Coaxial Cables: S.W.R. READINGS, TESTING AND INSTALLATION

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The s.w.r. indicator at the transmitter never indicates the exact s.w.r. between the transmission line and antenna. Most often, however, the reading is close enough to be useful. This article explores what can cause erroneous s.w.r. readings on coaxial lines and how such lines can be tested and installed to prevent problems with them.

MANY amateurs erect a dipole or other antenna with a coaxial transmission line, place an s.w.r. indicator at the transmitter and then proceed to operate confident that everything is in order, as long as the s.w.r. indicator reading is low. If contacts are made easily, the s.w.r. indicator is just watched occasionally for any change which would indicate a deterioration in the antenna system performance. However, if contacts are not made and still the s.w.r. reading is low and the transmitter loads properly, the tendency is to blame either the antenna and proceed to try another type or to blame the QTH. To reach such a conclusion on the basis of a low s.w.r. reading may be false. In spite of the s.w.r. reading, it is possible that the coaxial transmission line is defective and that a great deal of the power which the transmitter is putting into the line never reaches the antenna.

Many amateurs find it a difficult idea to grasp that an s.w.r. indicator located at the transmitter can indicate very satisfactory line matching conditions and yet the antenna or line may not be working properly. The basic reason such a situation can occur is that although a perfectly lossless line will accurately reflect back the effects of changes in its termination (antenna), a practical line has losses which increase with frequency and such a line does not reflect back all the effects of changes in its termination.

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Conditions for Erroneous S.W.R. Readings

Although line attenuation is the basic cause of false s.w.r. readings, exactly what indication is noted depends upon a number of factors such as frequency, type of line, line condition and installation methods. It

Band	*RG-58*	*RG-58/A*	*RG-59*	*RG-8*
2	6.3	7.5	4.8	2.5
6	3.4	4.4	2.8	1.4
10	2.7	3.0	2.0	1.0
15	2.2	2.5	1.7	0.8
20	1.7	2.0	1.3	0.7
40	1.2	1.3	0.9	0.5
80	0.8	0.9	0.7	0.3

Fig. 1—Db attenuation/100 feet for common coaxial cables.

