VHF/UHF WORLD

Joe Reisert W1JR

impedance-matching techniques

Because hardly a month goes by that I don't receive at least one question about impedance matching, this month's column will first address the subject generally and then describe some specific techniques.

impedance matching in general

When impedance matching is discussed, it usually refers to matching to an antenna. Often the only question is "How do I get a low VSWR?"

For years Amateurs have had the notion that if the VSWR isn't close to unity (1:1), valuable power is being lost. They seldom consider the insertion loss of the transmission line, the accuracy of the measurement gear, or the mismatch loss (if any).

It's true that if the VSWR on a transmission line isn't 1:1, there's an additional line loss over and above that of the insertion loss of the feed line.[1] This is often referred to as "mismatch loss." For many years a graph published in several Amateur journals and the ARRL's *Antenna Book* has shown how to estimate the mismatch loss if the VSWR at the load and the nominal insertion loss of a transmission line are known.[2] Because I didn't know how precise it was, and because using it involves a two-step addition process (another possible source of error), and because it doesn't include low transmission line losses such as typically encountered at EME, I haven't had much confidence in it.

Thanks to Dick Turrin, W2IMU, I now have the mismatch loss mathe-

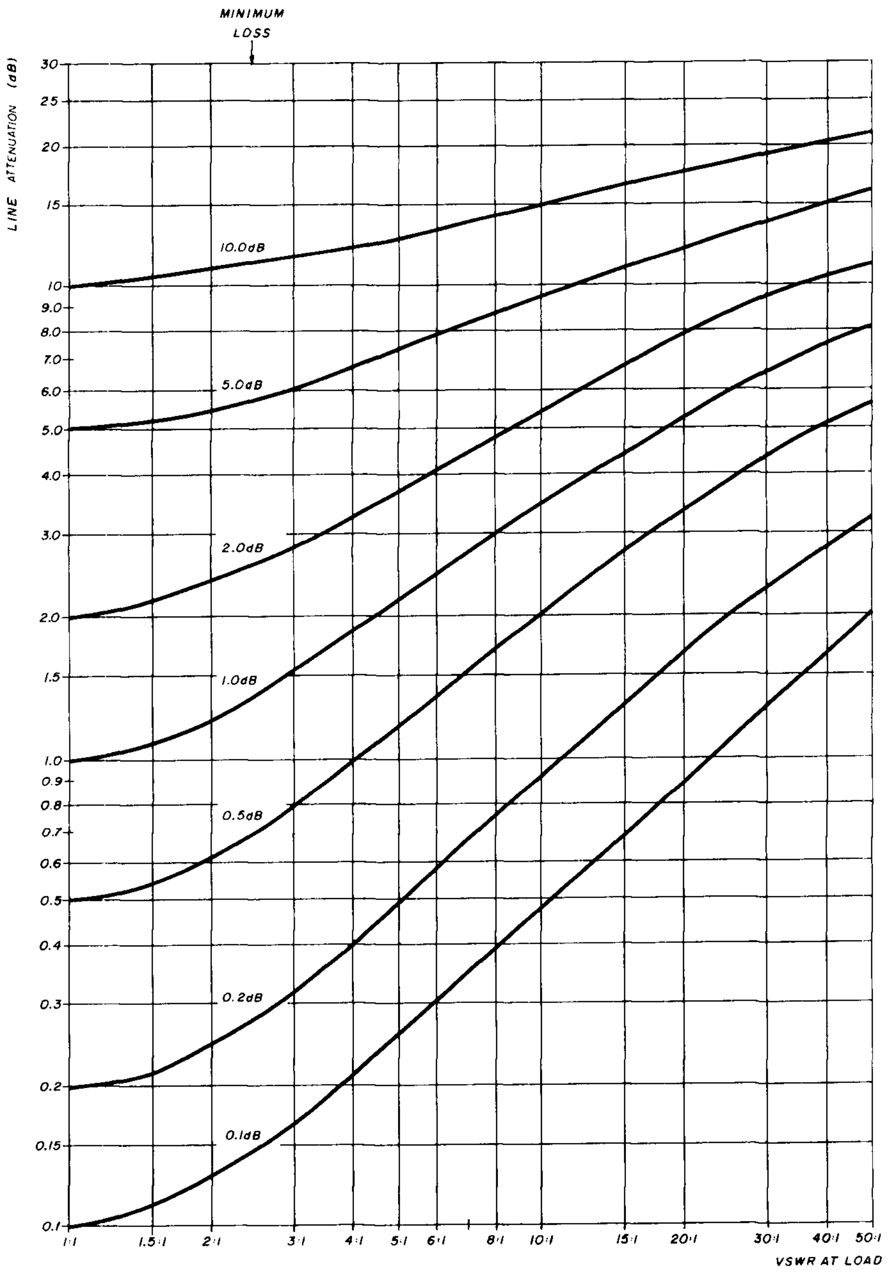

fig. 1. Total insertion loss in a transmission line terminated in a mismatch (see text).

matical equations, but they are lengthy. Dick pointed out to me that a mismatch loss graph using a different format was published in the 1940s.[3] Sure enough, I'd had the information in my files all these years and hadn't noticed it!

I've verified the math. The older and, in my opinion, more useful graph for mismatch loss is shown in **fig. 1**. Note that this graph stands alone, in that the loss indicated is the total loss, not just an incremental amount which then has to be added to the nominal insertion loss. As with the former graph, you still have to know the VSWR at the load as well as the nominal insertion loss of the transmission line. The latter quantity, however, is readily available.[1,2]

For example, using **fig. 1**, if the VSWR at the load is 5:1 and the nominal transmission line insertion loss is 0.2 dB, the total insertion loss — including the mismatch loss — will be 0.5 dB. Furthermore, if the VSWR at the load is 3:1 and the nominal insertion loss of the line is 5 dB, the total insertion loss will be 6 dB. I feel that **fig. 1** is easier to use and more realistic than the graph most Amateurs are presently using.

Impedance matching is especially important nowadays because of the proliferation of solid-state power amplifiers that will shut down or decrease power in the presence of VSWR above 1.5 or 2:1. However, the subject of impedance matching extends beyond antenna systems, since impedance matching can also refer to matching into or out of a low-noise, medium, or high power amplifier. Impedance matching can be narrowband as well as broadband and between resistive or reactive loads.

categories of impedance matching

Before we go any further, we should discuss what I feel are the three major categories of impedance matching: nonreflective, conjugate, and optimum source. Nonreflective matching is probably the most common type. In this scheme, an impedance matching network or "antenna tuner" is placed somewhere in the line between the source and load. This network is then tuned for minimum VSWR looking into the load. In a worst-case scenario, a large attenuator could be placed between the source and load to yield a good impedance match. (More on this shortly.)

