Build Your Own *Lowfer* Transceiver

Explore the 1750-meter band with this high-performance CW transceiver.

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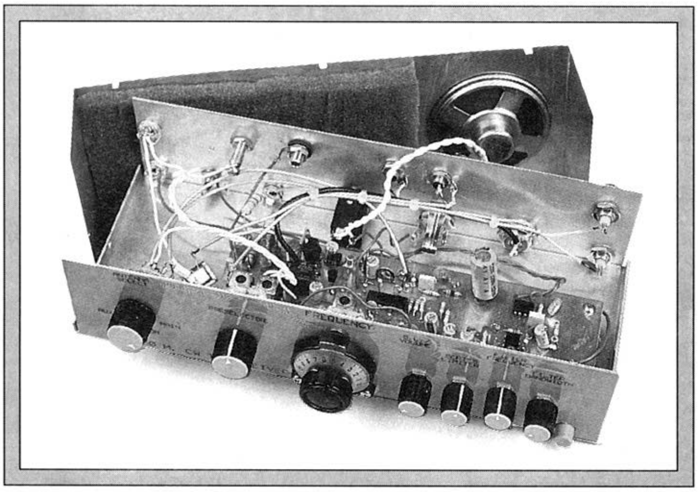


Black crinkle finish, 82 pounds, 1944. What do these words have in common? Why the *RBL* low-frequency receiver, of course! And what makes the RBL LF/VLF receiver so special? The RBL symbolizes the Low Frequency/Very Low Frequency experience for the people who explore the depths of the 1750-meter band (160 to 190 kHz). They're the *Lowfers*, radio experimenters—many of them hams—who enjoy this band and manage to carry on useful communications despite low-power restrictions and high noise levels. *No license is required to operate on 1750 meters*. Anyone can use the band. All you need is the proper equipment.

Which brings us back to the RBL...

My first encounter with an RBL was at Fred Wilson's electronic shop in 1971. He had one sitting on a shelf, next to an old Tektronix 'scope. You could feel the warmth of the tubes and smell the capacitors when you opened the door to his shop. There was something alluring about his RBL receiver. Even the dials were impressive, especially when you turned the big frequency vernier.

One day we connected a wire antenna and heard...noise! Lots of noise. Fred sold it to me later for $40 and I used a garbage cart to take it around the block to my house. Sometime later Ken Cornell, W2IMB, gave me some details on how to make a simple loop antenna that worked very well with the RBL. Sure enough, I received dozens of distant aero/marine beacons late at night in the bedroom closet, lit only by the yellow lights of the RBL.

In due time I became a Lowfer after building my first 1750-meter station and working Todd Robert's "ABC" in January 1974. The "feel" of 1750 meters is in harmony with the RBL. The Lowfer band is filled with mystery, challenge, antiquity, and much history. These low frequencies are where radio communication began. During WW II the RBL was a symbol of the state of the art. Many of these receivers served our nation's interests, and remain to this day in sunken hulks at Pearl Harbor, and in ill-fated submarines.

The RBL design was the inspiration for this simple Lowfer CW transceiver—the *CW-893*. You can build it in a couple of evenings and you'll soon be on the air on 1750 meters!

Description

The receive portion of the CW-893 is a virtual duplicate of the RBL, but in modern form! The RBL had unbeatable stability and sensitivity with its regenerative detector. The transceiver described here does not use a regenerative detector, but a *direct conversion* approach instead. The front end preselector uses a tunable two-pole Chebychev bandpass filter to remove unwanted signals. Noise is always a problem at these frequencies, so two noise limiters are included that provide very effective limiting of man-made and natural noise.

Audio filtering is included, with variable frequency and bandwidth controls for precise filtering of the desired signal. Ample audio output drives headphones and most speakers. The CW-893 is capable of providing over 100 dB of receive gain with virtually no power supply hum.

The transceiver generates 1 W of input power with its Class-E MOSFET amplifier. FCC Rules limit Lowfer power to 1 W, which is why CW is the mode of choice for this radio. Semi-break-in operation is provided with an adjustable time delay. The frequency is VFO controlled.

Although this transceiver is basic in concept, it incorporates all the required features for successful two-way operation on 1750 meters. Your range will extend from about a mile to 200+ miles, depending on band conditions and the quality of your antenna.

As you probably know, purchasing components these days can be expensive, which was a major concern when I designed the CW-893. All parts are off the shelf, with part numbers provided.

Construction Notes

Several parts are soldered directly to the component side of the circuit board. This provides the ground connection for many components. Be sure to solder these leads to *both sides* of the PC board. All parts are easy to identify. The capacitors are disc or round shaped, while electrolytics are round with the polarity marked. Transistors are designated by the half moon shape, or round with a key. ICs are rectangular with notches at the ends.

I recommend soldering the ICs first. Notice that some pins must be soldered on the component side. The next step should be soldering L1, L2 and T1. Switch S1 should be installed after you mount the potentiometer. The switch is mounted on the solder side of the circuit board.

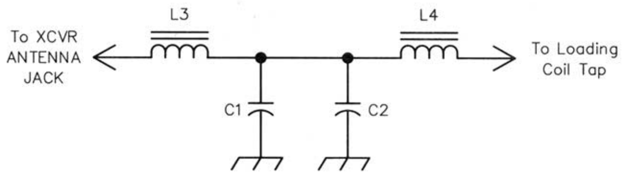


Figure 1—An auxiliary low-pass filter for the CW-893 transceiver. Installation is optional. L3 and L4 are made from 43 turns of #20 wire wound on an Amidon T-94-3 core. C1 and C2 are 0.01 µF polystyrene capacitors (Mouser 23PS310)

The auxiliary low-pass filter described in Figure 1 is not strictly necessary. It does offer a substantial reduction in harmonic output, however. To make absolutely certain that your transceiver conforms to FCC Part 15 Rules, I recommend that you build and install the filter in the enclosure.

Transformer T2 must be wound by hand on a T-68-3 toroid core available from Amidon Associates and other sources. The kit manual provides detailed instructions. In addition, see the *ARRL Handbook* for more information on winding toroid transformers. The T2 primary consists of 93 turns of #30 enamel-insulated wire. The secondary is made of 49 turns of #25 enamel-insulated wire. Wind the turns evenly and firmly. After you've finished, cut the wires so that about one inch remains from the toroid to the end of each wire. Remove the enamel insulation from the ends with sandpaper.

The CW-893 is available as a kit complete with a circuit board, parts and instructions. All you have to supply is a suitable enclosure and various knobs. You can purchase the kit directly from me for $94, shipping included (California residents please add sales tax). If you want to shop for your own components, you can buy only the circuit board at a cost of $22. I can provide information sheets on the CW-893 in return for a self addressed, stamped envelope and three units of First-Class postage.

Checkout and Alignment

Refer to Figure 2 and locate the following points:

A:	50-Ω transmit/receive antenna jack.
B:	CW key jack.
C:	Speaker/headphone output.
COMM:	Common terminal for auxiliary relay.
D:	Frequency monitor port.
E:	Audio output for external amplifier, or AB1 deluxe audio board (available as a kit from the author).
GND:	Ground.
JP1:	Receive input select. Short JP1A and JP1B to use an antenna at port A for receive. (Receive-only antennas connect to JP1B.)
N/C:	Normally closed terminal for auxiliary relay control.
N/O:	Normally open terminal for auxiliary relay control.
VCC:	12 to 18 V dc.

Connect a 12-V power source to the V_{CC} points and ground. A frequency counter or receiver covering 150 to 250 kHz will be required for the following steps.

Connect a frequency counter to point **D**. Switch the transceiver on. Adjust tuning capacitor C10 to its maximum clockwise position. Turn the slug in T1 until the frequency reads 189 kHz on the counter.

If you don't have a frequency counter, don't worry. You can also use a long-wave receiver, general coverage receiver, or ham transceiver that can accurately tune to 189 kHz. Attach a small piece of wire to the antenna jack. Tune your monitor receiver to 189 kHz. Listen for a tone while turning the slug of T1. Keep turning the slug until a zero beat is heard.

Next, align the preselector. Inductors L1 and L2 must be tuned to the same frequency. If you have a signal generator, adjust it for a low level (approximately 100 μV) at the antenna jack. Turn the **Preselector** and the **Filter Frequency** controls to their 12 o'clock positions. Rotate the **Series Limiter** and **Filter Bandwidth** controls fully counter-clockwise. Tune the **Frequency** control until you can hear the generator's signal. Adjust the slugs on L1 and L2 for maximum volume in your speaker or headphones, decreasing signal generator output as the generator tone becomes louder.

If you don't have access to a signal generator, connect a long piece of wire to the antenna jack and listen for any signals you can find (even an interference signal will do!). Once you find a usable signal, turn the **Preselector** capacitor to the same general setting as the **Frequency** capacitor. Now adjust the slugs in L1 and L2 for maximum signal strength.

Operating Tips

The audio gain stage (adjusted through the use of the **Volume** control) has a built-in limiting function. This can be used to increase the gain of a signal that's buried in man-made noise, effectively cutting off the peaks of the noise while leaving the signal unaffected. The **Series Limiter** clips any remaining distortion from the shunt limiter and lowers the volume to a comfortable level. The audio **Filter Frequency** and **Bandwidth** controls are adjusted for the amount of filtering desired.

While there is plenty of audio power available to drive a speaker, I recommend that you use headphones whenever possible. Direct-conversion receivers derive much of their gain in the audio amplifier stages. As a result, a high-gain audio amplifier—such as the one used here—may begin to oscillate if you turn it up too high. (You'll know this is happening if you hear a howling sound!) By using headphones, you'll hear the weak signals much better and you won't need nearly as much audio power.

Direct-conversion receivers are also prone to *microphonics*—amplification of mechanical vibrations. Care should be used if you install a speaker near the chassis or circuit board to avoid any audio feedback.

An important feature of the CW-893 receiver section is the input **Preselector** control. The preselector filter is very sharp, allowing only a small slice of the band to be received. If, for example, the signal you want to hear is on 180 kHz, tune the **Frequency** control to either 179 or 181 kHz. The signal will be heard as a 1-kHz tone (180 kHz – 179 kHz = 1 kHz, or 181 kHz – 180 kHz = 1 kHz). Choosing whether the upper or lower frequency is best depends on which provides the clearest reception. During two-way operation, for example, you might be transmitting at 182 kHz with the preselector peaked to your friend's signal at 182.4 kHz. By the same token, your friend's preselector would be peaked at *your* frequency (182 kHz). As you can see, tuning the preselector above and below your center frequency provides a lot of flexibility.

Transmitting with the CW-893 is as easy as plugging in a CW key, selecting a clear frequency, and using a *resonant* vertical transmitting antenna. Consider a call sign that uses the last two or three letters of your Amateur Radio call sign. (It's considered poor practice to use your full call sign.)

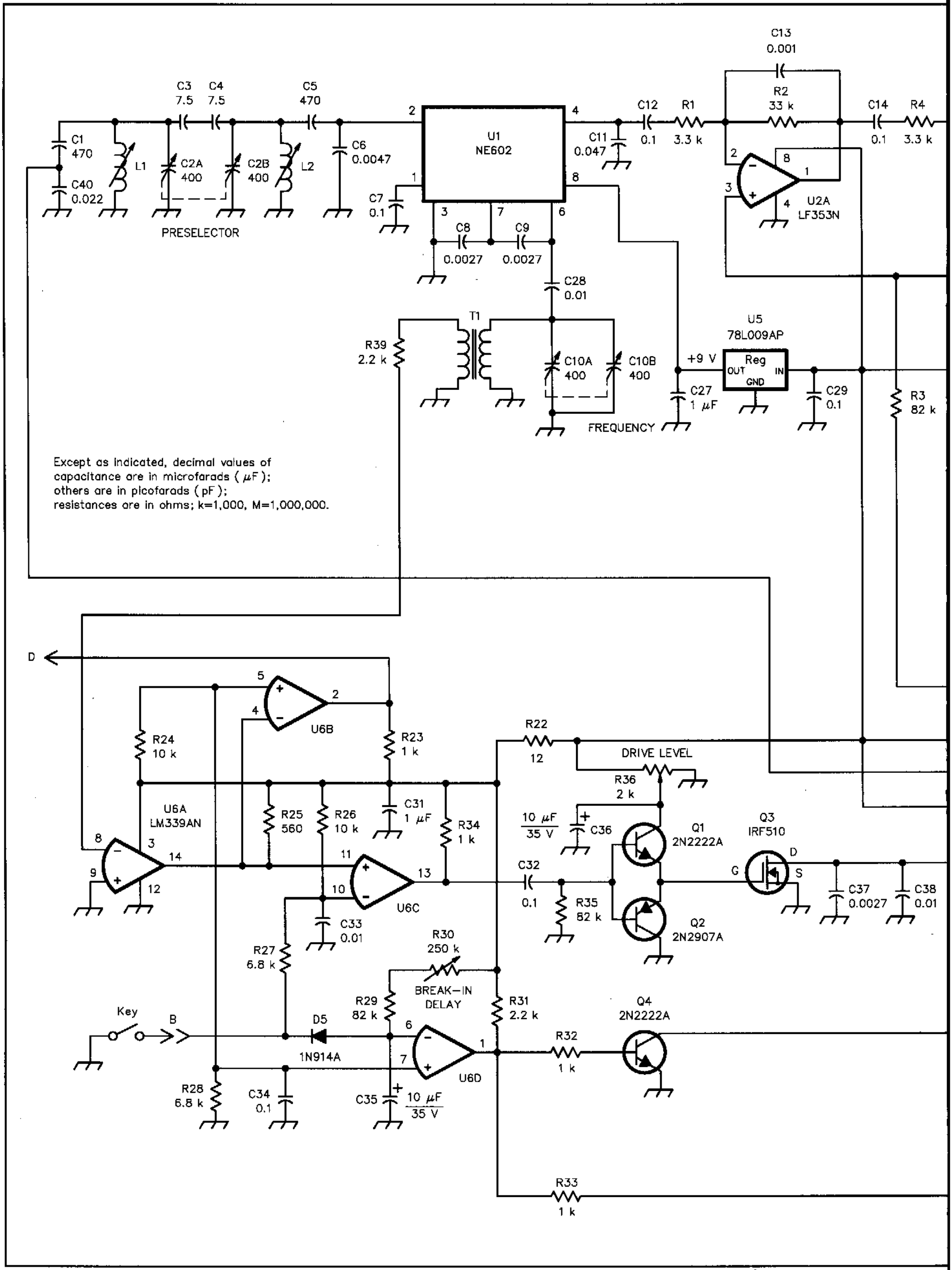
When transmitting, you'll want to adjust your TR delay potentiometer (R30) for the desired keying delay. In addition, the power amplifier drive control (R36) should be set for desired input power. You could install a 1-mA meter in the enclosure to monitor the power amplifier current. Meters can be expensive, however, so a VOM or VTVM can be used instead. Connect this to the meter – and + points on the circuit board. The voltage indicated corresponds to the input current to the power amplifier. One watt of input power is 83 mA at 12 volts, or *83 mV* on a VOM or VTVM connected to the – and + points.

When you're not enjoying a conversation, you can use the transceiver to send a beacon signal. Beacons are helpful to other Lowfers who want to know if they can hear you. It also helps with antenna experimentation and propagation tests. The transceiver is easy to use as a beacon. Simply connect your beacon ID generator (a CW keyer set to the "repeat" mode, for example) to the key input (point "B").

Antennas

The type and location of your 1750-meter antenna are of paramount importance. FCC Rules restrict the length of your *transmitting* antenna system to 15 meters. Just about any type of antenna design will do for casual, short-range experiments (less than one mile).

If your goal is optimum transmitting performance over greater distances, you *must* use a *resonant* vertical antenna (see Figure 3A). This involves resonating the antenna with a *loading coil* at the feed point and using a good ground system. The ground system can be composed of eight (or more) radial wires, each 30 feet or more in length. Terminate the radial ground wires with four copper pipes used as ground rods. If a ground system is required in rocky or sandy soil, or you want to roof mount the antenna, use a counterpoise resonant radial system. The cold water pipe in your home is an alternative if



Except as indicated, decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); resistances are in ohms; k=1,000, M=1,000,000.

