# An Effective 160 Meter Antenna

## *How to build one on a small residential lot.*

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Since the time of the year had arrived when low frequency propagation characteristics are improving, my attention turned to finding a way to erect an effective yet low profile antenna for 160 meter operation. Since we live on a small residential lot, approximately 100 feet by 100 feet square, my options were limited. After reviewing a few designs from several antenna reference books, it looked as though the "inverted L" Marconi antenna was going to be the only practical choice given the space available.

### The Marconi L-Type

A typical Marconi L-type antenna consists of a wire which is 1/4-wavelength overall at the desired operating frequency. The length in feet is determined by the formula:

$$\frac{234}{F_{MHz}} = \text{length (feet)}$$

The usual installation of a wire inverted L antenna for 160 meter operation consists of two support poles or other structures spaced approximately 100 feet apart. Both supports need to be 30 to 40 feet overall in height. Figure 1 shows a vertical elevation sketch of the typical L-type antenna. Note that a single wire is used to form the radiator portion of the example antenna.

I chose to use steel mast tubing, sold by Radio Shack in 10-foot lengths, to act as the end supports for the antenna system. The feedpoint had to be located near the back corner of our property so I used the inside wall of the concrete block fence which surrounds our back yard to act as the only support for the 30-foot mast. After drilling the concrete wall and installing expansion bolts, I used two 1-1/4" electrical conduit clamps to fasten the mast to the concrete. The installation is simple: The conduit clamps hold the mast tightly against the wall up to approximately seven feet above ground level. The masts have sufficient tensile strength so as to not break. They do, however, flex a bit in the wind. The other 30-foot mast is anchored to the outside wall of our house. A standard mounting kit was used for the support. Neither mast has any guy wires or ropes attached to it for stabilization—it simply was not necessary.

As you can see from Figure 1, ground radial wires are required in order to achieve satisfactory performance from the typical L antenna. In many cases like mine a few radials can be installed but the number and length are somewhat limited. The basic rule of thumb is to install as many as possible that are 1/4-wavelength long at the frequency of interest. My antenna system has two radials that are 135 feet long and several more that are shorter. You may want to bury the radials to protect them.

After erecting the wire as shown, I made several resistance/reactance measurements at frequencies between 1.800 MHz and 2.000 MHz by using an RF impedance bridge connected to the feedpoint of the antenna. I used a General Radio model 916A RF bridge, along with a General Radio 1211-C unit oscillator as a signal source. I also used a Kenwood model R-2000 receiver as the null detector for the test setup. The results showed that the feedpoint resistance was generally quite low, approximately 10 ohms resistance at the band center, which is 1.900 MHz. This presented a very poor match for the HF transceiver used at my station. I might add that since I use one of those newfangled units with a solid-state output stage, the transceiver is designed to fold back or limit output power if the SWR is in excess of 1.5:1 in order to protect the output transistors from damage. I considered using a tuner, but since the coax cable between the operating position and the antenna feedpoint was rather long, the performance and bandwidth in this particular instance would be quite poor. Some consideration was also given to installing a remotely-controlled matching network at the antenna feedpoint and running the control wiring back to the operating position. This option seemed too complicated. What we really needed was a 50-ohm input impedance for the antenna so that standard RG-8 U coax could be used between the antenna and the operating position, where