Conjugate matching is often used in the design of solid-state power amplifiers where gains are typically low and therefore losses must be kept at a minimum, both in the input matching network and in the components involved.[4] In order to accomplish a conjugate match, all reactive components must be cancelled and the resistive component of the load made equal to the input line impedance.[5] Conjugate matching is often used in applications where wider bandwidth or no tuning is desired.

Optimum source matching usually refers to providing the impedance required for best operation of the load. In the case of a vacuum tube power amplifier, if a conjugate output match is used, at least one-half of the rf output power generated would have to be dissipated in the tube — a very inefficient condition.[5] Therefore, conjugate matching is usually not used in high-power amplifier designs.

In a similar manner, the input circuit of a low-noise preamplifier is often tuned to an impedance that produces the lowest noise figure, which seldom yields a good impedance match. Therefore a device or circuit that requires optimum source matching will usually have a moderate to poor input and/or output VSWR.

simple impedance-matching techniques

There are many ways to perform impedance matching. Resistors, transformers, reactive elements, transmission lines, and stubs are some commonly used VHF/UHF/SHF techniques. The optimum choice depends on whether the load is resistive or reactive, whether any insertion loss is allowable, and how broadband the match must be.

If loss isn't a problem, the load is resistive and doesn't have to see an impedance match looking back at the source; a simple resistor or resistor network is all that's necessary for a wideband impedance match. Several examples of resistor matching are shown in **fig. 2**.

In **fig. 2A**, the impedance of the amplifier must be resistive and less than the source impedance. The matching resistor, R, will be the difference between the source and load impedance. For example, if you want to match a source of 50 ohms and the load is 40 ohms, R should be 10 ohms.

If the load impedance is higher than the source, use a shunt resistance as shown in **fig. 2B**. With a load of 75 ohms, the shunt R will have to be 150 ohms to provide a match to a 50-ohm source. In either case, the matching resistor will dissipate power and decrease overall gain. Furthermore, the source will see a good impedance match but the load looking back toward the source will see a mismatch. The larger the impedance difference between the source and load, the larger the insertion loss and the lower the gain.

Sometimes it's desirable to have both the source and load see a good impedance match. In this case, the so-called "minimum loss pad" can be used for impedance matching (see **figs. 2C** and **2D**). This type of impedance matching provides a match looking both ways but has a higher insertion loss than the single resistor matching shown in **figs. 2A** and **2B**.

For example, using **fig. 2C** with a source impedance of 50 ohms and a load of 40 ohms, R1 should be 22.4 ohms and R2 89.4 ohms. The overall insertion loss will be 4.2 dB. If the load impedance is higher than the source, use the circuit in **fig. 2D**. With a source impedance of 50 ohms and the load at 75 ohms, R1 will be 86.6 ohms and R2 43.3 ohms. The overall insertion loss will be 5.7 dB.

If gain is of no consequence, typical "T" or "PI" attenuator pads can be used for impedance matching as shown in **figs. 2E** and **2F**. If the at-

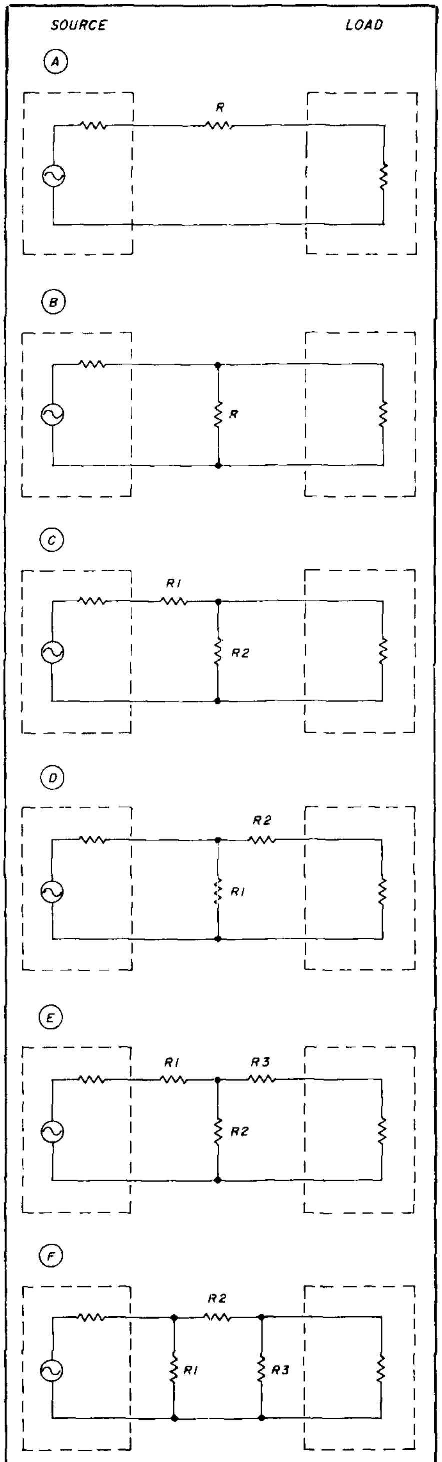

fig. 2. Different types of resistor matching for cases in which the source and load impedance are resistive: (A) source impedance is higher than load; (B) load impedance is higher than source; (C) minimum loss pad with source impedance higher than load; (D) minimum loss pad with load impedance higher than source; (E) typical symmetrical "T" pad attenuator; (F) typical symmetrical "PI" pad.