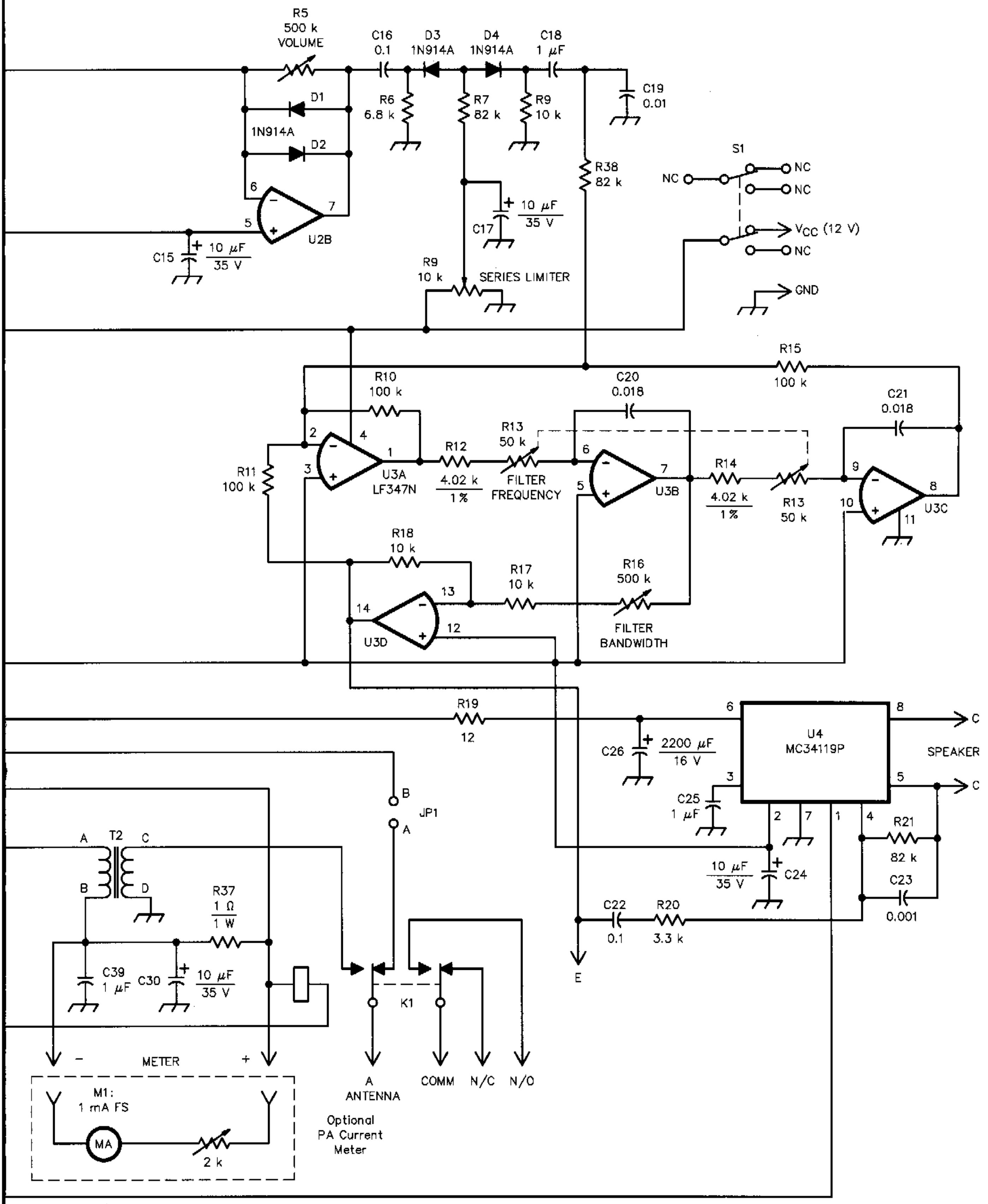


Figure 2—See caption on the next page.

Fig 2—Schematic diagram of the CW-893 transceiver. Resistors are ¼-watt, 5% tolerance carbon-composition or film except as noted below.

C1, C5—470-pF polystyrene (Mouser 23PS147).
C2, C10—400-pF variable (Mouser 24TR218).
C3, C4—7.5-pF ceramic disk (Mouser 21CB008).
C6—0.0047-µF polystyrene (Mouser 23PW247).
C7, C12, C14, C16, C22, C29, C32, C34—0.1-µF ceramic disk (Radio Shack 272-135).
C8, C9, C37—0.0027-µF polystyrene (Mouser 23PS227).
C11—0.047-µF film (Digi-Key P4521).
C13, C23—0.001-µF polystyrene (Mouser 23PW210).
C15, C17, C24, C30, C35, C36—10-µF, 35-V electrolytic (Radio Shack 272-1025).
C18, C25, C31, C39, C27—1-µF monolithic (Newark 90F1907).
C19, C33—0.01-µF ceramic disk (Radio Shack 272-131).
C20, C21—0.018-µF polypropylene 12% (Digi-Key P3183).
C26—2200-µF, 16-V electrolytic (Radio Shack 272-1020).
C28, C38—0.01-µF polystyrene (Mouser 23PW310).
C40—0.022-µF polystyrene (Digi-Key P3223).
D1, D2, D3, D4, D5—1N914A diode (Radio Shack 276-1122).
K1—DPDT relay (Digi-Key Z768-ND).
L1, L2—1.5-mH variable inductor (Digi-Key TK3203).
Q1, Q4—2N2222A (Radio Shack 276-2009).
Q2—2N2907A (Radio Shack 276-2023).
Q3—IRF510 power MOSFET (Radio Shack 276-2072).
R1, R4, R20—3.3-kΩ (Radio Shack 271-1328).
R2—33-kΩ (Radio Shack 271-1341).
R3, R7, R21, R29, R35, R38—82-kΩ.
R5, R16—500-kΩ, pc-board pot (Mouser 31CW505).
R6, R27, R28—6.8 kΩ.
R8—10-kΩ, linear taper, pc-board pot (Mouser 31CW401).
R9, R17, R18, R24, R26—10 kΩ (Radio Shack 271-1335).
R10, R11, R15—100 kΩ, 1% (Mouser 29MF250-100K).
R12, R14—4.02 kΩ, 1% (Mouser 29MF250-4.02K).
R13—50-kΩ, ¼-W, dual audio taper (Calrad 25-411).
R19, R22—12 Ω.
R23, R32, R33, R34—1 kΩ (Radio Shack 271-1321).
R25—560 Ω.
R30—250-kΩ trimmer (Mouser 32RM503).
R31, R39—2.2 kΩ (Radio Shack 271-1325).
R36—2-kΩ trimmer (Mouser 32RM302).
R37—1 Ω, 1 W (Mouser 29SJ901).
S1—DPDT switch (Digi-Key EG1003-ND).
T1—0.63-mH transformer (Digi-Key TK1201).
T2—Toroid transformer (see text).
U1—NE602 mixer/amplifier (Digi-Key NE602AN).
U2—LF353N low-noise op amp (Mouser 511-LF353N).
U3—LF347N quad op amp (Mouser 511-LF347N).
U4—MC34119P audio power amplifier (Newark MC34119P).
U5—78L009AP 9-V regulator (Mouser 333-78L009AP).
U6—LM339AN quad comparator (Mouser 511-LM339AN).

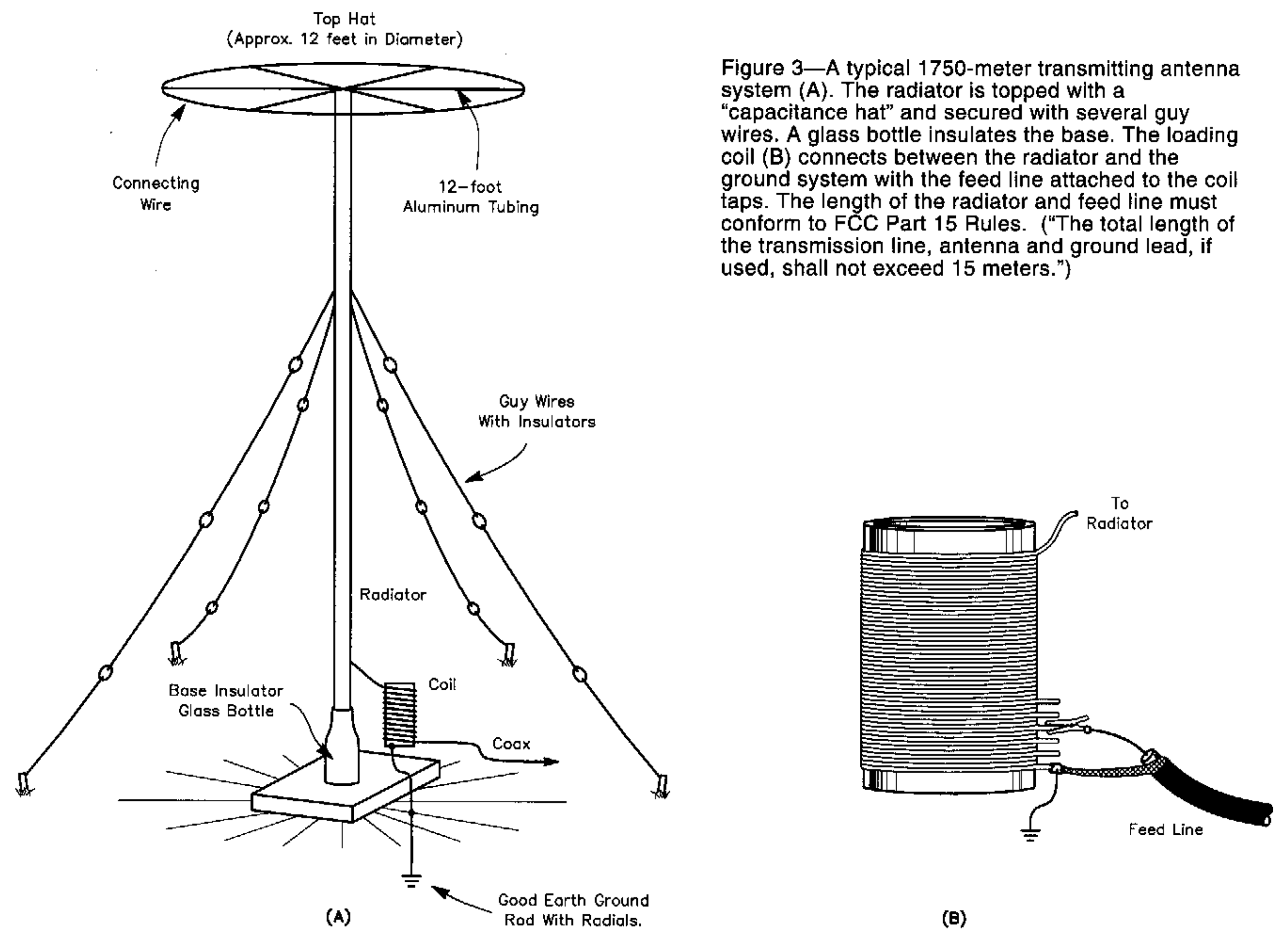


Figure 3—A typical 1750-meter transmitting antenna system (A). The radiator is topped with a "capacitance hat" and secured with several guy wires. A glass bottle insulates the base. The loading coil (B) connects between the radiator and the ground system with the feed line attached to the coil taps. The length of the radiator and feed line must conform to FCC Part 15 Rules. ("The total length of the transmission line, antenna and ground lead, if used, shall not exceed 15 meters.")

you have space limitations (performance will suffer greatly, though).

You can make the loading coil from a piece of *white* PVC pipe or Plexiglas tubing approximately six inches in diameter (see Figure 3B). Use #18 enamel-insulated wire, winding it tightly on the pipe to a length of five inches. Create taps at the cold end of the coil by sanding away the insulation of the first 10 turns. The braid of your coaxial feed line is attached to the ground system and cold end of the coil. The center conductor is soldered temporarily to the fifth turn of the coil. The top of the coil attaches to the antenna. Several small NE-2 neon bulbs can be soldered in series and used as a voltage detector. While transmitting a carrier, touch the bulb string to the antenna and watch for an indication. Place your hand near the antenna and note the illumination. If the capacitance of your hand makes the bulbs brighter, *add* more turns to the coil; remove turns if the bulbs dim. Once the best number of turns is determined, experiment further to find the best tap point. When you're finished, paint the coil with clear marine varnish.

It's important to note that there are no restrictions on the type and size of your *receiving* antenna. With that in mind, you may want to consider separate receiving and transmitting antennas. For example, many Lowfers use a broadband high-impedance probe with a built-in preamp called an *active whip* antenna. The small size of the whip antenna makes it convenient for it to be placed in a location where noise is at a minimum. A separate ground rod should be used as a noise-free isolated ground reference for this antenna. Active whip antennas are considered the best overall LF/VLF receiving antennas and can be purchased from LF Engineering, 17 Jeffery Rd, East Haven, CT 06513; tel 203-248-6816.

Lowfers also use loop antennas because of their ability to reduce or eliminate noise by rotating the antenna *null* for minimum noise pickup. Magnetic noise from residential wiring is a problem in city or suburban environments, so a loop is not recommended for these areas. But in a clear area such as a park, a loop can effectively remove strong carriers and noise that block the signal you are trying to receive.

Receiving and transmitting antennas should be located away from power lines, trees or buildings. Noise may wipe out reception completely, discouraging the casual listener from using this band. Smart antenna design and placement will significantly reduce the noise to an acceptable level. Man-made noise tends to rapidly diminish as you move away from the source. Light dimmer interference, for example, will radiate throughout the wiring in the home, eliminating useful reception from an antenna on the roof, or within 20 feet of the home. If the receiving antenna can be moved near the curb, however, the noise may disappear.

Conclusion

Much more needs to be said about Lowfer antennas and Lowfing in general, but I'd need a lot more space! The CW-893 kit manual includes a detailed discussion of antennas with several suggested designs. I also recommend that you pick up a copy of Ken Cornell's book, *The Low and Medium Frequency Radio Scrapbook*. It's available by mail directly from Ken at 225 Baltimore Ave, Point Pleasant, NJ 08742. The cost is $17.50 (shipping included). You'll find a partial list of 1750-meter CW beacon stations in WB8IMY's article, "Lowfing on 1750 Meters" in the October 1993, *QST*, page 67.

Lowfer newsletters are also available. If you join the Longwave Club of America, you'll receive the *Lowdown*. For details, write the LWCA at 45 Wildflower Rd, Levittown, PA 19057.

David Curry, WD4PLI, has been an active Amateur Radio operator and Lowfer for more than 20 years. He is a regular on the Los Angeles area 1750-meter SSB Net Saturday mornings at 9 AM on 183.5 kHz. He also participates in the 80-meter Lowfer Net Sundays at 8 AM on 3927 kHz. David is a professional musician and enjoys snow skiing, wind surfing and fine dining.

BASIC 1750m TRANSMITTING ANTENNA

By Mitchell Lee

Newcomers to 1750m find a mystique surrounding transmissions on such a low frequency. There is no magic involved; 1750m responds to the same physical principles that apply to other frequencies. In this article we will discuss the transmitting "loop" (not to be confused with a loop of wire) and how to maximize the radiated signal. The transmitting loop consists of a loading coil, an antenna, and a ground.

For the purpose of developing a useful antenna model, let's consider an average city lot 1750m installation (see Figure 1). It is constructed from three 10' TV mast sections with four 20' top loading wires extending out horizontally to all four points of the compass. The antenna stands on an elevated plastic slab that acts as a base insulator. Beneath this is a water pipe and several ground wires that run out in various directions to the property lines where they are terminated by 8' ground rods. There are no buildings or trees anywhere near this antenna because the owner/operator went berserk one day with a Brush Hog. The loading coil is also located at the base of the antenna.

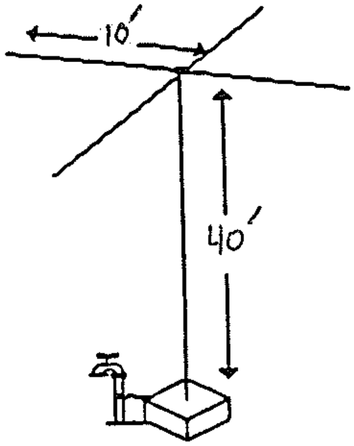


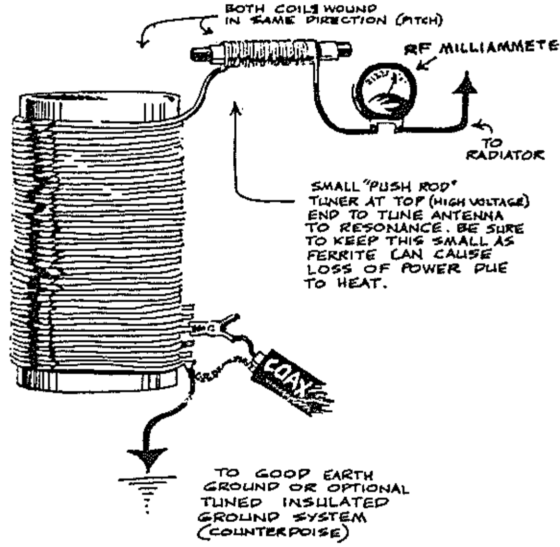
Figure 1. Typical 1750m antenna.

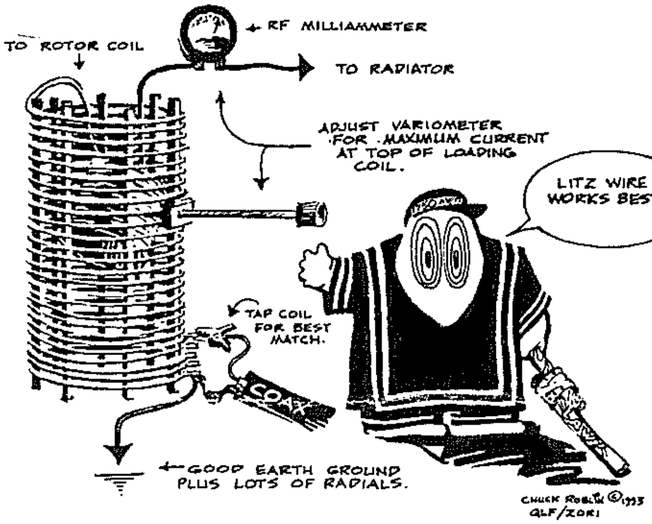
The capacitance as measured between the base of the antenna and the water pipe/radial system is 320pF. Antennas of this genre run anywhere from 120pF (30' vertical) to 500pF or more (30' vertical with lots of top loading radial wires). Note that top loading wires exhibit 200pF capacitance, while the vertical section contributes 120pF. The utility of more tophat capacitance will be illustrated shortly. The resistive component of the impedance (modeled as a resistor in series with the capacitance previously discussed) as measured at the base of the antenna is 50 ohms. The impedance bridge used was a fairly good one; a resistive component of only 50 ohms is difficult to find when the capacitive reactance is 57 times greater, or about 2,842 ohms.