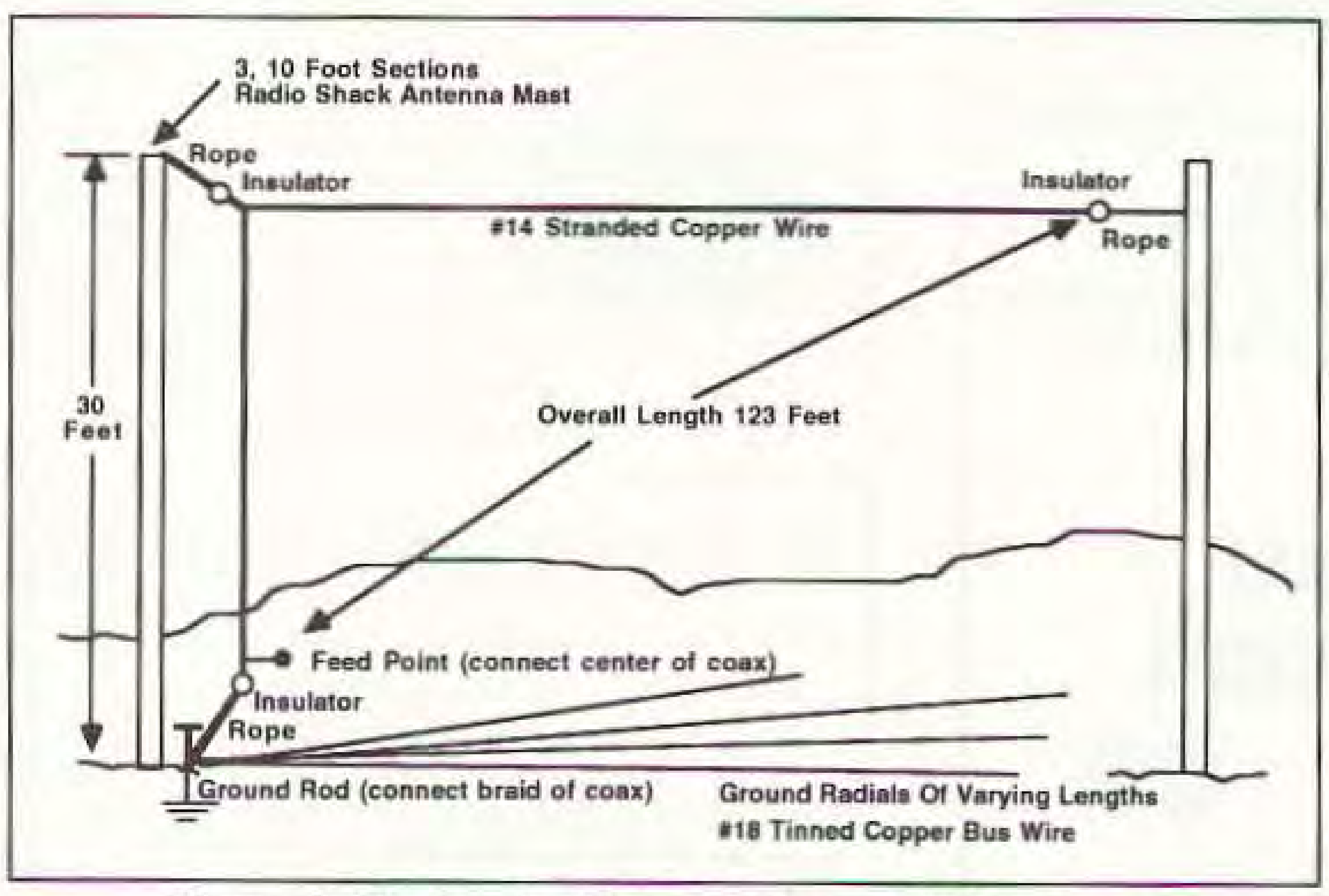


*Figure 1. Single-wire Marconi "inverted L" antenna.*

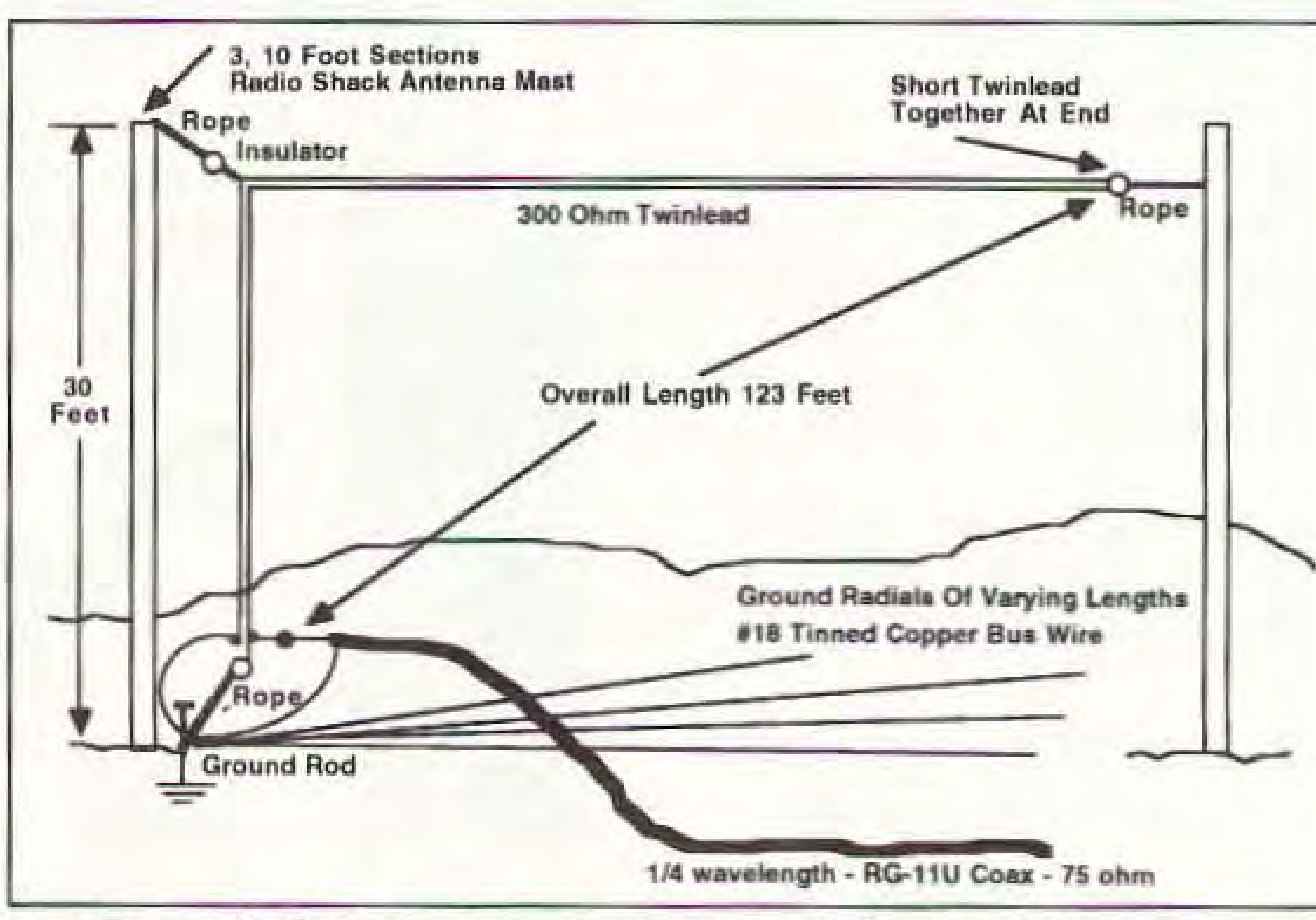


*Figure 2. 300-ohm twin-lead Marconi "inverted L" antenna.*

the transceiver was located.

## The Twin-Lead L Antenna

After some additional investigation, I found a design for an L-type antenna to be constructed from 300-ohm TV-type twin lead. The physical dimensions were to be approximately the same except the twin lead was to be used to form a loop, similar to a folded dipole. The far end of the twin lead was to be shorted together and one end of the loop connected to ground at the feedpoint, while the other wire was to receive the power from the transceiver. Figure 2 shows a diagram of the "twin-lead L" antenna. The theory of this type of system is that the twin lead acts as an impedance transformer which increases the "radiation resistance" of the antenna, which in turn helps overcome the inherent ground system losses. The result is a more efficient antenna and a higher feedpoint impedance.