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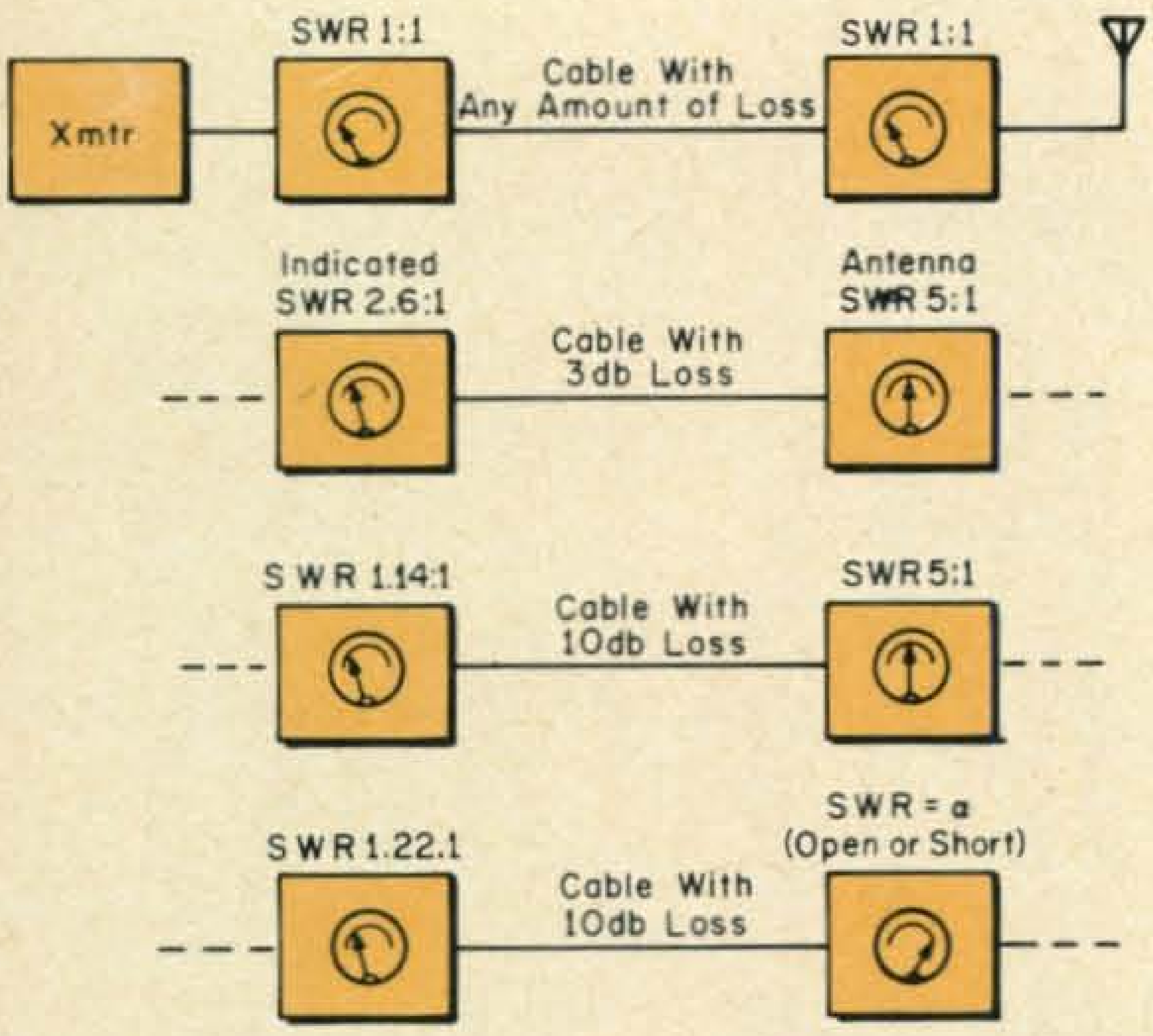

Fig. 2—S.w.r. indicated at transmitter may not be the same as actual antenna s.w.r., depending on cable loss. Loss may be due to faulty cable or long run of small cable on high frequency.

doesn't take very much attenuation, however, to produce s.w.r. readings with quite a bit of error. For example, a fairly long run (several wavelengths) of the commonly used RG-58/U cable, even in reasonably good condition, will show a relatively small change on the s.w.r. indicator at a transmitter when its far end termination goes from a direct short to an open circuit when operating on 10 meters. The high attenuation of the line simply washes out the effect of the termination, the transmitter sees 50 ohms (the cable impedance), the s.w.r. is low and conditions appear proper although the antenna may actually have *broken off* from transmission line. Of course, with a shorter length of line, a line in excellent condition or a line having less inherent loss (RG-8, for example, as shown in fig. 1) such a drastic event as the antenna becoming disconnected will be noticed on the s.w.r. indicator although it may still not accurately indicate the real value of the s.w.r. existing between the antenna and the transmission line.

The obvious point to the foregoing statements is that the readings on an s.w.r. indicator installed at the transmitter only have meaning if one knows how these readings react to changes in the antenna system in which the indicator is installed or used with. The s.w.r. indicator is a very useful instrument but not an absolute indicator of antenna system performance. The ideal situation, although in practice rarely possible, would be to use two s.w.r. indicators, one at the transmitter and one at the junction of the transmission line and antenna. Changes in antenna tuning or transmission line condition will then be readily apparent. See fig. 2.

Calculating Effect of Attenuation on S.W.R.

It is not difficult to calculate how attenuation will effect s.w.r. readings. One can make the calculation for any given installation although, unfortunately, it is necessary to do so for each band since coaxial transmission line loss is frequency dependent.

The following examples assume the use of 100 feet of RG-58/U on 10 meters and a 100 watt transmitter. Taking into account the normal line loss for new cable and about ½ db allowance for connectors and other minor discontinuities, the overall loss for the 100 feet of line is 3 db. This will cause a power loss of 50%. If the antenna is perfectly matched to the line and the line to the transmitter, there will be a 1:1 s.w.r. shown on an s.w.r. indicator at each end of the line.