ANTENNA COIL

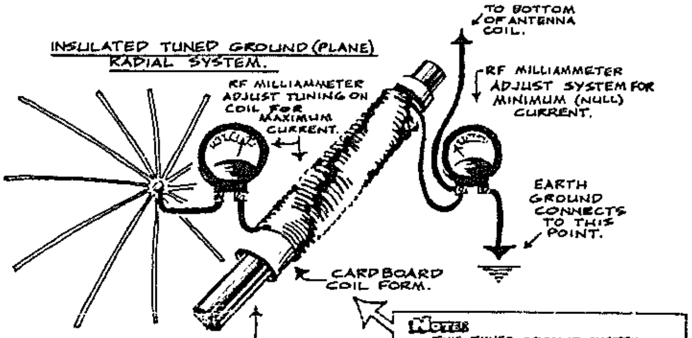
NOTES:
USE WHITE PVC PIPE ONLY AS IT HAS THE BEST INSULATION CHARACTERISTICS!

USE SOLID NUMBER #22 GUAGE ENAMELLED COPPER WIRE OR LITZ WIRE FOR COILS



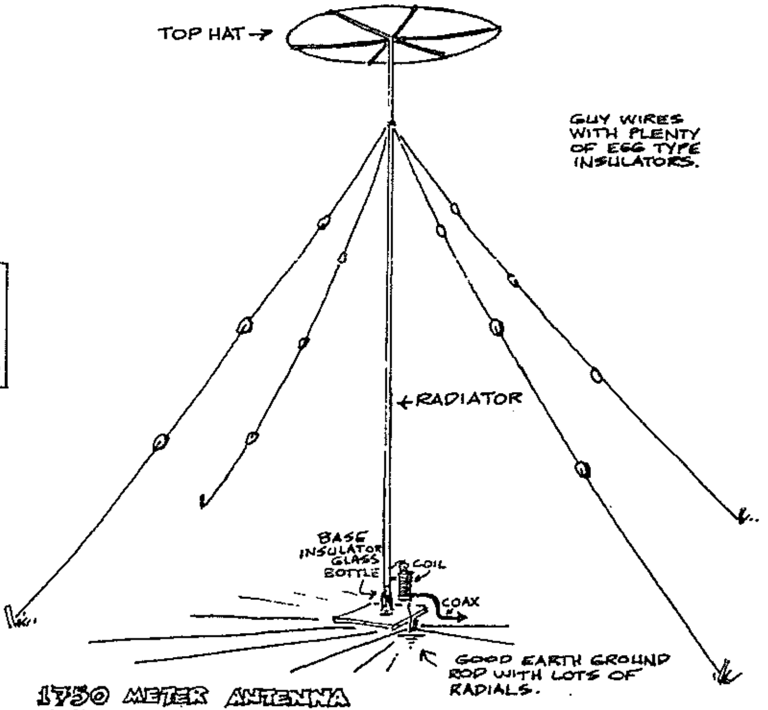


OPTIONAL TUNED GROUND (PLANE) SYSTEM



THIS SYSTEM COULD BE PLACED ON A ROOF AS AN ELEVATED TUNED COUNTERPOISE.

NOTES:
THIS TUNED GROUND SYSTEM WAS USED FOR YEARS AT LOWFER STATION "QLF" WHERE THE ANTENNA WAS ONLY 18 FEET HIGH WITH ONLY FOUR TOP HAT WIRES...ONLY ONE WAS 32 FEET, THE OTHERS SHORTER. THIS SYSTEM MADE THE DIFFERENCE!



1750 METER ANTENNA
TOTAL LENGTH NOT TO EXCEED 50 FT INCLUDING TOP HAT RADIUS.

While the the 2,842-ohm capacitive reactance is easily tuned out by a 2,842-ohm inductive reactance, still buried in that 50-ohm resistance is a useful(?) radiation resistance of 0.025 ohms. Graphs showing radiation resistance for electrically short top-loaded verticals are found in various engineering literature (1,2,3,4). Figure 2 shows a schematic representation of the transmitting loop.

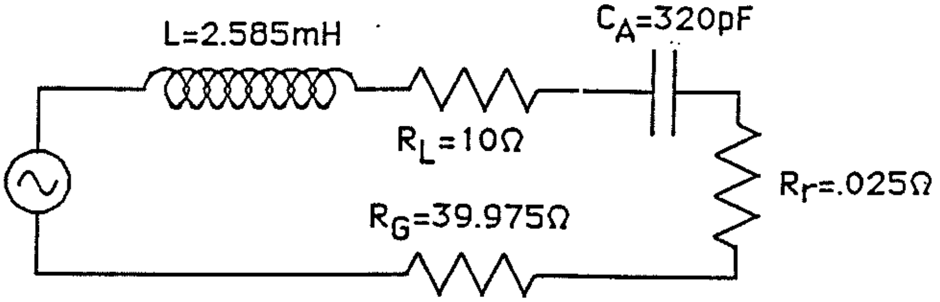


Figure 2. Transmitting loop of a typcial 1750m installation.

The most common transmitting scheme is a series tuned circuit. It affords a manageable driving point impedance with transmitter voltages and currents well within the reach of inexpensive components. When the antenna capacitance is series resonated by the loading coil, nothing is left but loading coil loss, radiation resistance, and ground resistance. Therefore the transmitter thinks it is driving a pure resistance.

Our loading coil depicted in Figure 2 has a Q of 284. Q is the ratio of inductive reactance (2842 ohms) to resistance (10 ohms). When the coil is hooked up to the antenna and transmitter the overall Q is 2842/(10+39.975+0.025)=2842/50=57. Q is also related to bandwidth and in this case (175kHz) the bandwidth is 175000/57=3kHz. A +/-1.5% shift in antenna capacitance or coil inductance will drop the output 3dB--half power. Since transmitter characteristics are unknown, the previous statement is at best a very crude approximation, but it is in the ball park and tuning is critical. If we assume that the circuit is resonant, we can further simplify as shown in Figure 3.

$$I_A=\sqrt{\frac{P}{R}}=\sqrt{\frac{1}{(39.975+0.025+10)}}=\sqrt{\frac{1}{50}}=141\text{mA}$$

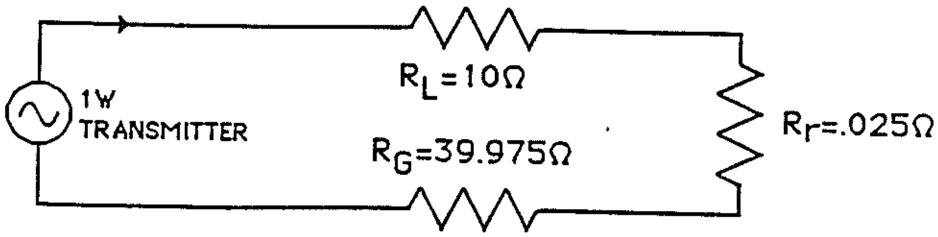
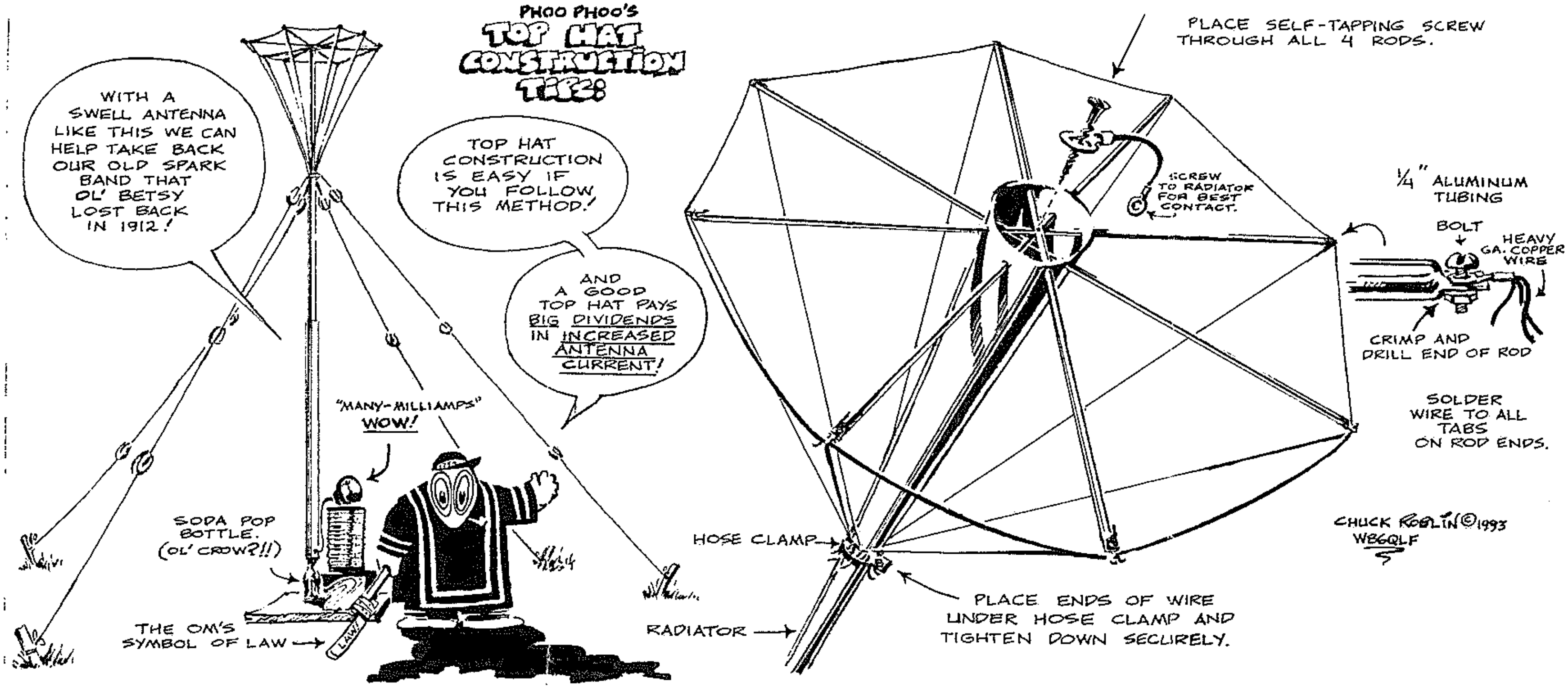


Figure 3. Transmitting loop in resonance reduces to resistances.

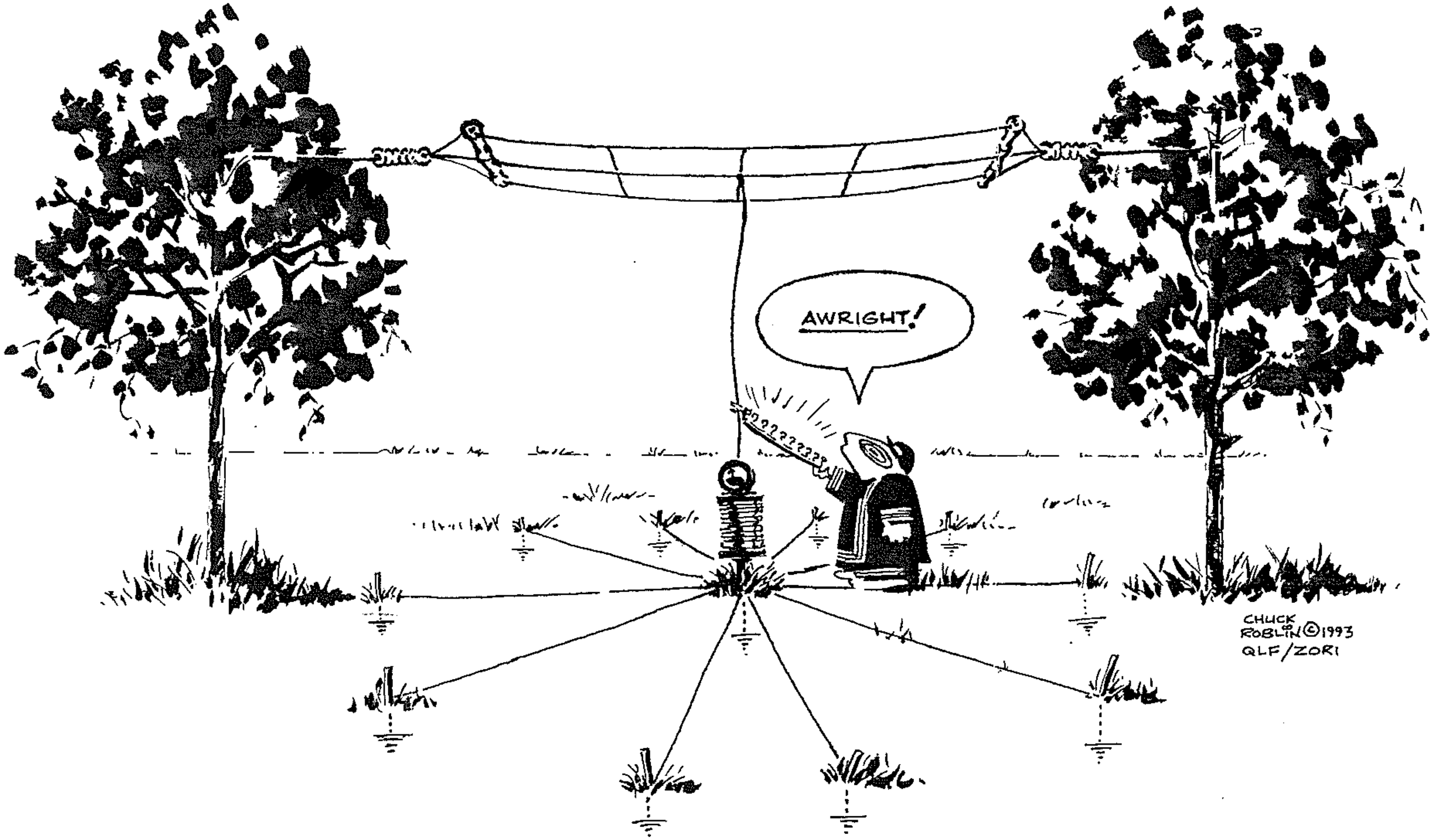

PHOO PHOO'S
TOP HAT CONSTRUCTION TIPS!
WITH A SWELL ANTENNA LIKE THIS WE CAN HELP TAKE BACK OUR OLD SPARK BAND THAT OL' BETSY LOST BACK IN 1912!
TOP HAT CONSTRUCTION IS EASY IF YOU FOLLOW THIS METHOD!
AND A GOOD TOP HAT PAYS BIG DIVIDENDS IN INCREASED ANTENNA CURRENT!
"MANY-MILLIAMPS" WOW!
SODA POP BOTTLE. (OL' CROW?!!)
THE OM'S SYMBOL OF LAW
LAW
PLACE SELF-TAPPING SCREW THROUGH ALL 4 RODS.
SCREW TO RADIATOR FOR BEST CONTACT.
1/4" ALUMINUM TUBING
BOLT
HEAVY GA. COPPER WIRE
CRIMP AND DRILL END OF ROD
SOLDER WIRE TO ALL TABS ON ROD ENDS.
HOSE CLAMP
RADIATOR
PLACE ENDS OF WIRE UNDER HOSE CLAMP AND TIGHTEN DOWN SECURELY.
CHUCK ROBLIN © 1993
WB6QLF

Even the most non-technical person can analyze Figure 3, and Ohm's law will suffice for all of our calculations. To radiate a signal it is necessary to dissipate some energy in the radiation resistance, Rr. The power in this resistance (ERP) is given by I^2Rr. Assume that the transmitter is 100% efficient (80 or 90% is more representative) and calculate the antenna current for 1W. I^2=P/R=1/50. Therefore the best antenna current we can achieve is about 141mA (.141A) with 1W of power and a 50 ohm loop resistance. Let's make a table with various ground+coil resistances and show how the antenna current and the relative signal will vary. 1W transmitter power and .025 ohms radiation resistance is assumed, and 50 ohms (a typical loop resistance for someone on good soil with some metal in the ground) is our reference level. The radiation resistance used for this table includes that of the vertical section of the antenna only, and does not consider the effects of radiation from the tophat or the ground. ERP=effective radiated power.

loop resistance	I (mA)	signal (dB)	ERP
10 (copper plate)	316	+7	2.5mW
20 (copper soil)	224	+4	1.25mW
35 (much effort)	169	+1.55	714uW
50 (good soil)	141	0.0dB	500uW
75 (ok)	115	-1.76	333uW
100 (bad soil)	100	-3	250uW
150 (no skywave)	81.6	-4.77	166uW
250 (rocks)	63.2	-7	100uW
500 (find another hobby)		-10	50uW

If you run out and measure your antenna current and find 63.2mA, that doesn't mean that your ground is a total "loss." Your transmitter efficiency might be low, you could be mistuned, your coil could be a loser, or your RF ammeter could be a basket case. If you measure 224mA, don't pat yourself on the back because even if your ammeter is working, you may not be radiating all of it. Look at Figure 2 again. Suppose we add some capacitance from the base of the antenna to ground. Not all of the current that flows from the transmitter through the coil will make it to the radiation resistance. Some will be shunted away in the loss capacitance. The stray capacitance doesn't dissipate energy, but it does divert current away from the radiation resistance and therefore decreases the radiated signal. Excessive base capacitance is caused by insufficient base insulation (separation from ground), and non-vertical feed lines running from the coil to the antenna.