After disassembling the antenna shown in Figure 1 and replacing it with the twin-lead antenna shown in Figure 2 , we repeated the resistance/reactance measurements and found that the numbers had changed significantly from the original single-wire unit. The following results were noted:

| Frequency | Resistance | Reactance |
|---|---|---|
| 1.800 MHz | 110 ohms | -152 ohms |
| 1.900 MHz | 100 ohms | -3 ohms |
| 2.000 MHz | 190 ohms | +144 ohms |

While these values depart from the ideal 50-ohm figure required for optimum transceiver match, they represent workable parameters which can be transformed to 50 ohms. It would be expected that the impedance measurements obtained would vary somewhat from one installation to another; however, in my case, the center of the band at 1.900 MHz measured 100 ohms resistance with a small amount of capacitive reactance. A review of transmission line theory shows us that a 1/4-wavelength section of transmission line, when presented with a load other than the nominal impedance of the line, will act as an impedance transformer under the mismatched condition. The impedance inverting property of the line provides a good match between a high-impedance circuit and a low-impedance one. I had some RG-11 U coaxial cable on hand which has a nominal characteristic impedance of 75 ohms and decided to put that to a good use. A quarter wavelength of the RG-11 U can be calculated by the formula:

$$1/4 \text{ wavelength} = \frac{246}{F_{MHz}} \times 0.66$$

In this equation, the value 0.66 represents the velocity factor of the transmission line, which provides a correction for the line propagation characteristics when compared to propagation of the radio wave in free space. In this case, I wanted to optimize the antenna for 1.900 MHz and have minimal SWR present at the edges of the band, which are 1.800 MHz and 2.000 MHz. So what we are really talking about is trying to make the transceiver operate across 200 kHz of spectrum. The actual length of RG-11 U coaxial cable worked out to be 85.4 feet. The cable was installed as shown in Figure 2 and the resistance and reactance measurements were repeated for the three frequencies previously outlined.

This time the antenna bridge was looking at the antenna through the 75-ohm cable. The following results were noted:

| Frequency | Resistance | Reactance |
|---|---|---|
| 1.800 MHz | 17 ohms | +18 ohms |
| 1.900 MHz | 56 ohms | +2 ohms |
| 2.000 MHz | 18 ohms | -9 ohms |

Due to the physical layout of my ham shack in relation to the antenna and feedpoint, I needed approximately 120 feet of coaxial cable to get to the transceiver from the antenna so I decided to coil up most of the 75-ohm matching section and then install 52-ohm RG-8 U coaxial cable. Again the velocity factor was 0.66. I was a bit apprehensive about the potential attenuation from coaxial cable lengths this long; however, after consulting one of my textbooks, I determined that the worst case loss was 0.45 dB at 2.0 MHz, assuming a matched condition and a total cable length of 205 feet for the RG 11 and RG 8 types. This means that for 100 watts out of my transceiver, 90 watts would arrive at the antenna. After the installation of the coaxial cable to the operating position was complete, I again connected the antenna bridge and noted the following measurements:

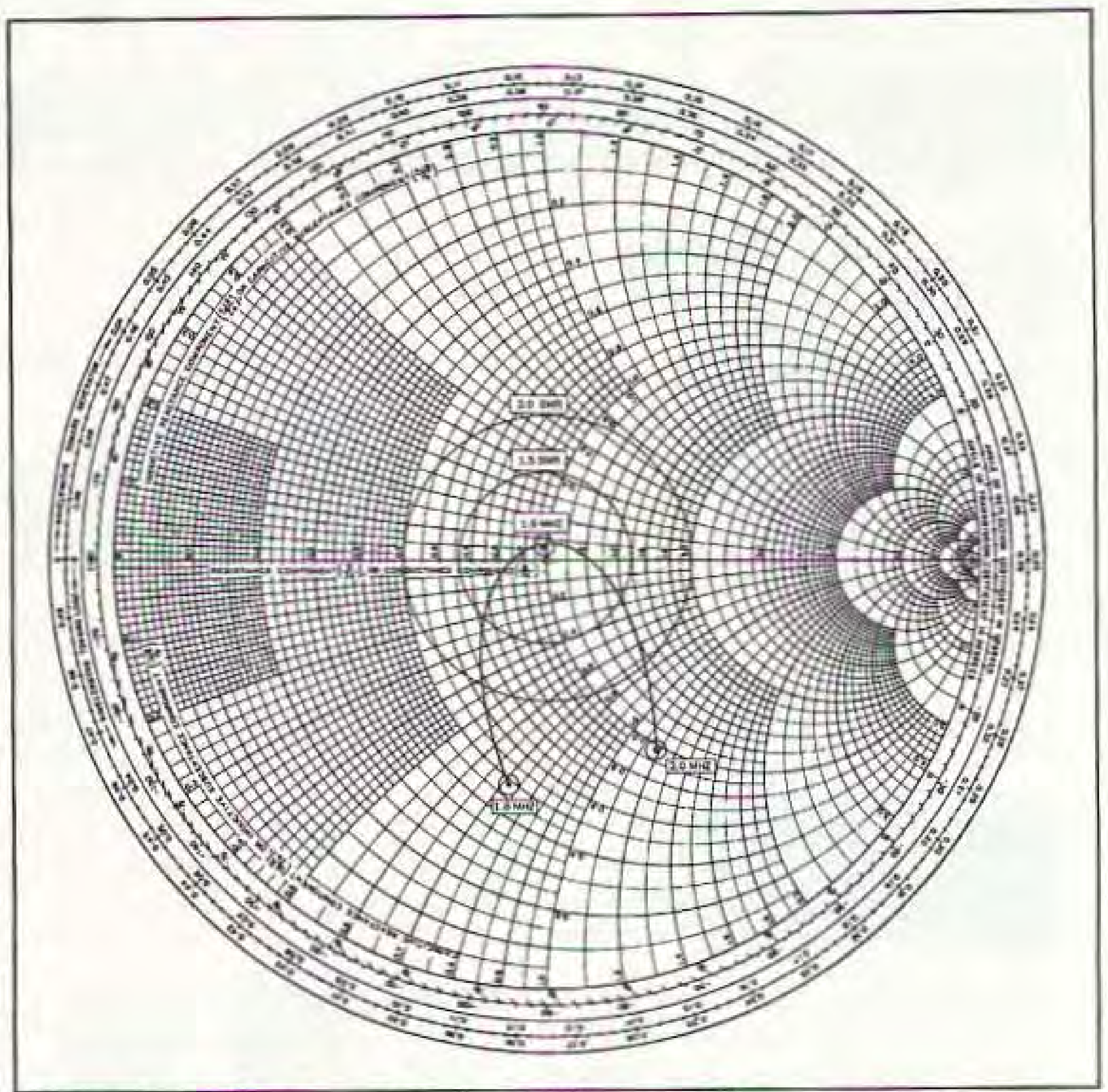

*Figure 3. Smith chart showing SWR versus frequency measurements taken at the operating position.*