Example 1—The s.w.r. at the antenna goes up to 5:1 either because of a fault developing at the antenna or because the transmitter frequency is shifted to a point where the antenna presents a poor match to the transmission line.

The power delivered to the antenna is:

$$\begin{aligned} P_{\text{ant.}} &= P_{\text{out}} \times \text{Line losses} \\ &= 100 \times 1/2 \\ &= 50 \textit{ watts} \end{aligned}$$

The power reflected at the antenna is equal to:

$$\begin{aligned} P_{\text{refl.}} &= P_{\text{ant.}} \left(\frac{s.w.r. - 1}{s.w.r. + 1}\right)^2 \\ &= 50 \left(\frac{4}{6}\right)^2 \\ &= 22.2 \textit{ watts} \end{aligned}$$

The reflected power measured at the transmitter can be calculated by:

$$\begin{aligned} P_{\text{refl. at Tx}} &= P_{\text{refl. at ant.}} \times \text{Line loss} \\ &= 22.2 \times 1/2 \\ &= 11.1 \textit{ watts} \end{aligned}$$

The s.w.r. at the transmitter can be calculated from:

$$s.w.r.\ at\ Tx = \frac{\sqrt{P_{\text{Tx}}} + \sqrt{P_{\text{refl. at Tx}}}}{\sqrt{P_{\text{Tx}}} - \sqrt{P_{\text{refl. at Tx}}}}$$

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$$= \frac{\sqrt{100} + \sqrt{11.1}}{\sqrt{100} - \sqrt{11.1}}$$
$$= 2.6{:}1$$

The s.w.r. indicator at the transmitter indicates about half of the actual s.w.r. existing at the antenna. The s.w.r. meter at the transmitter would certainly be useful to indicate that matching conditions have changed but the operator may also have a false sense of the performance being adequate at frequencies near the band-edge when, in fact, it is twice as poor as indicated on the s.w.r. meter. The same false sense of performance may occur when experimenting with different forms of antennas and taking s.w.r. readings across a band. An antenna that seems to be "broadband" may not be so after all.

Example 2. The antenna s.w.r. rises to 5:1 as before but something happens to the transmission line and instead of its normal 3 db loss, it develops 10 db loss. This will result in a loss of 9/10 of the power with only 1/10 delivered to the load.

$$P_{\text{ant.}} = P_{\text{Tx}} \times \text{Line loss}$$
$$= 100 \times 1/10$$
$$= 10 \textit{ watts}$$

$$P_{\text{refl. at ant.}} = P_{\text{ant.}} \left(\frac{s.w.r. - 1}{s.w.r. + 1}\right)^2$$
$$= 10\left(\frac{4}{6}\right)^2$$
$$= 4.44 \textit{ watts}$$

$$P_{\text{refl. at Tx}} = P_{\text{refl. at ant.}} \times \text{Line loss}$$
$$= 4.44 \times 1/10$$
$$= 0.444 \textit{ watts}$$

$$S.w.r.\ at\ Tx = \frac{\sqrt{P_{\text{Tx}}} + \sqrt{P_{\text{refl. at Tx}}}}{\sqrt{P_{\text{Tx}}} - \sqrt{P_{\text{refl. at Tx}}}}$$
$$= \frac{\sqrt{100} + \sqrt{0.444}}{\sqrt{100} - \sqrt{0.444}}$$
$$= 1.14{:}1$$

Not only has the actual power delivered to the antenna dwindled to practically nothing but about 90 watts are being wasted to heat up the transmission line. Yet the s.w.r. meter at the transmitter indicates everything being perfectly OK and the transmitter still loads properly, all because the line attenuation has gone up significantly.