Trees, nearby structures and metal objects (such as other antenna masts or wires) will absorb energy or act as a shield, robbing the signal of its precious few microwatts. Other losses such as leaky insulators, conductive guy wires/ropes, and losses in the conductors themselves, such as skin effect, non-copper antenna components, thickly-painted or rusted surfaces, and poor connections, take their toll on the available power.



THE WIRE ANTENNA; Optimum performance & flexibility!

Why is a horizontal antenna so bad? Providing we take steps to reduce all of the loss factors, why does a horizontal antenna have such a tough time radiating a signal? Horizontally polarized signals at low frequencies are greatly absorbed as they travel along the surface of the earth. If the signal was radiated way up in the sky (miles up) then this effect would be nonexistant. Vertically polarized waves are also attenuated as they travel along the earth's surface, but not nearly as much as horizontally polarized waves. Therefore, stick with a vertical antenna.

Tophats serve two functions. First, the larger the capacitance of the tophat, the greater the effective height and radiation resistance of the antenna. The 0.025-ohm radiation resistance is a lumped constant that is based upon uneven current distribution in the antenna. One must realize that the actual radiation resistance of the antenna is distributed throughout its length, as is the antenna capacitance. Therefore, not all of the current flowing into the base of the antenna makes it to all of the radiation resistance, or to all of the antenna. A large tophat will act to hog current from the vertical section. In this example, a fraction of current (200/320pF=62.5%) flows through all of the vertical radiation resistance and makes it to the tophat. The remaining 120/320=37.5% of antenna current flows through only part of the vertical radiation resistance. The bigger the tophat for any given vertical, the larger the EFFECTIVE radiation resistance. The 0.025-ohm value previously used was an effective radiation resistance and accounts for uneven current distribution such that $0.025XI^2$ yields the proper number for effective radiated power.

The second benefit of larger tophats is that the increased antenna capacitance will result in a proportionately smaller loading inductance. Less inductance means less coil loss resistance, and less capacitance from the physically smaller coil to ground. If a smaller coil is used, the loop Q will drop making tuning less critical. Antenna voltage will drop as well making for less stringent insulation requirements.

Our discussions assumed a flat tophat. In most instances a flat top hat is impossible to construct owing to a lack of support structures from which it may be suspended. Various studies have show that for drooping tophats, the length of the conductors may be extended until their ends are at approximately 1/2 the height of the vertical antenna. Beyond this point the tophat wires begin to exhibit a shielding effect on the prime radiating portion of the vertical, thereby reducing the radiated signal. Lowfer experiments have shown that a 10' vertical with a flat 40' radius tophat does not radiate as well as a 40' vertical with a 10' radius tophat. Given the 50' (15m) antenna length (vertical+tophat radius) restriction of Part 15.112(c) of the FCC rules, a 20' to 40' vertical with the balance in tophat is optimum. More exacting generalizations are pure speculation. A point is reached where much depends upon the individual transmitting site, ground conditions, and the characteristics of the receiving setup.

If safety and convenience are an issue, the 20' vertical is optimum since one person can easily erect 20' of TV mast. A 30' vertical really requires 2 people or more. 40' requires an antenna party. As an example, erecting the 45' LAH beacon vertical (with a spoked tophat) took 11 people. It was constructed from 5' military thick-wall aluminum mast sections. 3 people lifted the mast at the base, a fourth person positioned and inserted the next section, and 6 other persons fed out 3 sets of 3 guy ropes. The eleventh person ran around monitoring the lean angle. 6 months later a particularly windy storm compressed the antenna until it bowed in the center, and upon springing back into shape, so much upward velocity was generated that the entire antenna disintegrated into 5' sections distributed all over the back yard. All guy rope anchors were still in place and only one or two sections showed any signs of stress. Viewing such a spectacle at the base of the antenna could have been a most impaling event. Fortunately, the hot tub was vacant at the time.

Our 1750m transmitter analysis has benefited from a few assumptions and has obtained some numerical values (antenna/tophat capacitance, effective radiation resistance) from formulae and graphs not shown here. However, calculating these numbers exactly for any given antenna is a tedious and useless pursuit since there are so many effects that cannot be quantified. What has been shown will serve as a reference from which several conclusions may be drawn regarding an optimized 1750m antenna.

Now for some rules of thumb regarding 1750m transmitting antennae:

1) Put as much copper into the tophat as possible. Remember, don't let the tophat droop further that 1/2 way down the vertical. Try to maintain geometrical symmetry in the tophat for maximum capacitance per foot of conductor used.

2) Try to use copper throughout. Copper pipe can be bought in concentric sizes and brazed or soldered together. Maintain the integrity of each copper-to-copper connection by soldering or joining with sheetmetal screws and covering the connection with RTV or other suitable silicone sealant. TV mast can be shunted by copper wires to increase conductivity, and a cage of vertical wires can be substituted for a mast where the antenna is suspended.

3) Connect as many metallic objects and ground rods as possible to the ground system. Optimum radial length is slightly longer than the antenna is tall. For a 30' vertical, ten 40' radials make a better ground than one 400' wire.

4) Use an efficient coil. From the considerations of Figure 2, a coil Q of about 50 (57 was the overall loop Q) would result in an immediate loss of 6dB. The use of Litz wire vs. enameled wire is also worth 6dB improvement. Ferrite loading is useful for producing Qs of 250 to 350 and physically small coils. Note that the Q of a ferrite loading coil drops as the antenna current increases. A 7.5"X0.5" type 33 ferrite rod (available as part number R33-050-750 from Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91607, cost is around $3.50 including postage) is an excellent choice for loading coils. 100 turns or so will produce a maximum inductance of 5 or 6mH which can be tuned by sliding the coil around the ferrite rod. Large air-core coils or "basket" coils are probably the best, and they can exhibit Qs in excess of 600 in the 2 to 10mH range. For the curious, a ratio of 2.5:1 diameter:height is the optimum geometry for such a coil. Tuning a basket coil is best accomplished with a variometer.

5) Use an efficient transmitter. Its efficiency can be determined by measuring the ratio of output power (into a load resistor that is approximately the same value as the loop resistance) to the DC input power. You will need an AC voltmeter with enough bandwidth to cover 1750m (or an RF

ammeter) to measure the output power into a resistive load. Replace the loading coil and antenna with a carbon composition resistors until a value is found which results in the same DC input power as was observed when operating into the coil/antenna. Power MOSFET transmitter circuits with 80 to 90% efficiency can be constructed.

6) Use high-quality insulation throughout. A 1' porcelain base insulator is not overkill. In addition, pyrex or ceramic strain insulators are not an excess used in series with nylon guy ropes. Do not use metallic guy wires. The top hat often substitutes as part of the top set of guy ropes. It has been found that polypropylene guy rope deteriorates rapidly when exposed to sunlight. 0.1" nylon weed-eater line has a useful lifetime and yet is low-profile and lightweight. This material can be purchased in bulk at most hardware stores. Beware of PVC pipe. Tesla coil tests show that while white-colored PVC pipe seems to be an adequate insulator, gray (and perhaps other colors) PVC pipe is very lossy. Do not use gray PVC pipe for coil forms or insulators. Use other colors at your own risk.

7) Tune your loading coil frequently until you have an idea about how the system tuning varies with time, season, and weather. Most air-wound loading coils detune when a hand is brought within 3', and some are even more sensitive than this. Tune with a proverbial "ten-foot pole." Observe your tuning by watching antenna current (measured in line with the antenna itself), a neon lamp, or a field strength meter. An ammeter and neon light will each take a small amount of power, but in most cases it is inconsequential when compared to the available power. For instance, an RF ammeter might take 20mW from a transmitting circuit that has an available power of 800mW. The loss is about 0.11dB. A friend with a receiver and a telephone can provide excellent remote field strength measurements.

8) Locate the antenna in as clear a location as possible. A mountain top is best; leaning it up against a metal barn in the bottom of a canyon is the worst. Keep the area near the base of the antenna clear of bushes, fences, buildings, and other lossy capacitances. A clear area with a diameter equal to the height of the vertical is a plus. Buildings, power poles and other antennas are the worst offenders. In a residential situation it is best to locate the antenna on the peak of the roof.

9) Try to reconstruct a "Figure 3" for your installation. Given the Q of the coil and figures for the transmitter output power and loop resistance this is easy to do. Inspection of Figure 3 will give an indication of where some improvement might be made. For instance, if the coil loss is 10 ohms and the ground loss is 90 ohms, your extra Litz wire is better utilized as ground radials.

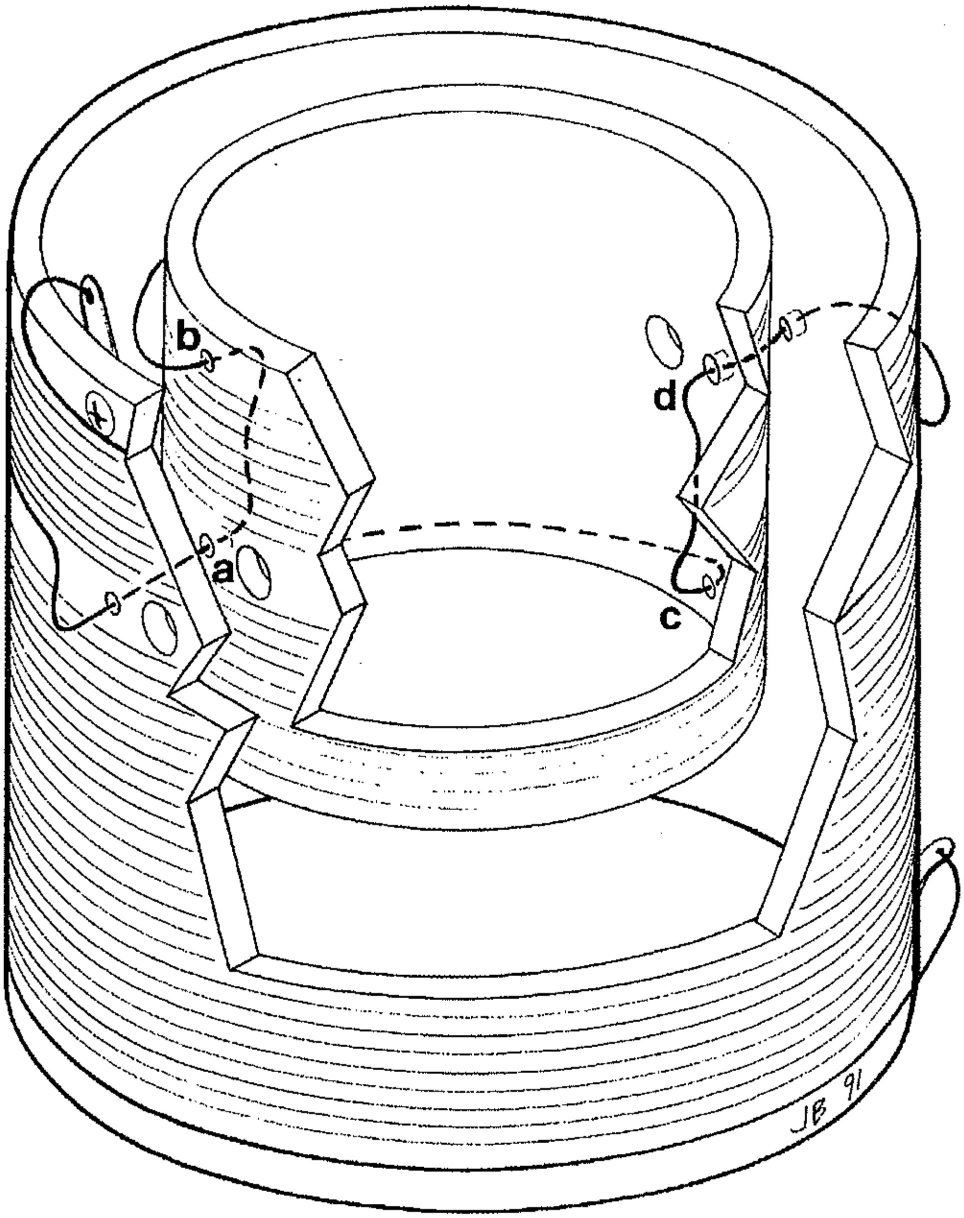
10) Keep your beacon running 24 hours a day, 7 days a week. There have been relatively few reports of people hearing beacons that were not running.

References worth reading:

1: LF Engineering Company, Catalog No. 100/Fall 1985. 17 Jeffry Road, East Haven, CT 06512. See "Low Frequency Engineering Data" for equations and graph of radiation resistance. This material was credited to Antenna Engineering Handbook, by Henry Jasik (a classic text on the subject).

BASSIC VARIOMETER

(All hail the variometer)



The variometer provides a large inductance range for antenna tuning. Two basic types of variometers exist: one that is tuned by rotating the inside coil and the other by lifting the inside coil in and out. As shown in this illustration, the smaller inside coil rotates to aid or reduce the total inductance.

Wiring between coils is shown by letters: a, b, c, d. The solder lugs at the top of the coil connects to the antenna, while the bottom lug connects to the feedline's center conductor. A non-metallic rod, usually ¼" diameter and 2 feet long, is inserted through both coils and glued to the center coil for rotation. The length of the rod should be as long as practical to minimize body capacitance while tuning. Plexiglas makes excellent coil forms, but is usually not stiff enough to support the inside coil without warping. Wood or fiberglass would be a better choice for rod material. Notice that each coil has its windings separated in the middle to allow the tuning rod to pass through.

In a letter from Ed Phillips, I received information giving several possible designs for variometers. A copy of this letter is included to aid your design, if necessary.

The exact number of turns is determined experimentally. It is recommended that more tuns than necessary should be wound on the outside coil, as it is easier to remove turns, than to add.

Litz wire made from several strands of 40-gauge wire will greatly improve efficiency over this frequency range. 150 strands of number 40, referred to as "150/40" is a good balance of size vs. current capacity.

Another important factor in achieving the highest possible "Q" is the length to diameter ratio of each coil (this includes single coil design). A diameter to length ratio approximately 2:1 being optimal. Most Plexiglas cylinders are available in 4", 6", 8", and 10" diameters, which would correspond to winding lengths of 2", 3", 4", and 5" (minus the gap for the turning rod).

A variometer is a better choice than using single inductors with variable capacitor tuning. When using a variable capacitor in parallel with the antenna much of the RF current will flow through the capacitor instead of the antenna which will lower the antenna feedpoint impedance, causing a mismatch. Most Lowfer antennas have to share their current with other losses already! Adding capacitance across the antenna will only add to the loss by directing current away from the antenna, where it could otherwise radiate.

The variometer will allow maximum current to flow to the antenna, and still be flexible enough for precise tuning on your desired frequency.

Dear Dave:

I've run off some calculations on possible variometers for you, based on the information you gave me on the 30 foot mast with 6 foot diameter loading hoop. I estimate that its total capacitance is about 146 uufd. In order to get a design of a little more general use I have assumed that the minimum capacitance anyone would want to tune would be about 120 uufd, corresponding to a 40 foot tower with no top loading; this would take 8250 uh of inductance at 190 kHz and 5817 uh at 160 kHz. The probable maximum capacitance for a large antenna would be 300 uufd which would take 2339 uh at 190 kHz. Based on this I will give you four possible variometer designs which will give the maximum inductance of about 8500 uh, and then discuss what might be best for antennas with more capacitance and thus requiring less inductance.

At this point I should mention that a variometer with rotating coil is a convenience, but definitely not as low loss as a straight solenoid with turns pruned to give the required inductance; that will have the minimum RF resistance for any given diameter and wire size, and thus will be the most efficient. A better design, but one requiring a much better initial knowledge of the exact antenna capacitanced and intended operation frequency, would involve a large straight solenoid in series with a much smaller coil at one end, which could be rotated (or slid in and out) to give the desired value for resonance. Many guys probably don't have the patience or technical knowledge to handle that sort of thing, or perhaps even to calculate resonance and inductance. I don't know how to help them.