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0 REM MISMATCHED TRANSMISSION LINE VER. 2.00
1 CLS : SCREEN , 0: COLOR 15, 1
2 CLS : KEY OFF:
3 PRINT : PRINT "  AN RF DESIGN AID DEVELOPED FOR AMATEUR USE BY KA6MMO"
4 PRINT : INPUT "  TRANSMISSION LINE or MATCHING SECTION IMPEDANCE     "; Z
5 PRINT : INPUT "  ANTENNA RESISTANCE                                  "; LR
6 PRINT : INPUT "  ANTENNA REACTANCE                                   "; LX
7 PRINT : INPUT "  SWR REFERENCE IMPEDANCE (Typical 50 Ohms)           "; N
8 PRINT : INPUT "  OPERATING FREQUENCY IN mHz                          "; F
9 PRINT : INPUT "  TRANSMISSION LINE VELOCITY FACTOR                   "; V
10 PRINT : INPUT "  TRANSMISSION LINE DELAY IF MATCHED ( Degrees )     -"; P
11 IF F <= 1.799 OR F >= 29.999 THEN BEEP: BEEP: GOTO 12 ELSE 14
12 CLS : PRINT : PRINT "  OPERATING FREQUENCY IS OUT OF RANGE!"
13 PRINT : PRINT "  SELECT OPERATING FREQUENCY 1.80 TO 30.0 mHz": GOTO 8
14 IF P > 0 THEN P = P * -1
15 R = .0174533
16 XA = LX - (Z * TAN(P * R))
17 S = (TAN(P * R)) / Z: XB = -LR * S: RB = 1 + (LX * S)
18 ZA = SQR((LR ^ 2) + (XA ^ 2))
19 ZB = SQR((RB ^ 2) + (XB ^ 2))
20  PA = (ATN(XA / LR)) / R
21 PB = (ATN(XB / RB)) / R
22 ZC = ZA / ZB: PC = PA - PB
23 IR = ZC * (COS(PC * R)): IX = ZC * (SIN(PC * R))
24 A = (Z / (TAN(P * R))) + LX
25 LP = (ATN(LR / A)) / R
26 IF LP > 0 THEN LP = LP - 180
27 IF IR < 0 THEN IX = IX * -1
28 IF IR < 0 THEN IR = IR * -1
29 MP = (ATN(IX / IR)) / R: MP = LP - MP
30 IF P <= -180 THEN MP = MP - 180
31 IF P <= -360 THEN MP = MP - 180
32 IF P <= -540 THEN MP = MP - 180
33 W = (983.6) * V / F / 360
34 Q = W * P: IF Q <= 0 THEN Q = Q * -1
35 IF N <= 0 THEN N = N + 1
36 IY = (IR + N) ^ 2
37 IU = (IR - N) ^ 2
38 IQ = (IX) ^ 2
39 E = SQR(IY + IQ)
40 C = SQR(IU + IQ)
41 O = E + C
42 G = E - C
43 H = O / G
44 CLS :
45 PRINT : PRINT "  MATCHED TRANSMISSION LINE DELAY =              "; P; "Degrees"
46 PRINT : PRINT "  MISMATCHED TRANSMISSION LINE DELAY =           "; MP; "Degrees"
47 PRINT : PRINT "  TRANSMISSION LINE INPUT RESISTANCE =           "; IR; "Ohms"
48 PRINT : PRINT "  TRANSMISSION LINE INPUT REACTANCE =            "; IX; "Ohms"
49 PRINT : PRINT "  TRANSMISSION LINE LENGTH =                     "; Q; "Feet"
50 PRINT : PRINT "  SWR AT TRANSMISSION LINE INPUT =               "; H; ": 1"
51 PRINT ""
52 PRINT : INPUT "  CHANGE MATCHING SECTION LENGTH  ( Y OR N )"; A$
53 IF A$ = "y" OR A$ = "Y" THEN 54 ELSE 55
54 CLS : GOTO 10
55 PRINT : INPUT "  ENTER NEW DATA & RERUN  (Y or N)"; B$
56 IF B$ = "y" OR B$ = "Y" THEN 57 ELSE GOTO 58
57 CLS : GOTO 4
58 SYSTEM
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*Figure 4. BASIC program: Mismatched Transmission Line.*

| Frequency | Resistance | Reactance |
|---|---|---|
| 1.800 MHz | 24 ohms | -36 ohms |
| 1.900 MHz | 49 ohms | +3 ohms |
| 2.000 MHz | 48 ohms | -59 ohms |

These final resistance/reactance measurements taken at the operating position are values which can be easily transformed to 50 ohms by using a simple matching network such as an L-type configuration. For the sake of visual interpretation of the final measurements, I

## Parts List, Antenna

| Quantity | Description | Source | Part # |
|---|---|---|---|
| 6 | 10' mast sections | Radio Shack | 15-843 |
| 1 | Wall-mount kit | Radio Shack | 15-883 |
| 3 | 50' lengths 300-ohm twinlead (to be spliced together) | Radio Shack | 15-1153 |
| 1 | Ground rod | Radio Shack | 15-530 |
| 2 | Egg insulator paks | Radio Shack | 278-1335 |
| 500' | #18 solid tinned copper wire for ground radials | Pacer Electronics | |
| 85' | RG11/U 75-ohm coax | Pacer Electronics | |
| 120' | Belden 8237-type RG 8/U coax | Pacer Electronics | |
| 2 | 1-1/4" conduit clamps | Ace Hardware | |
| 20' | 5/16" nylon rope | Ace Hardware | |

normalized the figures shown above for 50 ohms and plotted them on a Smith chart (see Figure 3) with a 1.5:1 and 2.0:1 SWR circle also drawn on the graph. As you can see in this chart, a substantial portion of the band falls within the 2.0 region, and approximately 40 kHz either side of the band center at 1.900 MHz falls within the 1.5:1 region. This means that from 1860 kHz to 1940 kHz my solid-state transceiver will produce full output power without any additional antenna tuner or ATU.