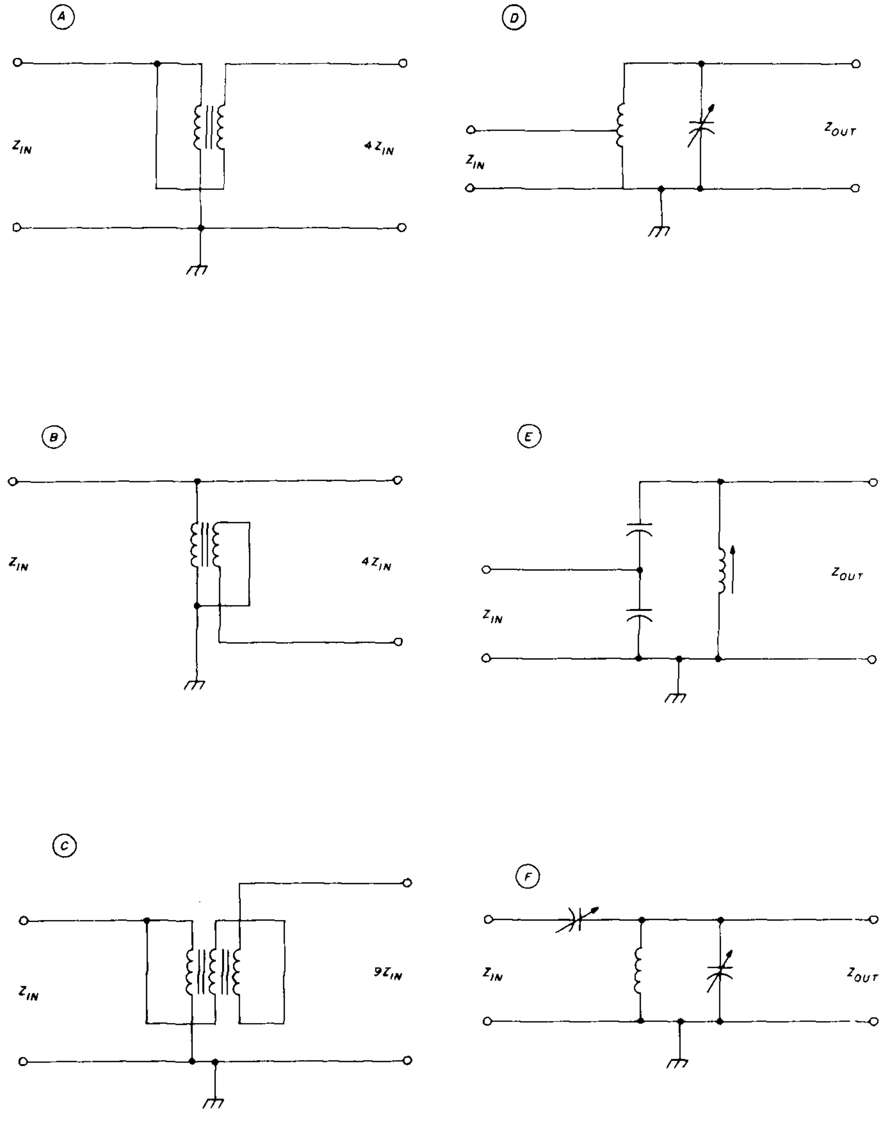

fig. 3. Typical transformer matching techniques: (A) simple 4:1 bifilar wound transformer; (B) typical 4:1 balun transformer; (C) trifilar wound 9:1 transformer; (D) typical resonant step-up/step-down transformer; (E) step-up/step-down transformer using tapped capacitor configuration; (F) variable tap transformer.

tenuation of the pad is high enough, for example 10 dB, the source and load will typically see a VSWR equal to or better than 1.2:1. Values for a 10-dB pad are 26, 35, and 26 ohms for R1, R2, and R3, respectively, in **fig. 2(E)** and 96, 71, and 96 ohms, respectively, in **fig. 2(F)**.

Finally, even lossy coax cable can act as an attenuator. For example, RG-58A/U coax has a loss of approximately 11 dB per 100 feet at 400 MHz. Therefore, about 90 feet of RG-58A/U would make an excellent 10-dB attenuator for the 70-cm (432 MHz) band with a power rating of 85 watts to boot.[1] Equations for designing minimum loss and matched attenuator pads are available in most design handbooks.[6] Typical computer programs are also available.[7]

transformer matching

Another method of impedance

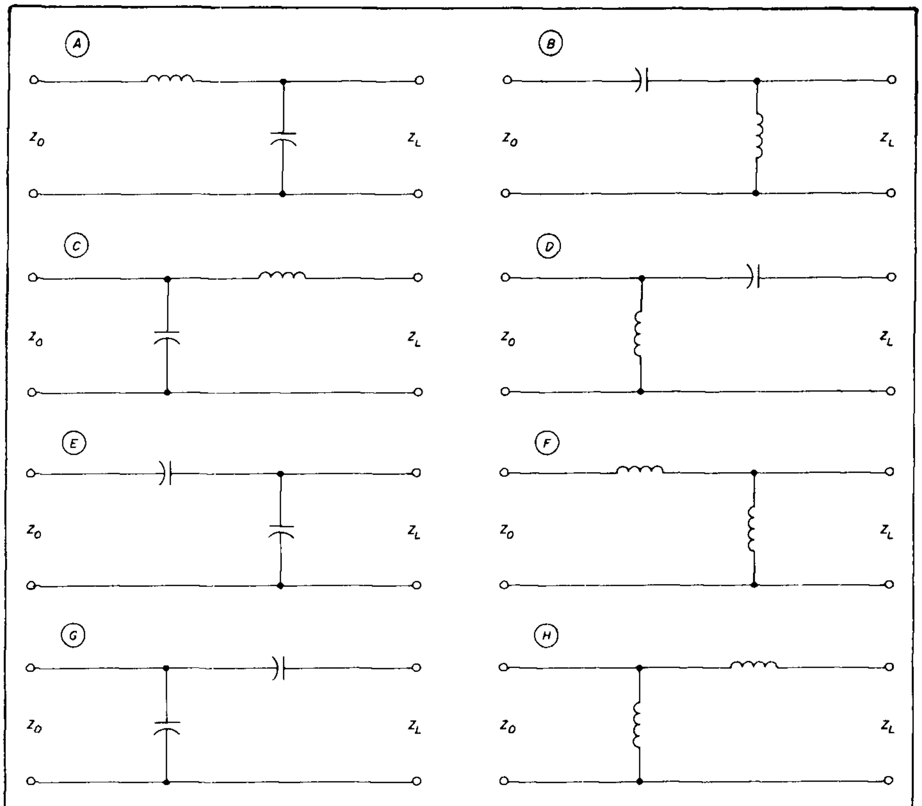

fig. 4. These eight "L" networks can be used to match any impedance to any other impedance (see reference 9).

matching is through the use of transformers. The 4:1 transformer is particularly popular with Amateurs. It will conveniently match a resistive source to a resistive load that is four times the impedance. A bifilar wound transformer is often used, as shown in **fig. 3A**. This technique was recently suggested by Bob Sutherland, W6PO, for matching out of GaAsFET amplifiers.[8] Bifilar wound transformers are also very popular for toroidal baluns (**fig. 3B**). Trifilar wound transformers can also be used to match resistive impedances that are a ratio of nine times (**fig. 3C**).

Another popular form of transformer is the resonant step-up/step-down type that is often used at the input of low-noise receivers. It has many forms, but those shown in **figs. 3D** and **3E** are the most popular. **Figure 3F** is a somewhat simpler but more obscure transformer configuration that's popular where the goal is to optimize the impedance in the circuit without changing taps or components. Resonant transformers are often used in reverse to match the output of a high-impedance small signal amplifier to a lower impedance. Other types of transformers using coaxial techniques will be discussed shortly.

reactive impedance matching

So far I've been discussing mostly resistive matching networks. At the lower VHF/UHF frequencies, especially when low-loss impedance matching is required over only a narrow bandwidth, simple "L" networks using inductors and capacitors are often used, especially when the load impedance is reactive.