In the first two tables I am assuming the inner coil is mounted on a 1/4" diameter shaft, with windings on both the inner and outer coils equally spaced on each side of the shaft, and wound as close to it as possible. This design puts the inner coil in the center of the outer one and gives the largest inductance change but has more loss than the second one I will discuss. The min, mid, and max inductance values correspond to the case where the inner coil is turned so the mutual inductances buck each other, the case where the coil is at right angles and neither aids nor bucks, and the case where the coil is turned so the inductances aid each other. The Q values and the AC resistance are given for 175 kHz (mid-band), and are probably optimistically high for the Q and low for the resistance. These first designs would probably work best where the loading coil is connected to some sort of matching network, as the coupling to a third (tank) coil would vary a lot as the inductance is varied, and it might be tough to get enough coupling at low inductance values.

	D (in)	L(in)	N	BS #	l(ft)	w(#)
Large coil:	6	6.75	225	22	355	.70
Small coil:	4	3.75	125	22	132	.26

L min (uh): 3465 Q: 218

L mid (uh): 5983 Q: 378

Lmax (uh): 8501 Q: 537

AC resistance (ohms): 17.4

	D (in)	L(in)	N	BS #	l(ft)	w(#)
Large coil:	8	5.25	139	20	294	.92
Small coil:	6	4.5	120	20	190	.60

L min (uh): 2064 Q: 130

L mid (uh): 5306 Q: 335

Lmax (uh): 8548 Q: 540

AC resistance (ohms): 13.3

In the next two designs, which I recommend for lower losses, the inner coil is mounted at one end of the outer coil, with the shaft as close to it as possible. The inner coil is wound as above, but the outer coil is a continuous winding. While the total inductance range is less than before, the AC resistance is only slightly higher and inductive coupling to a tank coil would be much easier. These are the designs I would select if I were building a new station.

	D (in)	L(in)	N	BS #	l(ft)	w(#)
Large coil:	6	8.00	267	22	421	.83
Small coil:	4	3.75	125	22	132	.26

L min (uh): 5687 Q: 315

L mid (uh): 7173 Q: 398

Lmax (uh): 8659 Q: 480

AC resistance (ohms): 19.8

	D (in)	L(in)	N	BS #	l(ft)	w(#)
Large coil:	8	6	160	20	337	1.06
Small coil:	6	4.5	120	20	190	.60

L min (uh): 3764 Q: 287

L mid (uh): 6084 Q: 464

Lmax (uh): 8404 Q: 641

AC resistance (ohms): 14.4

You will notice that for all designs the Q drops rapidly as you go toward minimum inductance, since the AC resistance of the coils is about the same but the inductance (and hence the reactance) are falling off. For this reason, once the coil is found to resonate it would be desirable to pull turns off the ends of the outer coil until resonance is obtained with the inner coil turned well past the mid-inductance point, leaving only enough turns to ensure a reasonable tuning range. Doing this will result in the least loss for any installation, and hence the maximum radiated power.

If I were building a coil I would use the smaller wire size and coil diameters, since the maximum AC resistance for any of these designs is probably quite a bit less than the effective resistance of the antenna and ground of almost any installation without a massive ground radial/counterpoise system. (Here at IZJ the effective resistance of the antenna/trees/ground is about 60 ohms!) Once I had the station tuned up and running (an RF ammeter, even if only of the rectifier type I described in one of the Updates, is almost essential for tuning) I'd consider making a bigger coil, probably a solenoid with a small "variometer coil" at one end, with a very limited tuning range.

That about does it for this morning. If you have any further questions drop me a line and I'll try to help when the time permits.

73,

Ed

PS: For anyone contemplating a new station I'd strongly recommend getting a copy of Mike Mideke's "Transmitting Antennas and Ground Systems for 1750 meters", published back in 1987. I don't know if Mike has any left, but he probably has the masters and you might consider reprinting it for your customers if he doesn't want to.
(probably)

TRANSMITTING ANTENNAS FOR 1750 METERS

BY ED PHILLIPS W61ZJ

successful transmission requires that the transmitting and antenna be of maximum possible height, and losses in the antenna and ground system be as low as possible. I shall now describe some general properties of small VLF antennas and their ground systems, and give examples of what you may want to build. The antenna system will first be considered from a constructional point of view, and the electrical properties will be discussed in their relation to the coupling system design and construction. The parameters of the antenna as a circuit element will be given next, followed by the design and construction of the circuits for coupling the antenna to the transmitter, together with methods for their adjustment.

In practice the design of your antenna system may be dictated by the space you have available, as is true in my own case. If your space is limited don't give up, but put up the tallest thing you can, as far away from trees and buildings as you can, and them give it a try. You may be pleasantly surprised!

There are no mysteries to working at 175 KHz, since use of this frequency goes back to the very earliest days of "wireless". In fact, any good old wireless book has wealth of useful information on antennas and grounds. The advice is excellent but hard to follow. A.P. Morgan's "Wireless Telegraph Construction For Amateurs" (1911) devotes chapter 3 to "aerials and earth connections". A few quotes are of interest:

"The higher an aerial is placed above the surface of the earth, the wider will be its electrostatic field, and consequently more powerful electric waves will be developed. But after a height of 180-200 feet is attained, the engineering difficulties and the expenses increase so rapidly the few stations exceed it. Other things being equal, the increased range in transmitting varies as the square of the height of the radiating wires. For example, a 25-foot aerial capable of transmitting one mile theoretically will send waves 16 miles if made 100 feet high.

"After the limit in a vertical direction has been reached, the only remaining possibilities are to increase the surface and spread out horizontally."

"Ground connections--the importance of a good earth or ground connection can hardly be overestimated,. Whenever possible commercial stations are located on moist ground may be secured by imbedding zinc or copper plates in the earth or water."

These quotations are still pertinent today, although note that the quantity which varies as the square of the antenna height is the radiation resistance, not the electric field produced by the antenna, as Morgan implies when he says the increasing the height by four times increased the range by 16 times. However, because of the increase in antenna system efficiency which goes with the increase in height, his remarks about increasing the range of the station are almost correct. A few things I did not quote are also pertinent, especially his remarks on making the antenna installation strong enough to withstand any possible weather, and providing the antenna with a grounding switch for use when lightning is possible. He also emphasizes arranging the antenna so it cannot fall down across power lines, thereby leading to all sorts of unhappy events.

The antennas which Morgan describes are all tall structures with some form of "flat top" or capacitive top loading. Figures 1 and 2 are copied form E. E. Bucher's "The Wireless Experimenters Manual" (1920), and illustrate two methods of constructing and antenna with top loading. In each case the loading consists of a group of horizontal wires spread out as much as possible to increase the capacitance to ground. The purpose of this top loading is to increase the current at the top of the antenna, thereby increasing its radiation resistance. the radiation resistance of an antenna is a fictitious resistance which, when multiplied by the square of the current flowing in the base of the antenna, gives the radiated power; increasing the radiation resistance increases the power radiated for a given antenna current. For a very short antenna the radiation resistance is proportional to the squares of the effective height and of the frequency. For an unloaded antenna 50 feet high the theoretical radiation resistance at 175 Khz

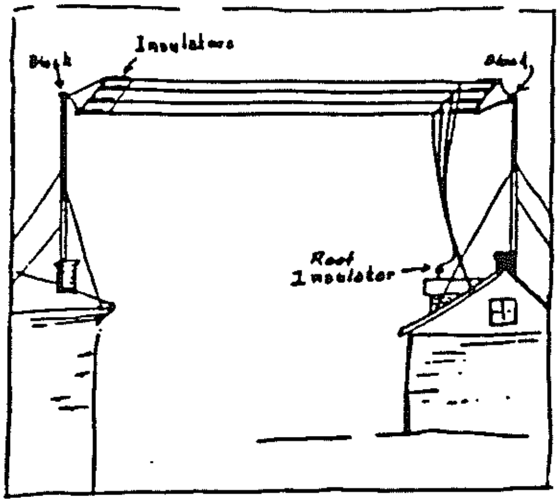


FIGURE 1 AN INVERTED "L" AERIAL

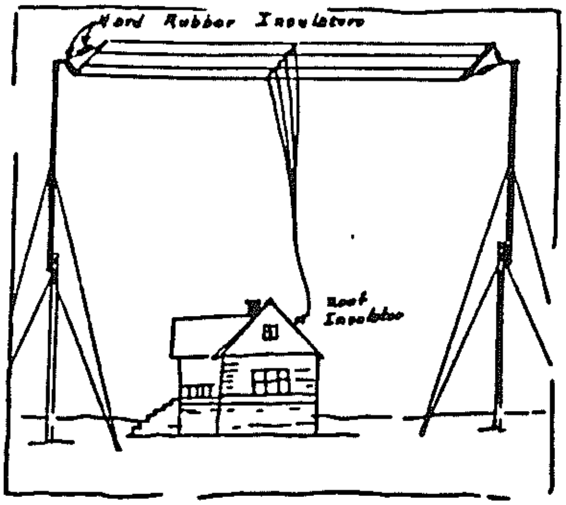


FIGURE 2 A "T" AERIAL

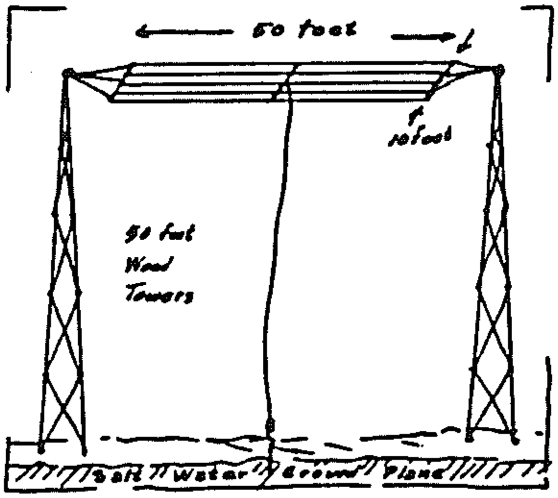


FIGURE 3 BEST

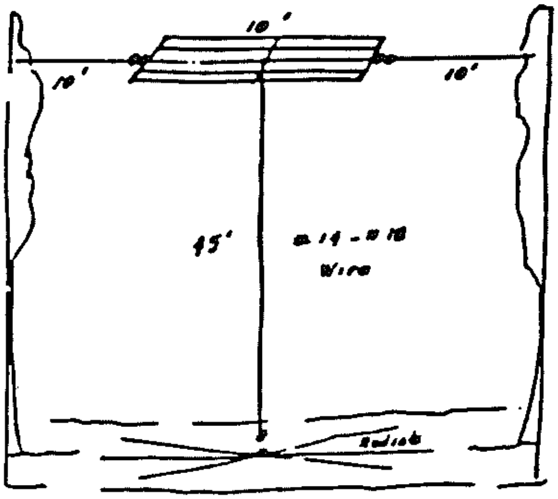


FIGURE 4 FINE IF YOU HAVE THE TREES

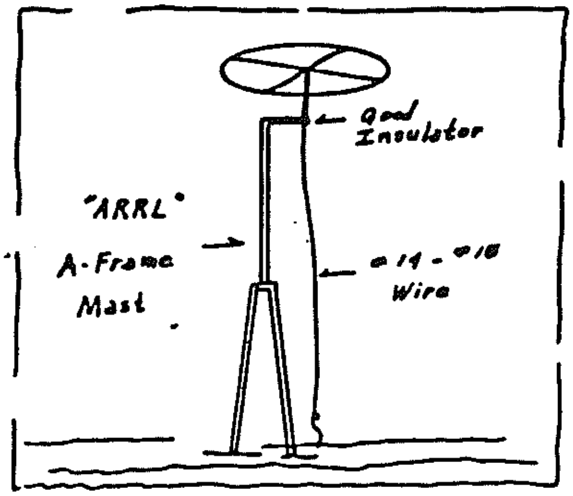


FIGURE 5 "ARRL" A-FRAME MAST AND "HOOP"

is only 0.0312 ohms. This is only a very tiny fraction of the minimum total resistance with which the antenna system can be built, and shows the importance of keeping the losses as low as possible. As and example of what this means, if the antenna current is 0.2 amperes, a typical value for a one watt transmitter and fairly low loss antenna system (sum of ground and loading oil resistance equal to 25 ohms), the radiated power will be only about 1/800 watt, and the efficiency will be only 1/8 percent!

For a straight vertical radiator whose length is a small fraction of a wavelength (the wavelength of 175 KHz signal is 620. feet) the antenna current decreases linearly to zero at the top. If capacitance is added at the top, the current there is increased. If the current at the top is equal to the current at the base the radiation resistance will be four times that of an loaded antenna. For the example given above this would mean an increase in radiation resistance to (5 whole milliwatts!), and the efficiency would be 1/2 percent. The effective range of the station would be doubled. Now that I have discussed the merits of top loading I must point out that in all probability you will not be able to use very much of it. I have no idea how the FCC would feel about antenna installations like those in the examples above, particularly if the height of the height of the vertical section is the magic 15 meters, but it is doubtful that they would be very happy. If we fudge the 15 meters to 50 feet, which was in the old regulations before the FCC :went metric" a literal interpretation would say that a single vertical conductor 50 feet long is all that is legal, and if the matter ever came to an argument I am sure that is what the ruling would be. (The best way to win such an argument is to avoid it: Keep your signals clean and your out of band radiation to a minimum and you will not bring attention to yourself.)

Two points regarding top loading may be in order First, if we accept the total length of the antenna to be 50 feet, then there is no advantage to reducing the height of the antenna and running part of it horizontally to produce top loading. If you can get 50 feet use it. If not, then make the vertical section as tall as you can and add top loading to bring the total length to 50 feet. An "I" shaped one in this case. Second, in principle the top leading can be made more effective if the antenna loading coil (or part of it) is placed at the top of the antenna. Examples of such tuned to loading circuits for use on 160 meters are given in "The ARRL Antenna Book" , which is recommended reading, particularly in the older editions which may be available in libraries or from long time hams, I believe that the problems in adjusting such loading coils, together with the fact that their losses will probably be excessive, makes such techniques of little or no value for 1750 meters, and I recommend their use only to the advanced experimenter. In the discussion to follow only base tuning will be considered.

Let us now consider some specific antennas. figure 3 shows and antenna similar to the previous examples: it is "best but clearly illegal". A 50 foot vertical wire is to loaded by a flat top of horizontal wires, supported by wooden poles. The whole setup is placed over a salt water ground plane, which served two important purposes. First, a connection to the salt water provides an effective, low resistance ground system. Second, the effect of the salt water is to make the resistance of the ground plane under the antenna very low. This minimizes the losses due to the currents which flow in the ground under the antenna due to capacitive coupling; they are a very important component of the total antenna (as contrasted to the loading coil) loss. More of this later. the only purpose of this example is show what could be done if the FCC restrictions are ever lifted.

Before discussing "how to build an antenna" let's consider "Where to build it?" The environment in which the antenna system is installed is the hardest part of the system to control, but it is of great importance in determining the antenna's overall performance. Because of capacitive coupling from the radiator, RF currents will flow in every object near the antenna, and the presence of electrically lossy material will increase the losses in the antenna circuit. (For all practical purposes only things within a radius equal to the height of the antenna are important loss contributors.) Any buildings or vegetation will have significant electrical loss, and detract from the antenna performance, so the first rule to try to follow is to keep the antenna at least 50 feet from any trees or buildings. This means, of course, that you have to run power and control leads out to the base of the antenna, and they may be inconveniently long.

Even if there are no objects above ground in the vicinity of the antenna, the ground itself can and will provide very significant losses. All of the current which flows in the antenna must return in (or on the surface of) the ground, and most soil is very lossy. For this reason it was common practice in the early days of wireless to locate transmitting stations at salt marshes, and build the antennas over them. In addition, hundreds of conducting cables were laid in or on the ground under the antenna to further reduce the loss, with some installation having literally hundreds of miles of them. These practices are still necessary and are still followed, in spite of the immense cost associated with them. In the case of simple vertical towers the ground system usually consists of "radials", or wires radiating from the base of the antenna in all directions to a distance at least equal to the height of the tower. The radials are usually buried beneath the earth with a special plow, in order to get them out of the way.

In principle there is a clear distinction between radial systems and ground systems. The primary purpose of the radials is to eliminate losses due to currents which are induced in the ground by the electric field of the antenna, and even fairly short radials accomplish this. However, there are still currents flowing in the ground beyond the radials, and a conventional ground is often needed in addition to the radials. If the soil conductivity is poor the radials, together with a few ground rods and a connection to the water pipes, will probably be about the best ground that can be hoped for.

E. A. Laport gives an excellent description of ground systems in his "Radio Antenna Engineering", McGraw Hill, 1952. Section 1.12 discusses VLF ground systems, while section 2.5 describes broadcast antenna ground system design. The latter section is of most interest, since in it he gives data on the performance of a simple vertical radiator with various lengths and numbers of radials. The results may be very crudely summarized by saying that radials of length equal to the antenna height are almost as good as those of infinite length, and that a length of half the antenna height (outside diameter of radial system equal to antenna height) is about 2/3 as effective as very great length. Furthermore, 2 radials are about half as good as a very large number, and 16 radials are within a few percent of being as good as 112. Applying this information to out hypothetical tower installation, we can say that it will be near to ideal in performance if the tower is at least 50 feet away from trees and buildings, and if the ground under it is provided with 4 or more radials whose length is at least 35 feet and preferably 50 feet. Improvements will result from more and longer radials but the increase in performance is probably not worth the extra trouble. The size of the wire used for the radials is not particularly important, so long as it is strong enough to withstand whatever mistreatment it may experience in installation, and even galvanized iron clothesline wire will do in a pinch.