### Program to Predict Impedance

The Marconi L antenna characteristics can vary greatly from one installation to another. It should be understood that, depending upon the resistance and reactance of the antenna feedpoint, it may or may not be necessary to use exactly 1/4-wavelength or -90 degrees of transmission line in order to obtain a satisfactory match. The matching section could be longer or shorter for optimum results.

Since a certain portion of this project could result in tedious trial-and-error cutting of coaxial lines, given the variables involved from one installation to another, I decided prior to beginning the work to write a simple computer program in BASIC to predict the resulting impedance at one end of the transmission line when the other end is terminated with an impedance other then the nominal characteristic impedance of the line.

See Figure 4 for the program listing. If you care to enter the program codes for yourself, it should only require a few minutes of time. Also, I have uploaded the program to the *73* BBS so that it can be downloaded for your use. The program is titled "Mismatched Transmission Line" and will operate on any IBM compatible computer. I should point out that the program and the matching/impedance transformation technology is applicable at any of the amateur HF frequencies you might be interested in.

### Matching Network Circuit

Now for a very simple yet effective matching network which will enable you to operate across the entire band from 1.800 to 2.000 MHz without making adjustments. That's right, no knobs to turn or tweak!

The circuit shown in Figure 5 has a basic ATU consisting of a single series inductor with two fixed shunt capacitors, either of which can be selected by switch S2. When operating in the bypass mode the unit is out of the circuit and, as I mentioned earlier, the transceiver will put out full power from 1860 kHz to 1940 kHz. If operation below 1860 kHz is desired, the ATU is switched in circuit and switch S2 is placed in the 1.8 MHz position. If operation above 1940 kHz is desired, switch S2 is placed in the 2.0 MHz position. It is important to understand that the design criteria for this circuit was only to keep the SWR at substantially less than 1.5:1 at all portions of the band, not to effect an absolute 1:1 match at any frequency.

If you examine one of the many graphs published in the various antenna textbooks, it is evident that the loss in transmitted power at an SWR of 1.5:1 is only 4%. That amount of loss is insignificant and will produce no perceptible change in the received signal from your station. If you must have a 1:1 SWR at whatever frequency you happen to be operating on, I suggest you use a standard ATU or transmatch, such as the SPC design. These are described in various antenna textbooks and are also for sale commercially from several equipment manufacturers. In that case, you may omit this ATU from the circuit. The ATU is designed to handle 100 watts CW or RTTY continuously, without heating or other problems. However, if you plan to operate with power levels in excess of 100 watts, you may wish to construct the matching network with components that have a higher voltage and or current rating.