This is probably the time to mention the venerable "Smith Chart," a tool used mainly by professionals to impedance match from any one impedance to any other impedance if the impedances of the source, load, and reactive components are known.[9] Smith points out in Chapter 10 of his book that any resistive impedance, Zo, can be matched to any complex impedance, Z1, using a simple L-net-

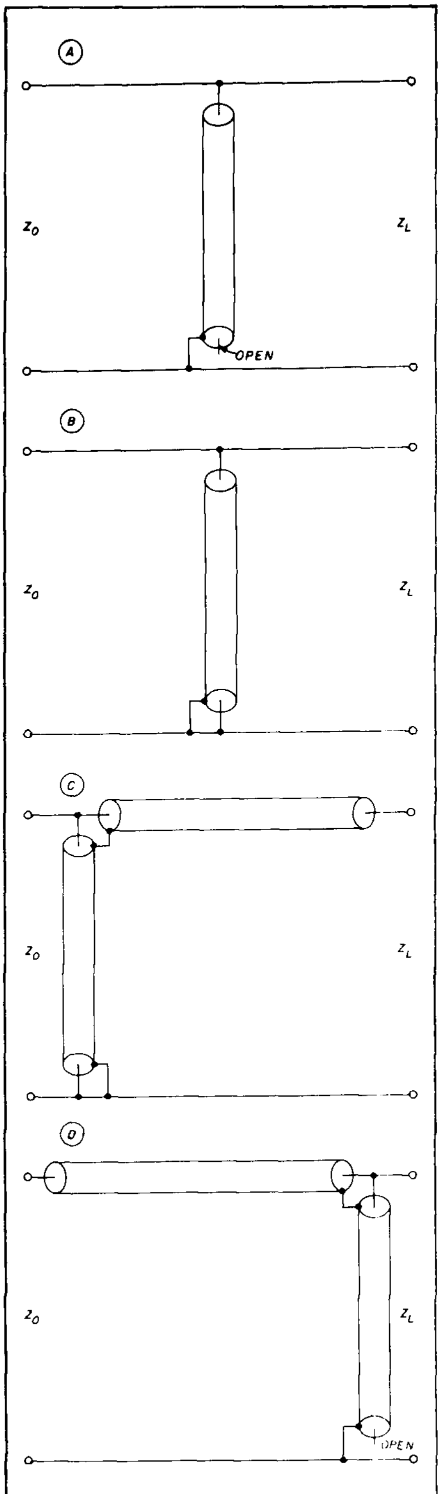

fig. 5. Typical stub impedance matching networks: (A) open shunt stub; (B) shorted shunt stub; (C) shorted shunt and series transformer; (D) series transformer and open shunt stub.

work. The eight required circuit topologies are shown in **fig. 4**. Smith shows the recommended network based on the portion of the Smith Chart where the load is present.

stub matching

Impedance matching can also be accomplished using coaxial stubs. The most common configurations are the open (**fig. 5A**) and the shorted (**fig. 5B**) shunt types. In most cases the stub is less than one-quarter wavelength. If a shunt stub isn't sufficient to complete the match, a tandem transmission line, also usually less than one-quarter wavelength, may be added ahead of or behind the shunt stub as shown in **figs. 5C** and **5D**. The Smith Chart is particularly useful for performing stub matching.

Use of the Smith Chart has been described many times in the Amateur literature[10,11,12] so I won't dwell on it here. Instead, I'll refer you to these references and use the rest of this month's column to show simple impedance-matching techniques that can be easily implemented by Amateurs.

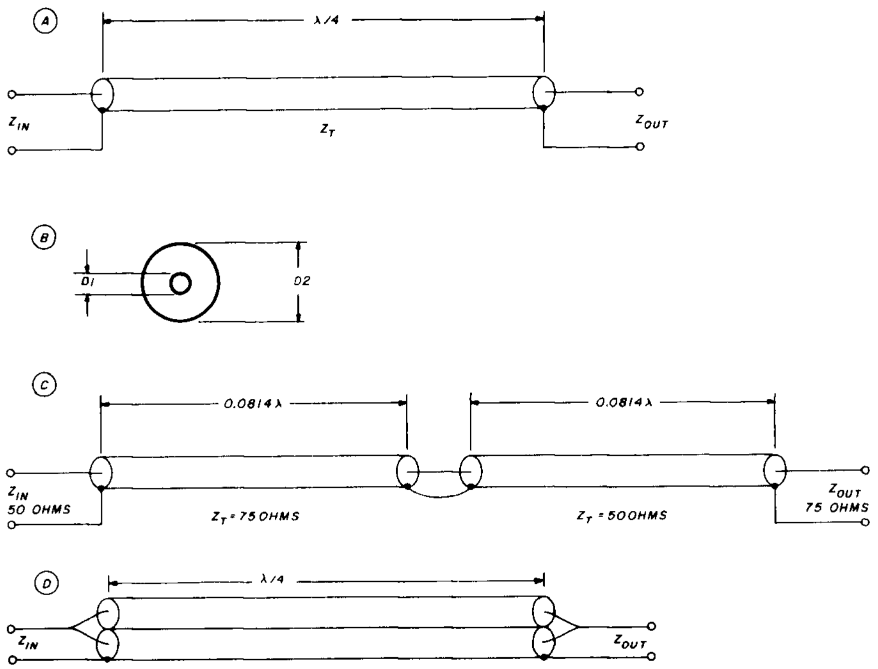

fig. 6. Typical coaxial transformers: (A) quarter-wavelength transformer; (B) elements of the physical properties of a coaxial line; (C) example of a 50- to 75-ohm non-synchronous transformer. (D) Coaxial cables can be paralleled to half the nominal impedance.

coaxial transformers

Probably one of the most widely used impedance matching techniques in the VHF/UHF spectrum is the "quarter-wavelength transformer" as shown in **fig. 6A**. In its simplest form it can match virtually any two resistive impedances. The impedance of the line is the geometric mean between the input and output impedances as shown below:

$$Z_t = \sqrt{Z_{in} Z_{out}} \qquad \textbf{eqn. 1}$$

Where Z_t is the impedance of the quarter-wavelength transformer, Z_{in} is the input impedance, and Z_{out} is the output impedance, all in ohms. For example, let's say that we want to match a 50-ohm resistive line to a 75-ohm resistive line. Using equation 1, the optimum impedance of the quarter-wavelength transformer, Z_t, is 61.24 ohms.

The length, as stated above, must be one-quarter wavelength at the operating frequency. This can be determined using equation 2:

$$L = \epsilon_r (2951/f) \qquad \textbf{eqn. 2}$$

Where L is the length in inches, ϵ_r is the dielectric constant, 1.0 for air, and f is the frequency in MHz. Therefore a quarter-wavelength transmission line at 432 MHz using air dielectric is approximately 6.83 inches long.

Now all you have to do is to build a coaxial line section one-quarter wavelength long that has a characteristic impedance of 61.24 ohms. The impedance can be determined using equation 3:

$$Z = 138 \log (D2/D1) \qquad \textbf{eqn. 3}$$

Where Z is the impedance of a coaxial line, D1 is the outer diameter of the inner tubing, and D2 is the inner diameter of the outer tubing (see **fig. 6B**). For an impedance of 61.2 ohms, the ratio of D2/D1 is approximately 2.78:1.