Unfortunately, it will be very hard to find room for this "ideal" antenna installation, and you will probably have to fall back on the advice I gave above. Make the antenna as high as you can, as far away from trees and buildings as you can, put down as many radials as you can find room for, and feel that you have done your best. Your antenna system will certainly work, and the results will probably satisfy you. In this discussion I have omitted one thing which may be of interest to those who really have a lot of space and ambition. The laying of the radials in or under the ground is done mainly to keep them out of the way, and results in an increase in loss because the current must "flow" through the ground to reach them. A better practice, but one which is much more awkward, would be to place the radials above the ground by several feet. I doubt if the difference in performance would be noticeable, but it would be a noble experiment. such installations are called "counterpoises", and were fairly common in the early days of wireless. They might still be of considerable interest to someone who wished to install his antenna on top of a house, where the length of the ground lead would be considerable. The counterpoise would be installed on top of the roof, with as many radiating wires as possible, run out as far as possible. It would probably be OK to run the, over the edge of the roof and down to ground level . I have an idea that such an installation might work very well, since it would place the antenna well out of the way of most trees, and would also be convenient for the use of guy wires.

As an example of an installation which violates most of the rules given above, I will use my own antenna system to show "what not to do". The tower is installed in the only spot my wife would permit, between the "radio room" and the driveway. One wall of our house is only two feet away, and extends up to the 30 foot mare. Two large oak trees grow within less than ten feet of the tower, and numerous camellia bushes are planted near the base. The soil in our neighborhood is shallow, with loose gravel and boulders underneath, and the water table is at least 100 feet down. I have a fairly good ground connection in the form of a number 4 wire running to a recently installed copper water connection to the street. The pipe has a total length of about 200 feet, but there are no radials and I have no space to put them. The total resistance of my antenna system at present is about 65 ohms, although when I first installed the VLF gear and had the oak trees pruned way back I measured something like 25 ohms, and could get about 0.22 amperes antenna current with one watt input to the final. I believe that in this installation the loss due to the trees is dominant, although as a second factor all of the surrounding ground is very dry due to being under houses and driveways. Cliff Walker has a much simpler antenna in the middle of his back yard, with a water pipe ground, and puts out about twice as strong a signal as I do. I think the absence of the big trees is one major difference, and the presence of a watered lawn beneath the radiator may be another.

Now for some specific examples of possible antenna construction. In general, the construction of the radiating section is independent of whether top loading is used, so most of the examples apply with or without it. The simplest and easiest antenna to install is a free standing tower of the type used to support TV antenna arrays or VHF/UHF transmitting and receiving antennas. these towers have the advantage of occupying minimum "floor space" and can be purchased from many manufacturers or distributors. This is a good way to go if you can afford it, but the price is nigh. As an example picked at random from a recent issue of WORLDRADIO NEWS, HILL Radio, 2503 GE Road, Bloomington, IL 61701, offers a Rohn 48 foot "BX" free standing tower for $213.40. You may be able to do a little better or a little worse by shopping around locally, but this is the general price range. Since the only wind loading on the tower will be that of its own structure, you should be able to get by with the very lightest weight of towers and save some money that way. For this expense you get an antenna which can be installed anywhere you can find a few square feet of ground space, and one that will not involve a tangle of guy wires. If your yard is as crowded ad mine this may be the only way you can go.

The tower is a radiator (antenna), not an antenna system. In addition to the surrounding physical environment which was discussed above in "where to install it", the complete antenna system includes the radiator, the base insulator(s), and the base itself. The latter two components are worth discussing. Insulation of the antenna is very important, since losses in the insulator can be a major contributor to overall antenna loss, particularly in wet weather. A shunt loss resistance of a megohm in parallel with your antenna can seriously reduce its efficiency. In the case of a free standing tower the base insulators must carry the full mechanical wind load of the antenna, and their choice must be a compromise between electrical performance and strength. My own antenna is a Hygain HT-18 "High Tower" which originally came with some kind of black "mud" base insulators. When I first got on VLF I discovered that I could not load my antenna at all when the base was wet, or even when the weather was moist. I couldn't measure the shunt loss because it was so high, but I would guess it as less than 100K Ohms. I was lucky enough to find some Mycalex insulators at a local surplus store, and the antenna now is supported by nine of them, each one inch square and two inches high. Since Mycalex is very weak in tension, I added a bolt, which is insulated by an epoxy-glass bushing, to each corner of the base to keep the insulators under compression when the wind blows. Even this insulation degrades in wet weather, and I regularly clean the insulators and spray them with silicone oil lubricant, which helps make the water "bead up" instead of forming a film across the whole insulator.

The choice of base insulators will depend on what you can find, with ceramic and glass being the best choices from the electrical standpoint, but the poorest mechanically. Glass impregnated epoxy is very strong and expensive, while hardwood boiled in paraffin will also serve well, but is subject to deterioration due to moisture, so that it may need replacing from time to time. Regardless of the material from which the insulators are made, you should keep them clean and spray them with silicone lubricant regularly.

Whatever you do do remember that insulating materials tend to be brittle and weak in tension, and that the wind loads at the base of your antenna will be hundreds of pounds. If you can arrange to keep the insulators in compression you will be much safer. The choice of materials is best left to your own ingenuity, but remember that you don't want your antenna to tumble down, wrecking itself and everything in the vicinity! While we are on this subject I must emphasize the importance of following the manufacturer's instructions as to the size and depth of the concrete base which is needed to keep the antenna from overturning in the wind. My tower has a base 3 feet square and 3 feet deep, which is supposed to hold it in a 75 mile per hour wind. That's a yard of Ready Mix, but worth it for the peace of mind it brings.

Most of you probably won't want to go to the expense of a free standing tower, and the inconvenience of providing it with adequate base insulators and guys. The best compromise antenna is probably made from a 40 or 50 foot telescoping antenna mast of the type commonly used to support FM and TV antennas. Radio Shack lists a 36 foot mast for $ 42.95, and the local radio stores seem to have slightly taller ones for about a dollar a foot. this antenna will need plenty of guy wires, but is relatively easy to erect and has the advantage that almost no construction is required other than to provide it with a good base insulator. since this insulator will be in compression it may be made of glass, ceramic, or any other good insulating material. A large glass beverage bottle will serve quite well, though you have to be careful to mount it so it cannot be broken by the sideways motion of the mast during installation or while being blown by the wind. To be sure of electrical continuity, the sections should be electrically connected by soldering wires between them (may be difficult, most mast material "doesn't like to solder"), or using self tapping screws and washers to secure wire Jumpers between sections. The guys may be metallic, and if so should be broken every 10 feet or less with "egg" type strain insulators. Polypropylene and polyethylene rope in quite cheap, and will serve very well when dry. It has the advantage of not requiring insulators.

If you get a mast of less than 50 feet you have many choices of how to use it. First of all, you can use it as is, with some loss in efficiency. If you don't mind taking it down later for imp[improvements this may be your best choice, since you can get on the air sooner. Second, you can extend it to 50 feet with the 5 and 10 foot mast sections which can be had where you get the mast. This should be pretty easy to do. Third, you can top load it, either at its existing height or with a combination of extension mast and top loading. this is where the interpretation of the FCC rules is fuzzy, since they leave no way to figure what the "length" of a top loading device is. For example, suppose you load a 40 foot tower with a solid disk 10 feet in diameter. Is the "total length" 40 feet plus 10 feet? Is it 40 feet plus 5 feet, the maximum distance from the base to the furthermost extremity of the antenna? I have no idea, and don't advise an inquiry. I would feel free with my conscience if I used the last definition, which would allow a total height of 45 feet with a 10 foot top loading disk, and a total height of 40 feet with a 20 foot one. The latter would be a stinker to build, and would flap in the breeze unless it were guyed well. In practice a solid disc, unless it is made of screen chicken wire supported with some sort of frame, is impractical and the use of a round "hoop" of wire or tubing supported with cross pieces fastened to the top of the mast, is most convenient. The ARRL Antenna Handbook has several illustrations on the construction of top loading sections. In spite of my remarks that the antenna should be 50 feet high if possible, I feel anyone will be satisfied with the performance of a 40 foot mast with an 8 to 12 foot loading hoop at the top of it.

If you are willing to spend more construction time in order to save some money, you can make your own mast using the 1-1/4" 5 and 10 foot TV mast extensions mentioned above. They cost less than half as much as the telescoping masts, but will require more guys to make them secure, but will require more guys to make them secure, and should be reinforced with a wooden rod at each joint. The suggestions on base insulator, electrical continuity, and guys which were given for the telescoping mast should be followed here too. This mast will be pretty "rickety" so plan enough guys, and get enough help so you can handle the emergency situations which are almost certain to develop. Good luck!

If you are fortunate enough to have some big trees in you yard with reasonable spacing between them, you can save even more money be using the construction of Figure 4. Pick two spots about 45 or 50 feet above the ground, and provide them with pulleys and halyards. A top loading structure consisting of several wires held apart with 10 foot spreaders is isolated with insulators, following the same procedure as described above for the guys for the mast. Don't forget that it will be mighty hard to clean the insulators once they are installed, and use good ones to start with. The vertical radiator is a wire descending from the center of the loading section to the ground, where it is anchored with and insulator. This will be a very effective antenna if the trees are at least 50 feet or so apart, and will still work if they are much closer together. A variant of this theme would be to use a single tree with a slanting top loading section, and the halyards brought down to some convenient lower level such as the corner of a house or garage. Remember that trees and antennas like to move around when the wind blows, and leave enough slack to allow for the motion, or else use a spring or pulley and weight to keep the lines reasonably tight.

If all else fails you can always make your own "tree" following the design for an "A-frame Mast" which was found in all of the ARRL "The Radio Amateur's Hand book" and ARRL Antenna Handbook editions before 1980. (For some mysterious reason the A-frame design is omitted from the new handbooks, even though it has been "the old standby" for generations of hams!) you will need about 60 feet of 2" by 2"s, which even in these days of sky high lumber prices may still be an attractive way to go, and you will need guys and space to install them. If you want a single mast design I suggest that shown in figure 5. The top of the mast is equipped with a bracket and insulator(s) to hold the top loading hoop, and the radiator is a wire descending to the ground at the base. The same precaution with respect to the top insulator applies as in the previous example, and the guys should be as in the previous example, and the guys should be broken with insulators as described for the metallic mast.

With any of these alternate antenna systems the use of a good ground and radials is just as important as it is with the free-standing tower described first, and their design and installation should be considered in planning you antenna.

I have not tried to discuss all possible methods of antenna construction, but just to give some pointers you can use in planning your own version. If you are lucky enough to have space for a 50 foot tower with lots of radials, mounted over good moist ground, you are going to have a really king sized signal. If you can't meet all of these requirements, follow the suggestion in the
beginning: put up the tallest structure you can, as far away from trees as you can, with the best ground you can scrape together, and with radials if possible. You can't fail to put out a usable signal!

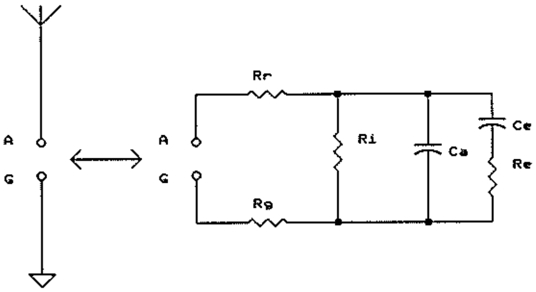
COUPLING THE VLF ANTENNA TO THE TRANSMITTER

By Ed Phillips W61ZJ

The previous section (Vol 7 7 page 10) discussed transmitting antenna systm design, construction and preferred installation sites. Efficient means of tuning the antenna and for coupling it to the VLF transmitter will be considered here, since they have a very strong influence on the success of the transmitting station. The subject will be introduced by examining the electrical parameters of the antenna, to give a feel for the sizing of the tuning components and of the impedance to be coupled.

Figure 1 is a simplified view of the electrical properties of a typical 50 foot antenna at an operating frequency of 175 KHz. If the antenna were mounted

Figure 1: VLF Antenna circuit elements

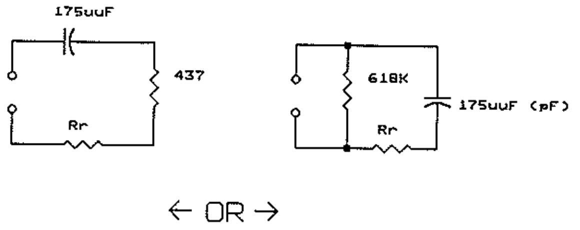


TYPICAL VALUES FOR 50 FOOT ANTENNA;

Rg - 10 ohms to 50 ohms
Ca - 150 mmfd
Ri - 1 megohm to 2 megohms
Ce - 25 uufd (Depends on surrounding trees),
Re - 500 ohms- buildings, etc.
Rr - .031 ohms - useful radiation resistance

Figure 1 is a simplified view of the electrical properties of a typical 50 foot antenna at an operating frequency of 175 KHz. If the antenna were mounted over a perfectly conducting ground plane, and on perfect insulators, its input impedance would consist of the radiation resistance R(R) in series with the capacitance C(A). As discussed before, the radiation resistance is a fictitious resistance which, when multiplied by the square of the RF current flowing into the antenna terminals, gives the value of the radiated power. In this example it is only about 0.031 ohms! The capacitance of the 150 mmfd (pf) would represent a typical telescoping TV mast, mounted well away from any conducting structures. The effect of the non-ideal installation may be seen from the other circuit elements in figure 1. First, the ground system will have a resistance (R(G)) which appears directly in series with the radiation resistance and the antenna capacitance, with typical values from 10 ohms to 50 ohms, depending on the type and moisture content of the soil, and the size of the ground rods or radial system used. This resistance represents a loss, and a very serious one. Note that even if the resistance can be held to 10 ohms it is still almost 300 times the radiation resistance, and that the maximum efficiency of such an antenna could be only 0.3 percent. In addition to the ground circuit loss, there will be additional losses due to any capacitance between the antenna and surrounding lossy materials such as trees and buildings. these are represented by a capacitance C(E) in series with a loss resistance R(E), and the values shown are only a very rough guess based on my own observations. Their effect is to increase the capacitance of the antenna and to introduce additional loss. A final loss which must be included is the shunt loss resistance of the base insulators, and my experience indicates that a value of one or two megohms is typical for good insulators, while a value of perhaps 100 K ohms is representative of bad ones.

When all of these losses and spurious capacitance's are summed up, the antenna can be represented by the series equivalent circuit shown in Figure 2.



Values for Rg = 20 ohms, Ri - 2 megohms, Re = 500 ohms

FIGURE 2

EQUIVALENT CIRCUIT OF ANTENNA AT 175 KHz

A ground resistance of 20 ohms, in insulator resistance of 2 megohms, and the values of C(E) and R(E) from Figure 1 were used to calculate the values shown; these values represent a pretty good installation. The equivalent capacitance is 175 mmfd, and the total series resistance is 43.7 ohms. another way of representing the antenna is by the shunt equivalent circuit which is also shown. Examination of these circuits will show that the effects of ground resistance, insulator resistance, and loss due to trees or buildings are roughly equal. In order to increase the station efficiency all must be minimized, and even when everything possible has been done this efficiency won't be very high! For this example it is the ratio of the 0.031 ohm radiation resistance to the 43.7 ohm series loss resistance, or only 0.07 percent. Don't get discouraged at this point; for my own station the total loss resistance is about 65 ohms, and the efficiency is only about 0.05 percent, but I still get out pretty well!

So far we have discussed a hypothetical antenna system. What will the parameters of yours be? Un fortunately there is no practical way of predicting the losses, and you will just have to do your best to minimize them by following the practices outlined in the transmitting antenna section. It is, however, possible to estimate the capacitance of the antenna, and to predict the radiation resistance pretty accurately. The estimation of antenna capacitance is necessary in order to plan the design of the antenna coupling circuit, and the calculation of radiation resistance is an exercise in futility, so formulas for calculating them are given below.

Calculation of the exact capacitance of a short vertical antenna, even for the ideal conditions where it is located over perfectly conducting ground, and where it is completely isolated from and other conductors which might have mutual capacitance to it, is difficult and no simple formula exists. A rough approximation for this capacitance, and one that is often quoted is the following (I have changed it to common units):

$$C = 7.359H/(\mathrm{Log}(24H/D) - 0.43)$$

Where:

C is the capacitance in mmfd (pf)
Log is the logarithm to the base 10
H is the height in feet,
D is the average diameter in inches.

I have calculated the value of capacitance for several possible types of antenna conductors, and for the entire range of heights which might be of interest. the following Table gives these estimated capacitance's for the various combination of antenna height and antenna diameter I considered. Note that these values are very approximate, and strongly dependent on the surroundings, including effects of nearby trees, buildings, power lines, and other conductors. In general, actual values will be slightly larger due to these effects.