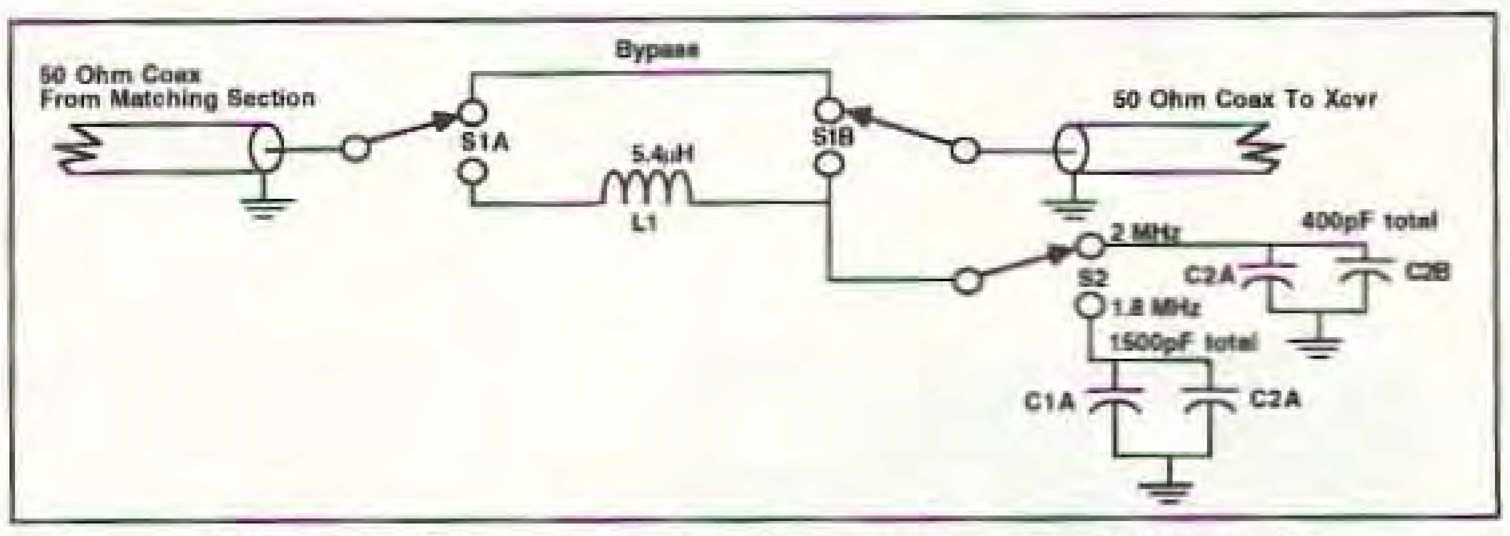


*Figure 5. Simple L network antenna matching unit.*

## Parts List, ATU

| Symbol | Rating or Value | Source | Part # |
|---|---|---|---|
| S1 | 6A @ 250 VAC | Radio Shack | 275-652 |
| S2 | 6A @ 250 VAC | Radio Shack | 275-652 |
| L1 | 5.4 uH | Barker & Williamson | 3052 |

(16 turns #14 solid copper wire on a 1.5" form, six turns per inch)

| Symbol | Rating or Value | Source |
|---|---|---|
| C1A | ARCO DM19 500-volt 680 pF | Circuit Specialists |
| C1B | ARCO DM19 500-volt 820 pF | Circuit Specialists |
| C2A | ARCO DM15 500-volt 200 pF | Circuit Specialists |
| C2B | ARCO DM15 500-volt 200 pF | Circuit Specialists |

Barker & Williamson, 10 Canal Street, Bristol PA 19007.
Circuit Specialists, P.O. Box 3047, Scottsdale AZ 85271.
Pacer Electronics, 1630 W. 12th Place, Tempe AZ 85281.

### Construction Techniques

As far as construction techniques go, I constructed my ATU on a small metal plate and mounted it on the wall of my shack so that it was out of the way. If you want to get fancy, you could put the circuit in a metal box with coax connectors.

There you have it, operation across the entire 160 meter band, with no remote motor controlled antenna matching units or other complicated devices. In fact, most of the matching is accomplished by the selection of coaxial cable lengths and types. The coaxial cable is a necessity in order to connect the antenna feedpoint to the transceiver, so why not let it solve the impedance matching problems also? The RF impedance bridge and oscillator I used to make the resistance and reactance measurements were purchased surplus for a modest price. There are also several new solid-state units on the market which have the generator and detector self-contained; one even has a frequency counter built into it.

One last note: I have enjoyed many contacts on 160 meters since installing this antenna and matching system. At night, I am consistently able to work other stations all over the country and receive good signal reports, with only 100 watts out of the transceiver. 73


### References:

*Antennas*, 2nd edition, by John D. Kraus W8JK.

*Radio Handbook*, 23rd edition, by William I. Orr W6SAI.

*Radio Data Reference Book*, 5th edition, G.R. Jessop G6JP.

*Antenna Engineering Handbook*, 2nd edition, Johnson and Jasik.