A suitable coaxial transmission line can be made using hobby shop brass or copper tubing.[13] Half-inch household plumbing uses copper tubing that has an approximate inside diameter of 0.532 inches. Therefore, a 3/16-inch outside diameter tube, such as you'll find in hobby shops, would make a good match for the inside tube in this particular application.

Yet another transformer matching scheme — the "non-synchronous" transformer — is an outgrowth of the work of Frank Reiger, OD5CG[14,15,16,17] offering similar matching properties. **Figure 6C** shows a particularly fine example of this kind of transformer using two lengths of coax of the same impedance as that to be matched but inverted. No longer is there a need for an "oddball" line impedance. The overall length is 0.1628 wavelengths, which is 35 percent shorter than an equivalent quarter-wave transformer.

Another trick is to parallel coax. For instance, if two identical pieces of coax are paralleled, the new impedance is half the individual value (**fig. 6D**).

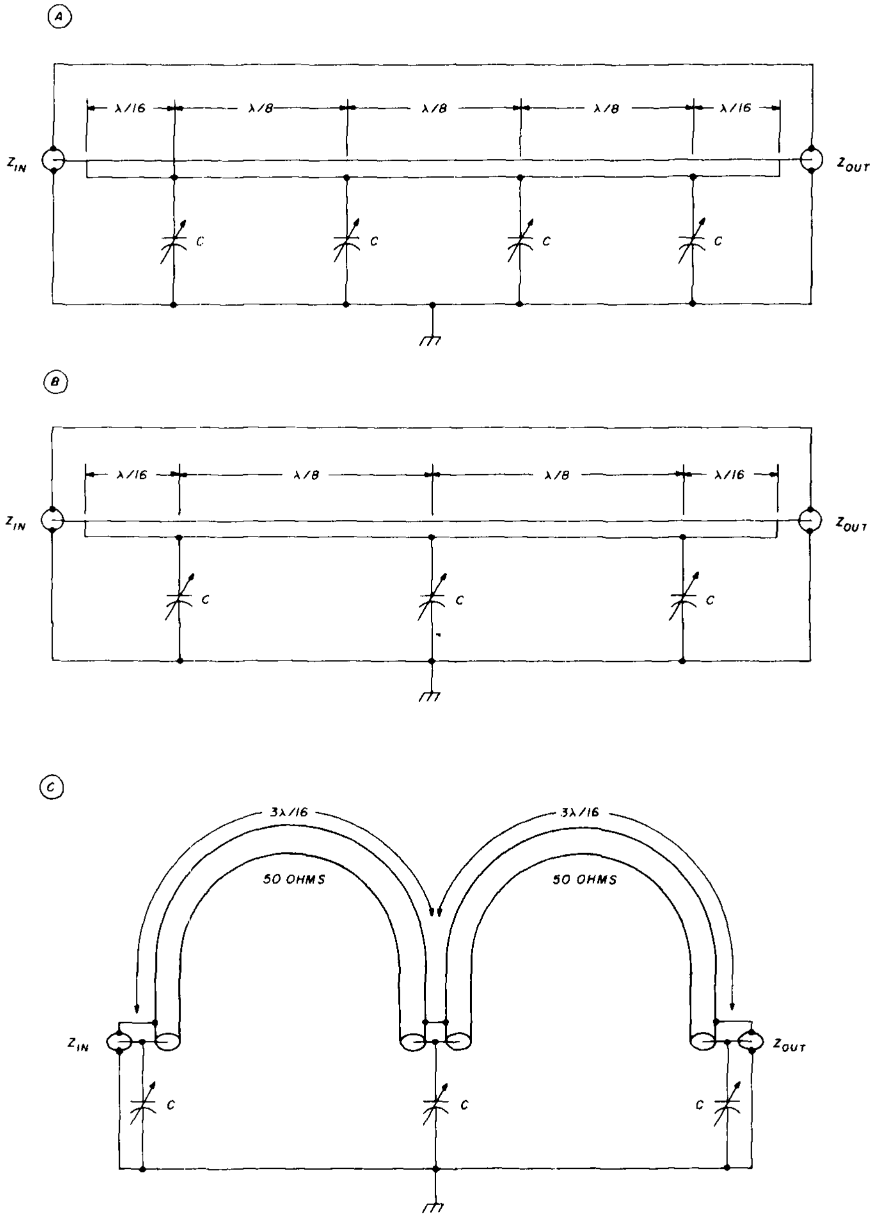

fig. 7. Examples of coaxial type antenna tuners: (A) half-wavelength adjustable transformer; (B) three-eighths wavelength adjustable transformer; (C) three-eighths wavelength adjustable transformer using coaxial cable.

Therefore, two quarter-wavelength pieces of 70-ohm coax in parallel would equal 35 ohms and could be used to match 25 ohms to a 50-ohm line. Likewise, two quarter-wavelength pieces of 50-ohm coax in parallel would have an impedance of 25 ohms and would be good for matching from 50 to 12.5 ohms.

variable impedance matchers

Some of the matching techniques just described are fine, especially when the impedances to be matched are resistive. But what do you do when you want to impedance match to a reactive load? The answer is that you need some sort of antenna tuner. At VHF/UHF/SHF frequencies this doesn't have to be the coil and variable capacitor type typically used at hf. Instead, you can build a very simple tuner using a section of coaxial line with a few small variable capacitors properly spaced along the line and shunted to ground.

Figure 7 shows some recommended types of coaxial line impedance matchers. The first, **fig. 7A**, is the most complex.[18] Basically speaking, a half wavelength of 50-ohm line is constructed in a trough, enclosure, or even in a microstrip line. Four variable capacitors are shunted to ground along the line at specific wavelength intervals as shown. **Figure 7B** shows a slightly simpler three-eighths wavelength matching scheme that probably has a little less tuning range.[19]

Figure 7(C) shows another scheme developed by one of my former colleagues, Dick Thurston. It originally used standard coax cable, so it has slightly higher loss than the schemes just described, but it's inexpensive and easy to construct. If standard coax is used, the line sections must also be shortened because of the dielectric constant of the line. At lower frequencies the coax can be coiled up. Thus a very compact, inexpensive impedance-matching transformer is possible.

The typical maximum capacitance required for the tuners shown in **fig. 7** can be determined empirically or by using equation 4 below:

$$C_{max} = 9,000/f \qquad \textbf{eqn. 4}$$

Where C_{max} is in pF and f is in MHz. For example, 60 pF and 20 pF are typical maximum values for 144 and 432 MHz, respectively. In any case, the minimum capacitance should be no greater than 10 percent of C_{max} or 6 and 2 pF, respectively.

In all of these coaxial type tuners, the capacitors must be physically small, have low inductance, and have very short leads. Mica compression trimmers similar to the types used in transistor power amplifiers are quite suitable. Air variables such as the E. F. Johnson type "U" or piston trimmers made by Johanson and others are excellent for low-power applications, especially at UHF frequencies.