CAPACITANCE IN MMFD FOR
ANTENNA HEIGHT IN FEET OF:

ANTENNA DIAMETER (INCHES)	10	20	30	40	50
0.064 (#14 wire)	23.4	42.7	61.0	78.6	95.7
0.102 (#10 wire)	25.0	45.4	64.6	83.1	101.0
1.00	37.7	65.4	91.0	115.3	138.9
1.25	39.7	68.3	94.7	119.9	144.2
1.625	42.3	72.1	99.6	125.7	150.9
3.00	50.0	83.0	113.2	141.8	169.4
5.00	58.8	94.8	127.7	158.8	188.7

The diameter of 1.25 inches is typical of common 10 foot TV mast extensions, while the diameter of 1.625 inches is typical of the average diameter of 1.625 inches is typical of the average diameter of a telescoping type TV antenna mast of 40 or 50 foot height. The diameter of 5 inches is typical of the smaller self-supporting towers.

The capacitance of a top loading device is even harder to estimate. Figures in the ARRL Antenna Handbook show that for a solid disk, the capacitance is given by the following approximation:

$$C\,(\mathrm{TOP}) = 10\,D \text{ mmfd}$$

Where D is the diameter of the disk, measured in feet.
A more convenient way to make the top loading device is as a hoop with crossbars to support it, and the capacitance will probably be pretty close to that for the solid disk, particularly if several additional "spokes", even of pretty small wire, are added.

The radiation resistance may be calculated by this formula:

$$R(E) = 0.03124\,(F/175)^2\,(H/50)^2 \text{ OHMS}$$

Where F is the operating frequency in KHz and H is the height in feet. This value is correct for an antenna without capacitive loading at the top. For an antenna with top loading the radiation resistance is increased by the factor,

$$(1 + I(\mathrm{TOP})/I(\mathrm{BASE}))$$

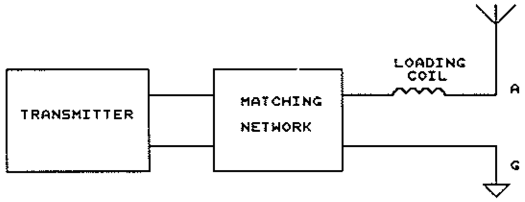
Where I (TOP) is the current flowing at the top of the antenna and I (BASE) is the current flowing in the base. A very crude estimate of this current ratio may be calculated from,

$$\text{I (TOP)/I BASE)} = \text{C(TOP)/C (BASE)}$$

Where C(TOP) is the top loading capacitance, and C(BASE) is the sum of the antenna capacitance and the top loading capacitance. This last formula will give optimistic results, since the formula for C(TOP) includes the effect of capacitance to the antenna beneath it, but it does show that even modest amounts of top loading will do some good. For example, if an 8 mmfd is used, the radiation resistance of the example antenna will be increased from 0.03 ohms to about 0.056 ohms, and the radiated power will go up by 80 percent. This is not an enormous change, but it will increase the station range by 40 percent and is certainly worth the effort involved.

To summarize all of this, a typical antenna will look like a capacitance of about 150 mmfd to 200 mmfd in series with a resistance of perhaps 10 ohms minimum to over a hundred ohms maximum. Almost all of this resistance is due to losses; the useful (radiation) resistance is only about 30 milliohms, or an insignificant fraction of the total. The job of the tuning and coupling circuits is to transfer as much as possible of the transmitter output power to the antenna, in order to maximize the current which will actually flow in the radiation resistance and thereby end up being transmitted to the world. If the transmitter is assumed to be 100 percent efficient, which isn't too optimistic, and if the output power is assumed to be coupled to the antenna with 100 percent efficiency, which unfortunately is pretty optimistic, then all of the power will be dissipated in the antenna losses. For the sample antenna with series loss of 43.7 ohms, one watt of transmitter power would result in an antenna current of 0.151 amperes, and the radiated power which is resonated with a series loading inductor, and a matching network is used to couple the resulting impedance (of the loading coil and antenna in series) to the transmitter. For our sample antenna parameters if the loading coil were lossless the net impedance would be the series resistance of 43.7 ohms, one Watt of transmitter power would result in an antenna current of .151 Amperes, and the radiated power would be about .71 milliWatts, for an overall efficiency of only .071 percent!! The reactance of the 175 mmfd is about 5200 Ohms, so that for this current the Voltage drop across it will be about 787 Volts. If the antenna were to be connected directly to the transmitter output, this would need to be the RMS Voltage across its tank circuit, and the DC supply Voltage to the final power amplifier would have to be over 100 Volts. Such a transmitter can actualy be built with TV sweep tubes, but most experimenters would prefer to go all solid state, so some form of matching circuit is needed between the antenna and the transmitter.

Figure 3 shows one way of coupling a short antenna to the transmitter. It is typical of the circuits used with a 160 Meter amateur vertical antenna, or with a mobile antenna for any of the HF Ham bands. The capacitance of the antenna is resonated with a series loading Inductor, and a matching network is used to couple the rusulting Impedance (of the loading coil and antenna in series) to the transmitter. For our sample antenna parameters if the loading coil were lossless the net Impedance would be the series resistance of 43.7 Ohms.



Example: For 175 mmfd antenna capacitance L = 4726 mh at 175 KHz operating frequency.

FIGURE 3

ONE WAY TO COUPLE ANTENNA AND TRANSMITTER

If the transmitter operated from a 15 volt DC supply voltage the RMS voltage across its tank circuit would be about 10 volts, and the required load resistance would be 100 ohms for an output power of 1 watt. The matching network would thus need to have an Impedance ratio of about .3 to 1. While this is a perfectly practical coupling technique, it has two undesirable properties. First, the components in he matching network may be quite lossy, though for cases where the required transmitter load resistance is greater than the antenna circuit resistance the antenna could simply be tap down on the tank coil, eliminating the matching network. Second, the selectivity, or ability to reject harmonic radiation, is quite poor. This will increase the possibility of harmonic interference with broadcast band receivers, and undesired attention form the FCC.

One thing which is a function of the antenna parameters alone is worth mentioning at this point. the antenna loading coil will not be lossless. If it has the rather good "Q" (ratio of reactance to series loss resistance) of 250 the effect of its loss will be to add an additional series loss resistance of about 20.8 ohms to the 43.7 ohms of the basic antenna for a total of 64.5 ohms. This means that the maximum antenna current for 1 watt transmitter power input can be only 0.125 amperes, the radiated power will be 0.48 milliwatts, and the efficiency will be only 0.048 percent! This is about the case with my own antenna, which has a measured loss resistance of about 65 ohms. The design and construction of loading coils will be described later. The only way to reduce the loading coil loss is to make its "Q" as high as possible through using a large diameter and winding it with the largest wire you can afford. By increasing the antenna capacitance through use of top loading coil, will be reduced so that for a given Q the actual series loss resistance will be reduced. this is a substantial added benefit of top loading.

Figure 4 shows an easier way to couple the antenna to the transmitter, and one I strongly recommend. You will find numerous examples of it in Ken Cornell's VLF Scrapbook. The loading coil is connected between the antenna and ground, and is inductively coupled to the transmitter by mutual inductance between it and the tank circuit, as shown pictorially. the advantage of this coupling technique, compared to the previous one is that transmitter loading (the load resistance coupled into the transmitter tank circuit) may be varied by changing the distance between the tank circuit and the loading coil, which should now be called the coupling coil. Large spacing results in "loose" coupling or light transmitter loading, while closer spacing increases the coupling and the transmitter power input. The transmitter may be run at any supply voltage where it is efficient and the power output (and hence the input) may be set to the desired value by simply adjusting the coupling.

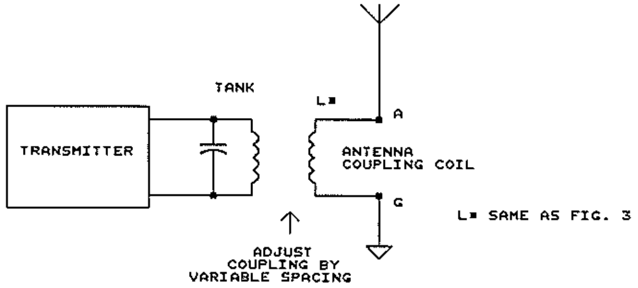
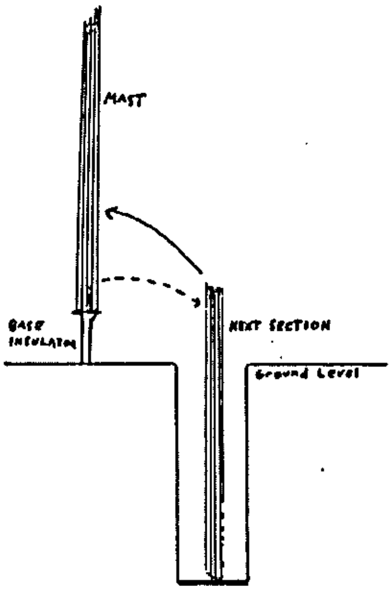


FIGURE 4 AN EASIER WAY TO COUPLE ANTENNA

This transmitter may be a transistorized one working with six volts collector supply or it may use tubes and run at 300 volts plate supply, and the loading coil will be the same. "Only the coupling need be changed." While the major attraction for this coupling method is its simplicity, it also provides better harmonic signal reduction than the first one, and at no added cost.

This discussion is directed toward the design and construction of coupling circuits, and their adjustment will be described later. However, a few additional comments on coupling circuits are in order here. most solid state transmitters will have a rather low loaded tank circuit "Q" (the load resistance for proper power output will not be very much greater than the reactance of the tank circuit tuning capacitor) and some readjustment of antenna tuning will be required as the coupling is varied. to be specific, if the antenna is tuned to resonance with very light coupling, as the coupling is increased it will be necessary to increase the loading coil inductance in order to keep the tuning at the point of maximum power output. Consequently, the complete antenna coupling circuit must include some provision for adjusting this tuning, and will not be quite as simple as I have shown. As an alternative to varying the inductance of the coupling coil I have found it convenient to adjust the antenna tuning by connecting a variable capacitor across either the whole coil or part of it. While such a tuning method increases the loss somewhat, it is much easier than building a coupling coil with variable inductance, at least in my opinion. I have recently had the opportunity to test some tank circuits built by Ken Cornell and by Jack Althouse of Palomar Engineers. Both used a variable tuning core for inductance adjustment and had very low loss, but the adjustment of tuning required very delicate variation of the position of the slug, and I think the beginner will have an easier time if he follows my suggestion.



ANOTHER USE FOR POSTHOLES

Solo or shot-handed erection of sectional masts can be greatly simplified by digging a posthole alongside the antenna base. The hole should be deep enough to contain all but a foot or two of the mast sections you are using it should have something solid at the bottom to prevent clogging the mast sections with dirt. A lining of 4" plastic sewer pipe will make the hole per manent, preventing cave-ins. beginning by erecting 15 feet or so of mast in the normal fashion. Mount the loosely guyed mast on the base insulator, put the next section in the hole. Then lift the mast from base insulator to the top of the new section. Loosen the guys a bit more and lift the extended mast back to the base insulator. Repeat the process until full height is achieved. The higher you go the harder (and slower!) it gets. 40 feet is about the limit for solo work with 5" sections.

SITE FACTORS AFFECTING PERFORMANCE OF 1750 METER TRANSMITTING VERTICALS

by

Michael Mideke

Over the years I've attempted to radiate LF signals from a number of sites. The most important lesson learned from a number of fairly serious installations has been the virtue of putting the antenna in the clear.

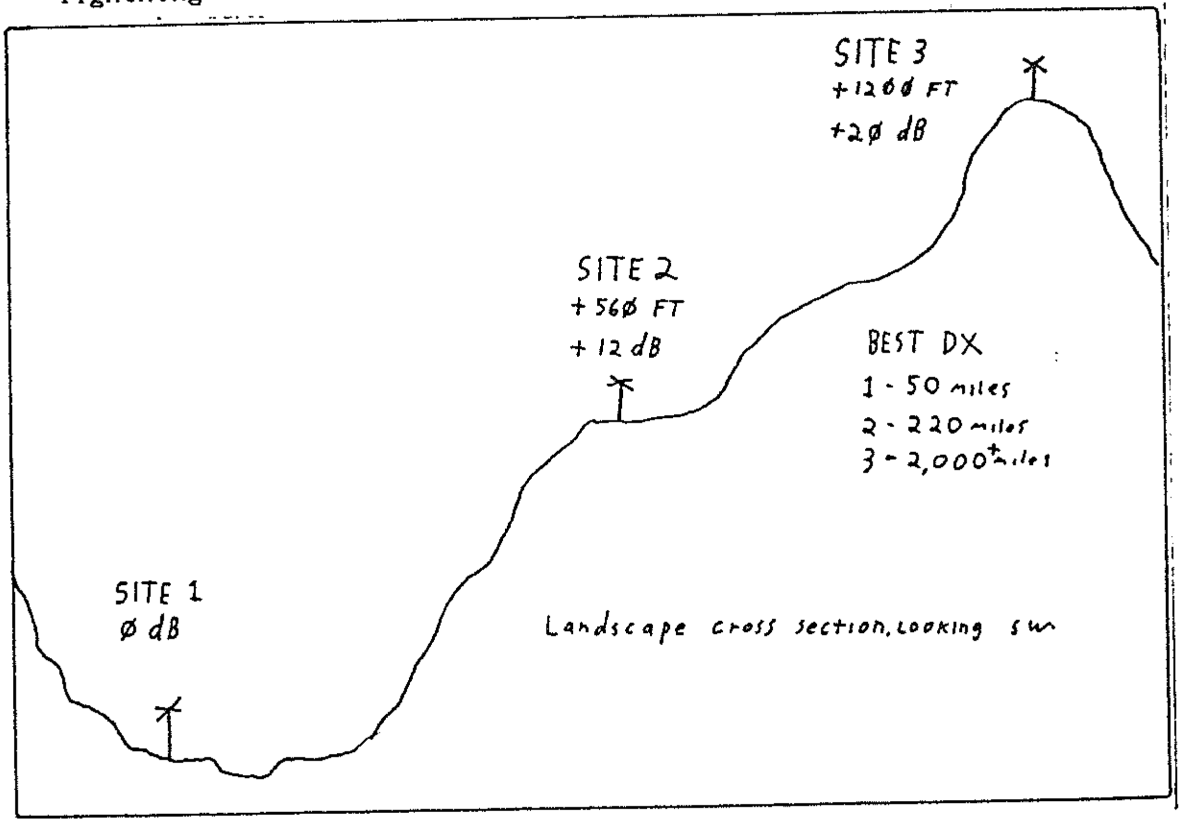
The accompanying drawing illustrates 3 real installations, each consisting of a 32 to 36 foot vertical with substantial capacity tophat and identical current in the antenna base. The relative signal levels are for groundwave at distances from 25 to 220 miles. Site 1 has never been heard beyond about 50 miles. Only Site 3 has generated a verifiable skywave signal, though it seems likely that Site 2 has skywave potential. Site 1 is wooded, Site 2 mostly brushy with scattered oak and pine trees. Site 3 is surrounded by brush ranging in height from 2 to 8 feet. However, except for a narrow ridge rising to the West, the ground drops away very steeply from Site 3, leaving the antenna essentially in the clear.

This suggests two main points:

1 - Given 1 watt input efficiently utilized, the EFFECTIVENESS of that power can vary by a factor of at least 100, depending almost entirily upon where the antenna is situated.

2 - Antennas in the clear have an overwhelming advantage over antennas that are obstructed.

Not much seems to have been done with high level LF transmitting sites. In view of the potential performance, such sites seem well worth considering. There are drawbacks also worth considering: effective ground systems don't come easily on rocky peaks, remote control becomes almost essential and lightning hazards are increased in high, exposed places.



TRANSMITTING GROUNDS FOR 1750 METERS

by

Michael Mideke

The following material is drawn from early issues of the WESTERN UPDATE and from numerous unpublished notes.

The explanations that begin this section probably leave much to be desired from an engineering standpoint but they should at least point fairly clearly to the kind of situations which must be addressed by ground systems to be used with radiators that are electrically very short.

Ground systems for electrically short radiators need to accomplish two things: they must establish a low-resistance connection with the earth and they must screen the intense electrical field from the lossy ground surface in the immediate vicinity of the antenna.

Short verticals are electrically lengthened by inductive loading to behave in many respects as if they were a full 1/4 wave long. In effect, the radiating element is made to look like half of a 1/2 wave dipole; the ground system provides the other half.

In a dipole, equal current flows in either half. In the case of the dipole formed by our short radiator and its ground system, the resistance of the ground half is invariably higher than that of radiating half. The current that flows in the antenna is limited by the higher resistance. So the more the ground resistance can be reduced the more nearly the antenna system will approximate a vertical dipole and the more efficiently it will perform as a radiator.

A simple ground system consisting of a ground rod or two and perhaps some connection to local plumbing may be more or less satisfactory at high frequencies but on LF it is of dubious value. Ground resistance may be 100 ohms or more, and it is clearly desirable to improve the situation. If ground resistance cannot be brought to a low value, there are real limits as to how far it is worthwhile to go in reducing the resistance of other parts of the system.....1" Litz wire and a gold plated antenna will be a waste of effort if the ground is no good.

PRACTICAL GROUND SYSTEMS -

Several measures may be undertaken to reduce ground resistance. What approach or combination of approaches will be most valuable or practical will depend on site, available resources and the ambition of whoever has to do the work.

