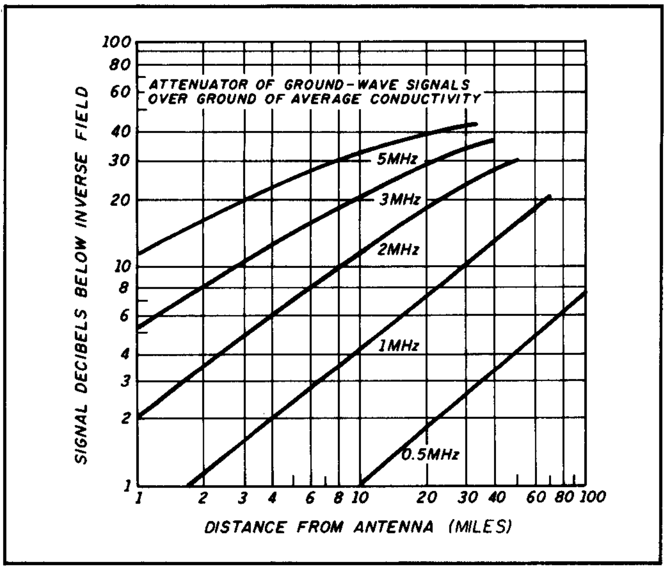
Signal strength as a function of frequency.

Frequency (kHz)	**Signal strength (mV/M)**
Theoretical	186, 1 mile, 1 kW
Typical reference—1600	165, good soil
KRXY—1600	160
N0SL—1800	110
160 mobile—1841	31
Typical reference 3800	112, good soil
75 mobile—3868	66

The ITT book also gives data on groundwave field strengths for different vertical antennas. A quarter wave should give an E-field strength of 186 mV/M over perfectly conducting ground for 1 kW of RF. The correction factor for power is proportional to the square root of power in kW times the 186 mV/M figure. For our 100-watt test level, the correction factor is 3.16 times the measured values.

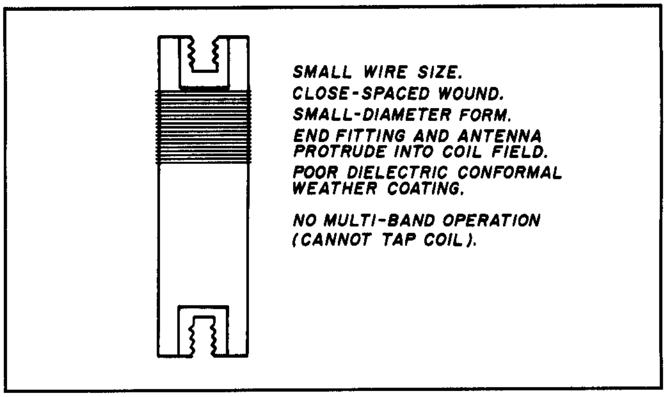
In the real world, with good soil, a value of 165 mV/M is reasonable on the high end of the broadcast band. We also obtained test data from the chief engineer of KRXY, which is licensed on 1600 kHz in Denver, as well as field-strength measurements made by N0SL on a top-loaded 50-foot vertical on 1.8 MHz. Measurements are summarized in **Table 1**.

FIGURE 5



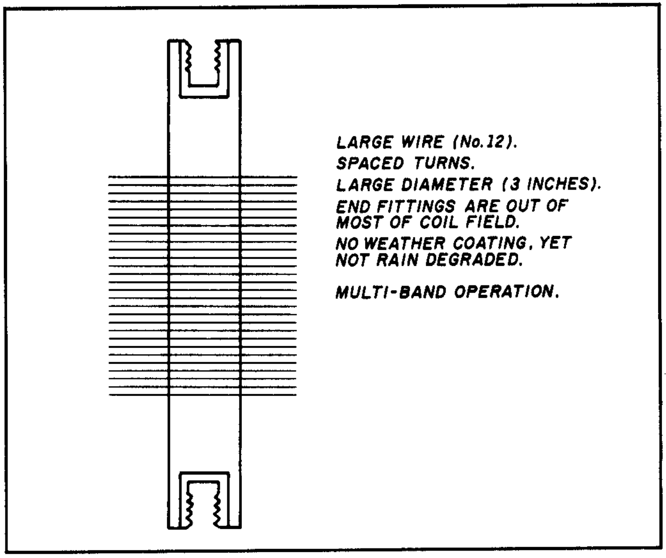
Distance from antenna (meters). (Taken from *Radio Electronic Transmission Fundamentals*, B. Whitefield Griffith, McGraw Hill.)

FIGURE 6



Characteristics of low-Q resonator.

FIGURE 7



Antenna High = Q SE-40/SE75 antennas.

When you compare E-field values of mobile antennas with reference values obtainable over good soil and a full quarter wave with 120 radials, the figures don't look too bad. Referenced to an antenna over a theoretically perfect conductor, groundwave losses at 2 MHz over good soil are about 2 dB, and approximately 8 dB on 4 MHz due to dielectric losses in the soil. When you compare the mobile signal levels to a fixed antenna over real ground, the 160-meter level is 15 dB down from a full-sized system and the 75-meter level is only 5 dB down (see **Figure 5**).

This means that groundwave range to a good base station is 100 to 125 miles for the prototype 160-meter coil used for these tests, and 200 watts of SSB. Compared with the 50 to 75-mile range of the 50-watt AM mobile mentioned earlier, this is a reasonable range increase. It may be interesting to note that it takes a rather elaborate 2-meter operation to better those ranges — unless your repeater is on a mountaintop.

Hardware hints

Here are a few reasons why these lower loss mobile antennas perform better than their smaller counterparts. Coils need to be air wound with only polystyrene ribs for support. Spacing of less than six turns per inch makes the coil susceptible to detuning and degradation from moisture (see **Figures 6** and **7**). Also, when we tried tighter spacing coils on 75 meters to allow a larger inductance and the option of no capacity hat, we noted spurious resonances that fell in the Amateur bands when the coil was tapped down for higher frequencies. While our initial coil support insulators were made from linen phenolic, its high cost and difficult machining problems necessitated a change to Lexan™.

This polycarbonate plastic is stronger, cheaper, and easier to machine. I think it looks better, too. The insulator should be considerably longer than the coil itself to keep the threaded brass inserts out of the coil's immediate field. This will also keep stainless steel antenna parts out of the field. Making frequency adjustment and band changes by shorting out turns with a clip lead may appear to be poor engineering, but so far any attempts at having multiple taps go to a switch have seriously detuned the coil.

You could argue that 6 dB isn't too much to give up to get the advantage of a small and aesthetically pleasing mobile antenna. Most will find that a signal that's an S-unit stronger often makes the difference between enjoyable mobiling and spending most of the time trying to find someone who can hear you. Add a good RF speech processor and a crisp microphone to this, and the difference is startling. Stations will start calling you! After you've done everything else, couple in a mobile kilowatt linear, and imagine that you're sitting in the passenger seat watching KD0U attack a pileup and come out with a contact and a new country against base station signals. The challenge is there waiting for you. hr