On 220 MHz, I have a cathode-driven final that has a moderate input VSWR. Normally this wouldn't require any attention, but my solid-state driver doesn't care for the input mismatch. Hence a tuner similar to the one in **fig. 7C** is now used with three 4- to 40-pF mica compression trimmers and two pieces of RG-58A/U coax, each 6-1/2 inches long. This tuner now provides a good input VSWR to my final.

All that's necessary to adjust this kind of tuner is to connect it in the line with a VSWR bridge (**fig. 8A**). First set all capacitors at minimum capacitance. Then tune one capacitor at a time, starting with the one closest to the load, alternating combinations until a satisfactory match is obtained. It probably takes less time to do than explain it!

One final thought on coaxial tuners. As I pointed out earlier, additional mismatch loss will be incurred if a transmission line has even a moderate (2:1 or higher) VSWR. However, if a tuner is placed close to or at the load instead of the source, the mismatch loss may be entirely eliminated — a double bonus!

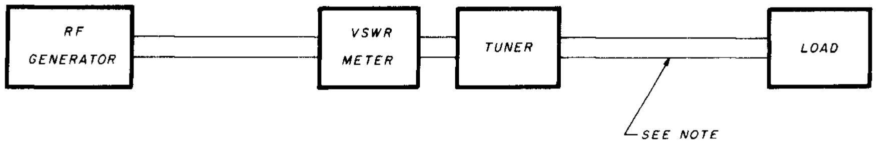

fig. 8. Typical VSWR test setup. Note that it's preferable to mount the tuner as close to the load as possible in order to decrease mismatch losses, as discussed in text.

UHF/SHF tuners

When you go higher in frequency, capacitors become inductive; consequently, the tuners mentioned above are probably usable only to about 1.3 GHz, provided that care is taken to select a good capacitor type. Above 1 GHz, impedance matching is often accomplished using variable shorted (or open) stubs, "line stretchers," and dielectric slug tuners.

Figure 9A shows the simplest type of stub tuner, usually fitted with a connector so that it can be easily inserted into a coaxial line, perhaps via a "T" fitting. If the stub won't decrease the VSWR sufficiently, a line stretcher (**fig. 9B**) may be inserted between the load and the stub so that the distance of the stub tuner from the load can be varied (**fig. 9C**).

Another common type of impedance matcher is the double-stub tuner (**fig. 9D**), which consists of two variable-length shorted (or open) stubs typically adjustable up to one-half wavelength and separated by the distance, D, one-eighth to three-eighths of a wavelength at the operating frequency. Double-stub tuners can match impedances only over a limited frequency range.

The triple-stub tuner shown in **fig. 9E** is more complex to use because it has more independent variables than the double-stub tuner. However, it will virtually match any impedance to any other impedance. It has one major drawback in that some settings will incur very high losses, so use it accordingly.

Stub tuners are in wide use, particularly where a quick impedance match is desired until a final circuit can be configured. However, most stub tuners employ some type of mechanical short circuit. This short sometimes increases insertion loss or causes intermittents due to high circulating currents, especially after extended tuner use. The construction of a suitable double-stub tuner is described in reference 20. Both double and triple stub tuners are manufactured by many companies, so they often turn up at flea markets.

Because of the mechanical problems associated with stub tuners as just described, dielectric slug tuners are sometimes used. A typical slug tuner is shown in **fig. 9F**. It usually consists of a 50-ohm air-type transmission line with electrical quarter-wavelength pieces of low-loss dielectric (such as PTFE/Teflon RTM) or metal slugs (covered with a low-loss insulating dielectric) placed along the line. Slug tuners don't have the tuning range of a stub tuner, but they will fit most applications and are usually easier to construct and use. Some recommended construction techniques for slug tuners are described in reference 21.

A variation on the slug tuner is the "multi-screw" tuner, which may be used in coax (**fig. 9G**) but is especially useful in waveguide (**fig. 9H**). It works on the same principle of operation as the coaxial tuner. The greater the number of screws available, the greater the tuning range. Brass or silver-plated screws are recommended, with appropriate nuts soldered to the housing for low-impedance, low-loss rf contacts. Some recommended construction techniques are described in reference 22.

Most of you are probably familiar with microstrip transmission lines which are very popular, especially above 1 GHz. Microstrip is often used where impedance matching is required. The quarter-wavelength transformer (**fig. 10A**) or shorted and open stubs (**fig. 10B**) are easily implemented. Microstrip is great for production equipment. However, it does require a thorough knowledge of the circuit elements and much tweaking with expensive test equipment before optimum performance can be achieved.

This explains the recent popularity — particularly above 2 GHz — of what I call the "empirical matching tuner." **Figure 10C** shows a typical configuration. A 50-ohm microstrip transmission line perhaps one-half wavelength long is etched on the pc board either ahead of or behind the device to be matched. Then thin narrow strips (0.1 to 0.5 inches wide) of brass or copper shim stock perhaps 0.05 to 0.25 wavelength long are slid along the line until an optimum match occurs.

When using this empirical technique, sometimes the size and/or shape of the metal strip has to be altered many times. Often more than