THE OPPORTUNISTIC APPROACH is to run a 'radial' to every grounded [or just massive] metal object within reach - plumbing, fences....buried metal of all sorts. Each wire should lead to only one earth connection and all wires should be brought to a central point near the base of the antenna. Assuming enough metal can be found, this process can continue until further additions produce no measurable change in antenna current or tuning. Wherever possible, connections should be soldered. Otherwise, use brass, copper or stainless steel clamps and connectors. Avoid aluminum and iron. If you need to make connection with a rusty (or rustable) iron pipe, an oxy-acetylene welding torch can be used either to bond heavy copper wire directly or to braze on bronze connecting hardware.

Where connections must be strictly mechanical, try to make them accessable for future cleaning and polishing.

When adding opportunistic grounds, it is a good idea to monitor both transmitter performance and signal level. (Best if signal is monitored from a few wavelengths away.) Some grounds or combinations of grounds turn out to be counterproductive; more is not always better. As grounds are added, antenna current SHOULD increase while loading inductance and/or capacitive trimming should decrease.

RADIAL GROUNDS - A more formal approach to the ground system is to construct a mat of radial wires centered under the vertical. Where, as is the case with Lowfers and most NDBs, the antenna is very short in terms of operating wavelength; it appears there is little advantage in using long radials (on the order of 1/4 wavelength). This is especially true if the operator is unwilling to install at least 100 such radials! In practice, radials 20% to 50% longer than the vertical itself will work very well. If one has a mile of wire to invest in radials, it will probably be better to cut it into many 35 to 70 foot sections than to use it all for three or four very long radials.

Obstructions such as buildings, trees and property boundaries can render the realization of a symmetrical radial mat impossible. In these situations one must just concentrate on doing what is practical. Make radials long where you can and try to spread their ends apart so that distribution is more or less even within the constraints of the location.

It is better to have radials on the surface than buried and better to have them above the surface than lying on the ground. If radials are buried or in contact with the surface, they should be insulated; otherwise contact with the lossy surface or immediate sub-surface will lead to unnecessary losses and exagerate the de-tuning that results from varying soil moisture conditions.

It is often totally impractical to elevate the radial system. Sometimes radials are buried just to get them out of the way. A practical alternative to burial is to "staple" radials to the ground. Just make a bunch of 'U's of heavy (10ga to 12ga) solid wire, an inch or less wide and 2 to 4 inches long and use them to pin the radials down every few feet. This will permit lawn mowing and un-tripped foot traffic while minimizing maintainence.

RADIAL WIRE SIZE - If we view all of the radials as parallel conductors each carrying a roughly equal share of the RF current,it would appear that once there are a dozen or more radials the resistive losses in the radial system become quite small. Any wire that is heavy enough to be durable will be plenty big enough to handle the current.

However, it won't hurt a bit if you DO use massive radials. Early in 1987, Lowfer Jerry Parker (OWR) hoisted a modestly tophatted wire vertical above a groundplane that consisted of 109 pieces of CATV hardline. The lengths of hardline varied from 250 to 400 feet! This installation was an outstanding success. Would results have been as good had the radials been shorter or made of something like #22 hookup wire.

There is no virtue at all in having radials that are either not connected or are poorly connected. Again, SOLDER WHEREVER POSSIBLE and take special care with purely mechanical connections.

CHICKENWIRE - Wire mesh reallly works. In a portable installation I had a tophatted wire vertical which initially was suspended over 12 thirty foot radials. There were four short ground rods and a couple of connections to plumbing and fencing. At 1 Watt input the antenna current was a discouraging 60 ma. When 60 sq. ft. of mesh was placed directly beneath the antenna and connected to the ground system, antenna current doubled and loading inductance was reduced to a coresponding degree. An additional 160 sq. ft. of assorted mesh material produced only minor improvements.

In a subsequent installation at another site, a more refined approach was taken. An 8' x 20' wooden framework was constructed from planks and 2x4s. 160 sq.ft. of 1" mesh was attached to the upper side of the framework and flooring was nailed over the screen to provide workspace and a platform for the transmitter, battery, etc. Radials (some with ground terminations), were extended from the edges of the screen rectangle. No earth connection was made immediately under the antenna. This arrangement has proven quite satisfactory. In comparison to a conventional radial mat laid on the surface, this system seems to be relatively immune to tuning changes caused by variations in soil moisture.

CHICKENWIRE ON THE ROOF - Sometimes roof mounting offers the best way to get an antenna into the clear. And sometimes the roof is the only available antenna site... Chickenwire mesh can be used to advantage here - either on top of the roof, tacked to rafters immediately underneath or simply laid out on the ceiling joists. Elevated radials or downleads tosurface radials and ground rods can be run from sides and corners of the building.

RADIAL TERMINATIONS - It is probably more helpful to provide numerous ground rod terminations for radials than to attempt a massive earth connection directly under the antenna. A case in point is the transmitter installation at Z2. The initial configuration consisted of around 120 thirty to sixty foot radials and a central ground consisting of copper pipe penetrating about 12 feet in a treated pit. Later, another 20 radials 40 to 70 feet long were added. These radials were each terminated with a treated copper pipe ground. This change resulted in a substantial increase in antenna current. Furthermore, the central ground no longer drew measurable current or made any other apparent difference to antenna system performance. I believe the ideal objective here is to make the effective diameter of the earth connection about the same as that of the radial mat.

DIMINISHING RETURNS - One of the sad facts about ground improvement is that the more you do the less return you get for each hour of labor. The first 3 or 4 radials or ground rods produce immediate and impressive results. The next few will produce measurable but less impressive results. After that you have to really work to see that anything at all is being accomplished. A rough but practical rule of thumb for this sort of work says that, for a useful result, it is necessary to at least double the number of elements already in place. If you have a dozen radials down, adding one or two more is not likely to show a measurable improvement (if it does, stop right there and figure out what was wrong with all the OTHER radials!) but the addition of another dozen should have some positive effect. The next step calls for a minimum of 24 more. How much is enough? My own feeling is that if a person manages to put out 30 to 60 radials and 10 to 15 ground rods, he has earned his rest. Its time to sit back for a few months, see how it works and seriously consider just what the next level of improvement is really worth.

GROUND RODS - Beware of the cheap "copperclad" rods intended for use with TV receiving antennas and the like. Not only are they rather short, the thin copper layer is more like paint than plating. What doesn't scrape off when the rod is driven will vanish in a few months and you will be left with nothing but rusty iron in the ground. Use heavy duty copperclad ground rods, 8 feet long if you can possibly get them that deep. Or use copper pipe. Even the thin 1/2"material can be worked down to considerable depths if one is patient.

PLACING GROUND RODS - I've found a posthole digger to be most helpful in placing ground rods. Using the posthole digger and a tamping bar, dig out a 6" to 10" diameter hole as deep as you can conveniently make it. 2 1/2 to 3 feet is usually fairly easy. Then place your ground rod in the center of the hole and drive it in as far as you can. With the right soil and a bit of luck you can get the top of the rod all the way to the bottom of the hole. While you can still reach the top of the rod, securely solder a length of #14 or heavier copper wire to it so that you will have something on the surface to make connections with. Best to do the soldering after the pounding is all over. This is propane torch work; soldering irons won't hack the job. Sandpaper all surfaces, tin the rod if you haven't already done so, take several snug turns of wire around the rod and flow solder over the whole thing.

TREATED GROUNDS - A further bonus of the posthole technique is that it leaves you all set to make a treated ground. Once the ground rod has been driven as deeply into the hole as it is going to go, the hole can be refilled with a mixture of dirt and rocksalt or copper sulphate. (The salt blocks sold for livestock consumption are inexpensive and can be broken up to provide slow-disolving hunks.)

As the crystals dissolve in rain or irrigation water, a conductive solution begins to spread through the hole, extending both deeper and outward. This increases the effective volume of the earth connection, reducing the resistance of that connection. If aesthetics and safety permit, don't completely fill in the postholes. Shallow depressions left in the surface will gather rainwater and focus it on the soil (and rod) underneath.

The treated hole technique can be further elaborated by digging a bigger hole. Make a pit that is large enough to climb into. Take care that you are not digging into material that can collapse around you, and go down 6 or 8 feet. Drive one or more rods into the bottom of the pit. Then line the pit with chickenwire to provide a nice conductive armature to support about a 2" thickness of clay. The clay work can be done in stages of a foot or so. Fill in each level with soil and chemicals as it is lined. This procedure is a LOT of work but it does result in a large diameter, deep treated ground. The clay limits dispersion of the conductive solution. There is no need to buy expensive potters' clay. Find a claybank and dig out what you need. Discard large rocks and ignore the small ones.

All treated grounds will tend to improve over time, especially if provision is made to renew their treatment every year or two.

HAZARDS - Both copper sulphate (which is marketed as root killer for septic systems) and rocksalt can be destructive to plant life. Massive injections of chemicals into the ground should not be performed without due consideration for potential damage to vegetation or groundwater contamination. While copper sulphate is supposed to be most effective in increasing conductivity, salt is nearly as good and consequences of contamination may be less serious. Diminishing returns apply in this area as well - there are real advantages to enhancing conductivity immediately around your ground rods but going on to saturate the neighborhood won't make all that much difference to your signal.

TAKE ADVANTAGE OF CIRCUMSTANCES - Whenever there is construction or an excavation around the place, make sure you have some copper at the bottom before the hole gets filled in. Do good soldering and build for permanence; you never want to see the bottom of that hole again!

POSTSCRIPT ON GROUND SYSTEMS

The reader will note that the expositions of ground systems found in this volume are somewhat at odds with treatments of the subject in HF and Broadcast Band literature. This is not entirely due to the myths of Lowferdom- The real point is that our antennas are VERY short, E-field generating devices which are plagued with different kinds of losses than those incurred by more current oriented radiators.

LOW POWER ANTENNA
CURRENT & POWER METER

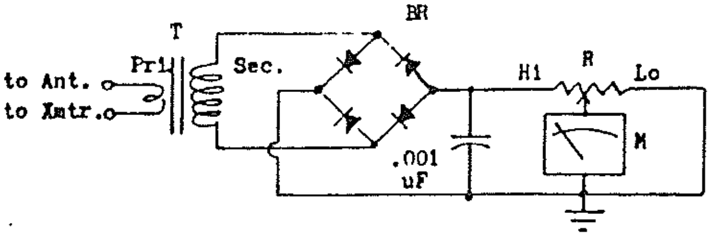
Dave Johnston, 9HDQ

This meter is a relative indication device sensitive enough to measure the antenna current generated by a CMOS chip.

Calibrate it for Power by using a non-inductive load resistor and measuring the load voltage with a 'scope or RF voltmeter.

$$P \text{ (watts)} = E^2/R \text{ (Ohms)}$$

Set full-scale deflection sensitivity with potentiometer R.



T - - T50-6 (substitution OK).
Pri.- 10t #24 (Ant/Xmtr may be interchanged).
Sec.- 20t #24 (May be increased for greater sensitivity).

BR - bridge rectifier, use four 1N914 or equiv.

R - - 5 k Ohms pot.

M - - 50 uA full-scale meter. A less sensitive meter will require more secondary turns in T.

SO239 receptacles can be used at input.

Technical Tips

Litz Wire

The word "Litz" is derived from the German word "Litzendraht" and refers to wire consisting of a number of separately-insulated strands woven or bunched together such that each strand tends to take all possible positions in the cross-section of the entire conductor. This design concept results in equalizing the flux linkages and, hence reactances, of the individual strands, thereby causing the current to divide uniformly between strands. The resistance ratio (AC to DC) then tends to approach unity, which is desirable in all high Q circuit applications. Typical applications for Litz conductors include high-frequency inductors and transformers, inverters, communication equipment, ultrasonic equipment, sonar equipment, television equipment, radio equipment and heat induction equipment.

By definition, Litz constructions are made with individually-insulated strands. Common magnet wire film insulations such as Formvar, Sodereze® (Polyurethane), Nyleze®, Thermaleze T®, Armored Poly-Thermaleze 2000®, and ML are normally used.[1] The outer insulation and the insulation on the component conductors, in some styles, may be servings or braids of Nylon®, cotton, Nomex®, fiberglass or ceramic. Heat-sealed polyester, rubber, vinyl and Teflon® tape wraps along with most thermoplastic insulations are also available as outer insulations if the applications dictate special requirements for voltage breakdown or environmental protection.[2]

Litz Design

Typically, the design engineer requiring the use of Litz knows the operating frequency and RMS current required for his application. Since the primary benefit of a Litz conductor is the reduction of AC losses, the first consideration in any Litz design is the operating frequency. The operating frequency not only influences to some extent the actual Litz construction, but it is also used to determine the individual wire gauge.

Ratios of alternating-current resistance to direct-current resistance for an isolated solid round wire (H) in terms of a value (X) are shown in Figure 1.

The value of X for copper wire is determined by the following formula:

$$X = 0.271\ D_M \sqrt{F_{MHZ}}$$

Where: D_M = Wire diameter in mils
F_{MHZ} = frequency in megahertz

From Figure 1 and other empirical data, the table shown in Figure 2 of recommended wire gauges vs. frequency for most Litz constructions has been prepared.

After the individual wire gauge has been determined, and assuming that the Litz construction has been designed such that each strand tends to occupy all possible positions in the cable to approximately the same extent, the ratio of AC to DC resistance of an isolated Litz conductor can be determined from Formula (2):

$$\frac{\text{Resistance To Alternating Currents}}{\text{Resistance To Direct Currents}} = H + K\left(\frac{ND_I}{D_O}\right)^2 G$$

Where: H = Resistance ratio of individual strands when isolated (taken from Figure 1 or 2)
G = Eddy-current basis factor = $\left(\frac{D_I\sqrt{F}}{10.44}\right)^4$
F = Operating frequency in HZ
N = Number of strands in the cable
D_I = Diameter of the individual strands over the copper in inches
D_O = Diameter of the finished cable over the strands in inches
K = Constant depending on N, given in the following table:

N	3	9	27	Infinity
K	1.55	1.84	1.92	2

Figure 1

X	0	0.5	0.6	0.7	0.8	0.9	1.0
H	1.0000	1.0003	1.0007	1.0012	1.0021	1.0034	1.005

Figure 2

FREQUENCY	RECOMMENDED WIRE GAUGE	NOMINAL DIA. OVER COPPER	DC RES. OHMS/M' (MAX)	SINGLE STRAND R_{AC}/R_{DC} "H"
60 HZ to 1 KHZ	28 AWG	.0126	66.37	1.0000
1 KHZ to 10 KHZ	30 AWG	.0100	105.82	1.0000
10 KHZ to 20 KHZ	33 AWG	.0071	211.70	1.0000
20 KHZ to 50 KHZ	36 AWG	.0050	431.90	1.0000
50 KHZ to 100 KHZ	38 AWG	.0040	681.90	1.0000
100 KHZ to 200 KHZ	40 AWG	.0031	1152.30	1.0000
200 KHZ to 350 KHZ	42 AWG	.0025	1801.0	1.0000
350 KHZ to 850 KHZ	44 AWG	.0020	2873.0	1.0003
850 KHZ to 1.4 MHZ	46 AWG	.0016	4544.0	1.0003
1.4 MHZ to 2.8 MHZ	48 AWG	.0012	7285.0	1.0003

Litz Design *(continued)*

The DC resistance of a Litz conductor is related to the following parameters:

1. AWG of the individual strands.
2. Number of strands in the cable.
3. Factors relating to the increased length of the individual strands per unit length of cable (take-up). For normal Litz constructions a 1.5% increase in DC resistance for every bunching operation and a 2.5% increase in DC resistance for every cabling operation is approximately correct.

Formula (3) derived from these parameters for the DC resistance of any Litz construction is:

$$R_{DC} = \frac{R_S\,(1.015)^{N_B}\;(1.025)^{N_C}}{N_S}$$

Where: R_{DC} = Resistance in ohms/1000 ft
R_S = Maximum DC resistance of the individual strands (taken from Figure 2)
N_B = Number of bunching operations
N_C = Number of cabling operations
N_S = Number of individual strands

An example of the calculations required to evaluate a Type 2 Litz construction consisting of 450 strands of 40 AWG single polyurethane operating at 100 KHZ and designed with two bunching operations and one cabling operation is given in Figure 3.

The value of Litz can easily be seen if the example in Figure 3 is compared with a solid round wire 94 mils in diameter. Using the same operating parameters, the DC resistance is 1.197 ohms/M′. However, the AC/DC resistance ratio increases to approximately 3.1 making the AC resistance 9.6 ohms/1000 ft.

1. Calculate the DC resistance of the Litz construction using Formula (3).

$$R_{DC} = \frac{1152.3 \times (1.015)^2 \times (1.025)^1}{450} \quad \text{or 270 ohms/1000 ft.}$$

2. Calculate the AC to DC resistance ratio using Formula (2).

$$\frac{R_{AC}}{R_{DC}} = 1.0000 + 2\left(\frac{450 \times .0031}{.094}\right)^2 7.8 \times 10^{-5} \text{ or } 1.0344$$

3. The AC resistance is, therefore, 1.0344 × 2.70 or 2.79 ohms/1000 ft.

Figure 3