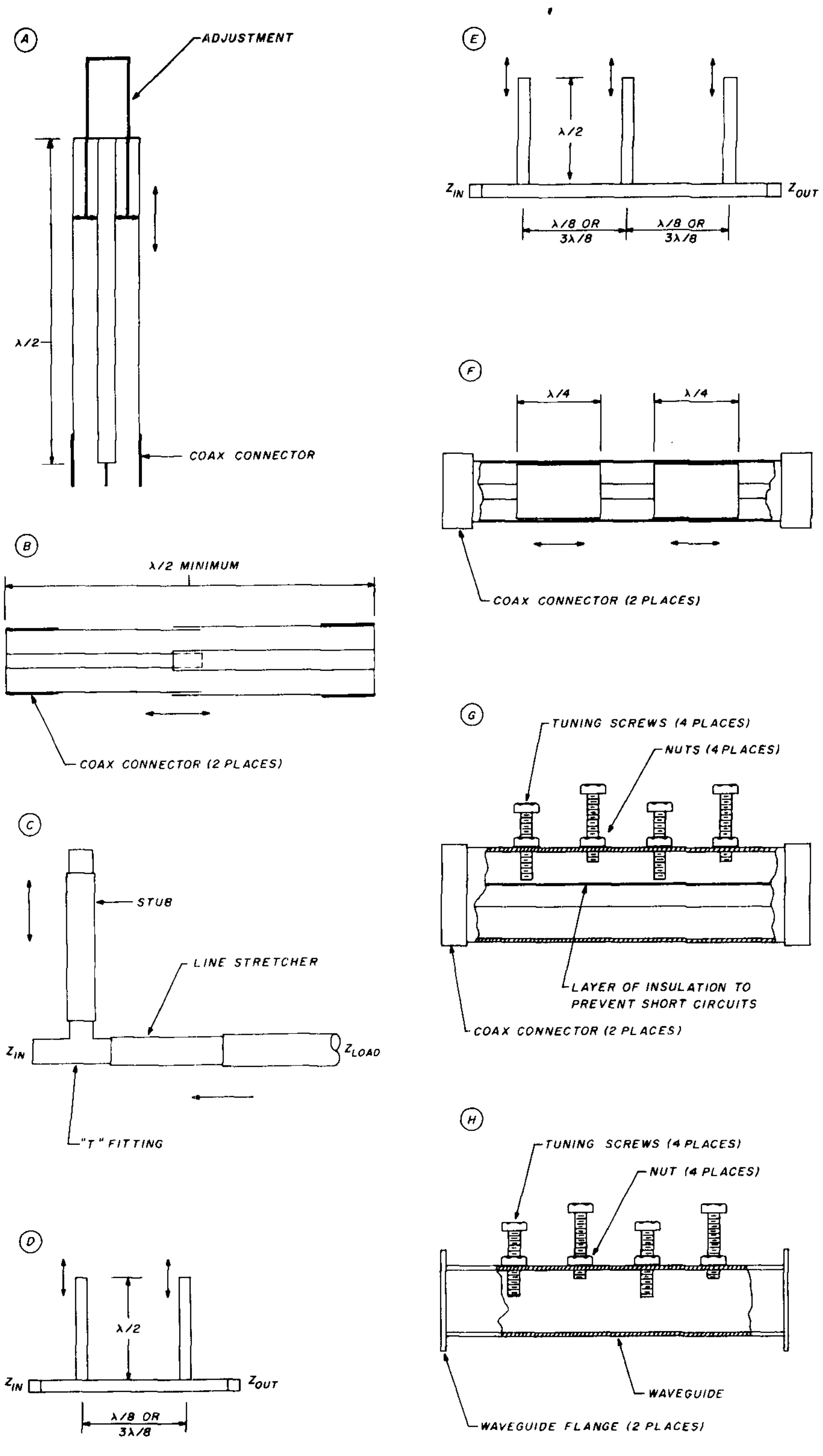

fig. 9. Examples of UHF/SHF tuners: (A) variable shorted (or open) shunt stub tuner; (B) typical line stretcher; (C) combination variable shunt stub and line stretcher; (D) typical double-stub tuner; (E) typical triple-stub tuner; (F) typical dielectric slug tuner; (G) multiple screw tuner; (H) screw tuner in waveguide.

one strip is required. These "tuners" can be slid along the main line with a small-diameter insulated material such as a wooden dowel from a cotton swab. When the optimum spot is located on the line, the strips are soldered in place and perhaps glued to the pc board so that they won't move. This approach is simple and inexpensive and can be quite effective.

wideband matching techniques

So far I've mentioned mostly narrowband matching techniques, since they're usually all that Amateurs need. Most wideband techniques require more hardware, several matching sections in cascade (rather than a single section, as previously discussed) and often have higher insertion loss.

Other wideband techniques involve the use of hybrid couplers, ferrite isolators, and circulators, but these usually aren't necessary in Amateur applications and are therefore beyond the scope of this month's column. For those interested, I'd recommend references 23 and 24 for some wideband impedance-matching transformers.

antenna impedance matching

By now you're probably wondering why I haven't covered any information directly related to antennas. The subject of antenna matching has been addressed many times in the literature. References 13 and 26 describe not only recommended techniques but also typical test equipment.

Basically, matching an antenna is largely a matter of setting up a measurement system similar to the setup in **fig. 8**. Then the length, spacings, and diameters of the driven element and matching section are adjusted until an optimum impedance match is obtained. If you have any specific questions about antenna impedance-matching techniques, let me know and they can be covered in a future column.

summary

The subject of impedance-matching techniques has been widely addressed in Amateur literature. New techniques — some simple, some complex — are constantly being presented. The material presented in this month's column reflects a summary of some of the information that should be most useful for Amateurs, especially those interested in the VHF/UHF/SHF frequencies. I hope I've described some new or interesting technique that will be of help to newcomers and oldtimers alike.

acknowledgments

I'd like to particularly thank Dick Turrin, W2IMU, for deriving the formulas necessary for me to calculate mismatch loss, and for providing appropriate references.

new records

Just as I completed this column, an important milestone in radio propagation occurred: the first two-way contact via sporadic E propagation on the 135-cm (220 MHz) Amateur band. As I've mentioned before, this has been a big plum, with at least two prior one-ways. (Yes, I was on one end of one of them!)

All that changed during the June ARRL VHF QSO Party, when sporadic E propagation was super on 6 and 2 meters in the southern portions of the United States. Finally, after a few unsuccessful attempts, on June 14, 1987, Bill Duval, K5UGM, of Irving, Texas (EM12MS) completed a two-way contact with John Moore, W5HUQ/4, of Orange Park, Florida (EM90GC), on 220.1 MHz — for a record 932 miles (1499 km). Both CW and SSB were used, and signals were much greater than S9. Congratulations to Bill and John. Another Amateur Radio propagation first! Now that it's been done, let's see how long it takes to do it again!

During this same contest, apparent double-hop sporadic E contacts took place on 2 meters. However, some of them that have been reported to me so far either were short of the present North American record (1891 miles or 3043 km) or were incomplete contacts. I would particularly like to hear from anyone who can better the existing record.

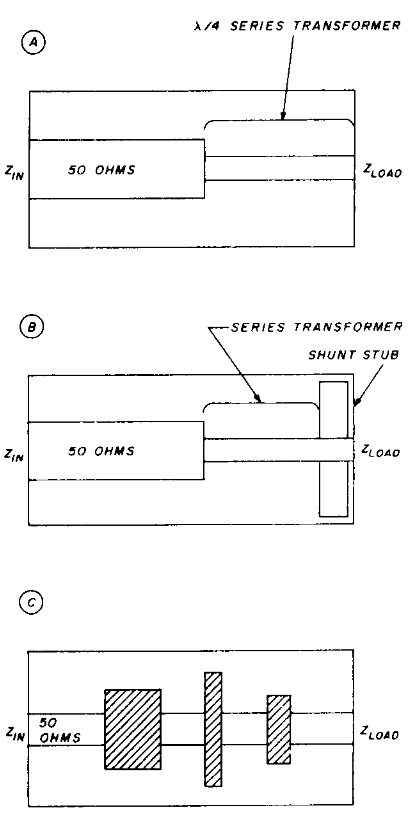

fig. 10. Examples of typical microstrip matching techniques: (A) series quarter-wavelength transformer; (B) series and shunt stubs; (C) empirical matching tuner.

important VHF/UHF events:

October 3-4	*International Region 1 UHF/SHF Contest, 70 cm and up*
October 4	*EME perigee*
October 9	*Predicted peak of the Draconids meteor shower at 0900 UTC*
October 10-11	*Mid-Atlantic States VHF Conference Warminster, Pennsylvania (Contact WA2OMY)*
October 17-18	*ARRL EME Contest, first weekend*
October 21	*Predicted peak of the Orionids meteor shower at 0830 UTC*
October 30	*EME perigee*
November 3	*Predicted peak of the Taurids meteor shower at 2200 UTC*
November 3	*Predicted peak of the Cassiopids meteor shower at 2100 UTC*

November 14-15	*ARRL EME Contest, second weekend*
November 17	*Predicted peak of the Leonids meteor shower at 1500 UTC*
November 24	*EME perigee*

references

1. Joe Reisert, W1JR, "VHF/UHF World: Transmission Lines," *ham radio*, October, 1985, page 83.
2. Gerald Hall, K1TD, *The ARRL Antenna Book*, available from *ham radio's* Bookstore; $8.00 plus $3.50 shipping and handling.
3. Theodore Moreno, *Microwave Transmission Design Data*, Dover Publications, 1958.
4. Joe Reisert, W1JR, "VHF/UHF World: Medium Power Amplifiers," *ham radio*, August, 1985, page 39.
5. M. Walter Maxwell, W2DU/W8KHK, "Another Look at Reflections — Part II," *QST*, June, 1973, page 20.
6. *Reference Data for Radio Engineers*, Sixth Edition, Howard W. Sams Company.
7. Joe Reisert, W1JR, and Gary Field, WA1GRC, "RF-CAD Electronics Design Program"; available for the IBM PC from *ham radio's* Bookstore; $39.95 plus $3.50 shipping and handling.
8. Joe Reisert, W1JR, VHF/UHF World: Low-Noise GaAsFET Technology," *ham radio*, December, 1984, page 99.
9. Phillip H. Smith, "Electronic Applications of the Smith Chart," McGraw-Hill Book Company, 1969.
10. Gerald L. Hall, K1PLP, "Smith Chart Calculations for the Radio Amateur — Part I," *QST*, January, 1966, page 22.
11. Gerald L. Hall, K1PLP, "Smith Chart Calculations for the Radio Amateur — Part II," *QST*, February, 1966 page 30.
12. Jim Fisk, W1DTY, "How To Use The Smith Chart," *ham radio*, November, 1970, page 16.
13. Joe Reisert, W1JAA, "VHF/UHF Techniques: Feeding and Matching Techniques for VHF and UHF Antennas," *ham radio*, May, 1976, page 54.
14. Frank A. Regier, "Impedance Matching with a Series Transmission Line Section," *Proceedings of the IEEE*, Volume 59, No. 7, July 1971, pages 1133-1134.
15. Frank A. Regier, OD5CG, "Series-Section Transmission-Line Impedance Matching," *QST*, July 1978, page 15.
16. Pat Hawker, G3VA, "Technical Topics: Transmission Line Transformers," *Radio Communications*, December, 1971, page 841.
17. Henry Keen, W5TRS, "Non-Synchronous Impedance Transformer," *ham radio*, September, 1975, page 66.
18. William L. Smith, W3GKP/A3GKP, "The C-Line Matcher," *QST*, September, 1968, page 23.
19. Robert D. Shriner, WA0UZO, "A Coaxial-Line Matcher for VHF Use," *QST*, July, 1969, page 20.
20. George Harterell, K6LK, "Double-Stub Tuner," *ham radio*, December, 1978, page 72.
21. Dick Turrin, W2IMU, "Technical Reports from the Crawford Hill VHF Club," available from W2IMU, P.O. Box 65, Colts Neck, New Jersey 07722 ($24.00).
22. A. B. Bereskin, "Multi-Screw Tuner for Any Mismatch," *Microwave Journal*, August, 1983, page 133.
23. George L. Matthaei, "Tables of Chebyshev Impedance-Transforming Networks of Low-Pass Filter Form," *Proceedings of IEEE*, August, 1964, page 939.
24. George L. Matthaei, "Short-Step Chebyshev Impedance Transformers," IEEE *MTT*, August, 1966, page 372.
25. Joe Reisert, W1JAA, "VHF/UHF Techniques: Matching Techniques for VHF/UHF Antennas," *ham radio*, July, 1976, page 50.

ham radio

QRO?

This is the first "QRO?" column, a collection of notes and anecdotes concerning ALPHA amplifiers, ETO, and RF power in general. We plan to print QRO? irregularly—whenever we think we have something of interest.

QRO? as you probably know, means, "Shall I increase power?" Some of our staff prefer the name "Power Lines" for this new column. If you'll help us settle the issue by dropping me a note before November 1 with your vote and the name of the magazine where you read this, we'll send you an ETO keychain as a token of our appreciation. (It may take a month or two, so please be patient.) Meanwhile, keep an eye out for QRO? (or "Power Lines") opposite ETO's regular ad.

Where have we been?

You may have wondered why ETO's monthly ad disappeared abruptly from the ham magazines in mid 1983. Well, at Dayton that year, representatives of one of the world's largest electronics companies saw our ALPHA 85 microprocessor-controlled RF linear amplifier (since superseded by the forthcoming ALPHA 88) and recognized the applicability of its basic technology to an imminent requirement of theirs.

The upshot is that ETO is now the principal supplier world-wide of the RF power amplifiers used in high field magnetic resonance imaging (MRI) systems. These sophisticated linear amplifiers typically deliver 15+ kW and cover 10-87 MHz automatically under remote computer control.

The incredibly complex medical diagnostic MRI systems in which our amplifiers are used can peer into the living human body and display images of the brain, spinal column—even the beating heart—with clarity and detail that rivals the illustrations in med school anatomy texts. Suffice to say for now, the opportunity to become involved in MRI was something ETO couldn't pass up, and we spent three years totally immersed in that challenge.

Today's ETO is a different company.

We're five times bigger than we were in 1983. A new building tripling our floor space was added in 1985. In the ETO tradition of investing heavily in new technology, our engineering group (mostly hams) has grown five-fold. We may even have a ham station on the air by the time you read this!

Meet our Technical Director.

Last year, Don Fowler (W1GRV, ex-W4YET/K6YXC) joined ETO as director of all technical activities including engineering, quality, and manufacturing. Those with long memories will remember Don as the young chief engineer of Signal/One, responsible for the original CX7 transceiver back in 1968-69. That design nearly two decades ago introduced a bevy of new techniques and features that since have become *de rigueur* in virtually all up-scale amateur transceivers.

Don spent the intervening years in increasingly responsible engineering management jobs with GenRad, Narco Scientific, and Sensormatic. There is absolutely no one I would rather have in charge of technological progress at ETO, and our new products will demonstrate why.

For now, please take a close look at the ALPHA 86 and all the truly new features and capabilities it incorporates. The '86 is FCC type accepted and shipments should be going out the door by the time you read this. Why not give us a call so we can send you a detailed brochure? Better yet, order now for earliest delivery of your new ALPHA 86!

73,

Dick Ehrhorn

Dick Ehrhorn
W4ETO