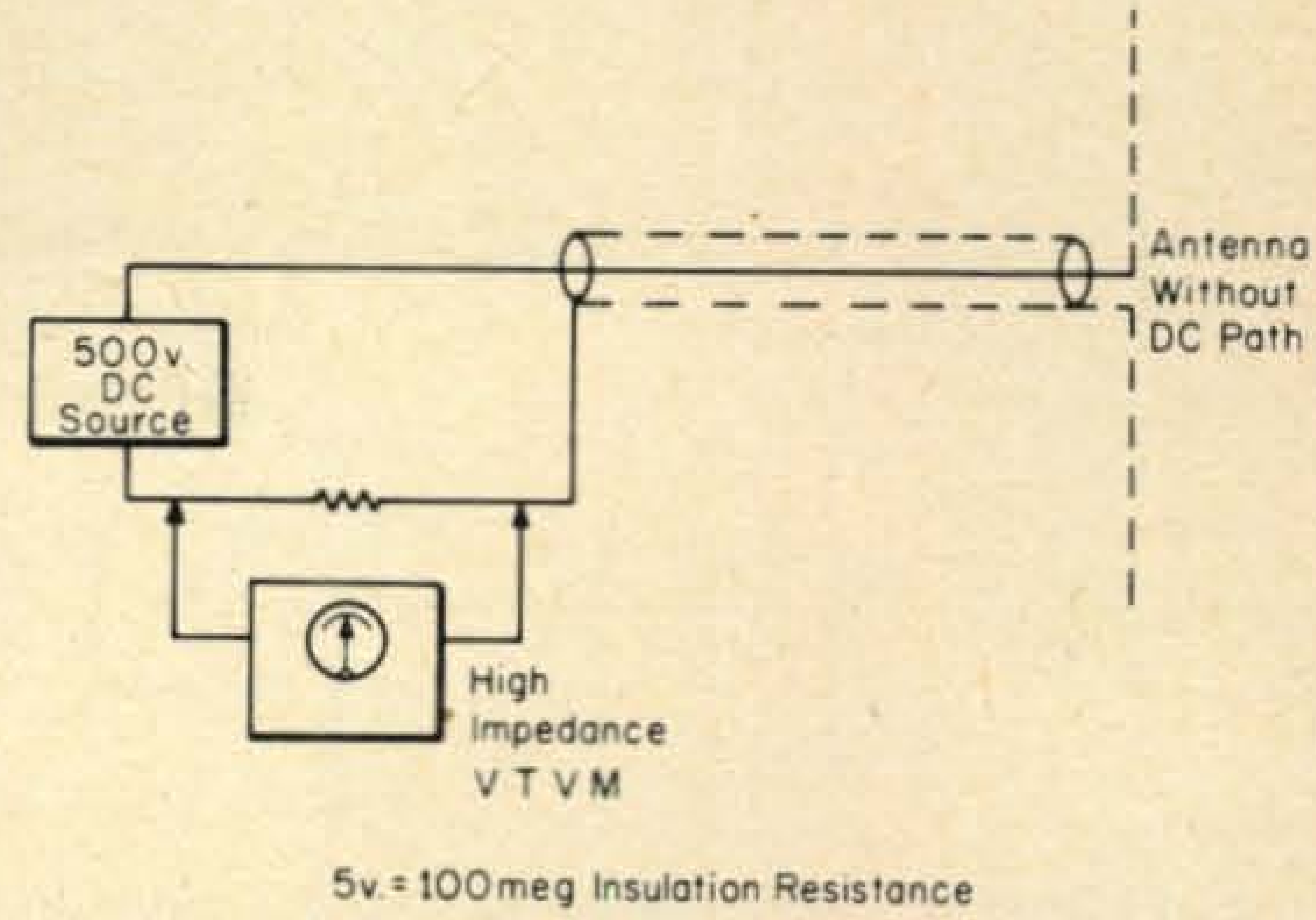

Fig. 3—Insulation resistance measurement is one simple means to obtain a quick check of cable condition. Some more expensive VTVM's have a special 1000 megohm range which can be directly employed.

When making the above calculations, the attenuation involved can either be measured or estimated. Attenuation figures for coaxial cables are available in many publications. An extra allowance must also be made for connectors, switches, filters and other devices placed in the line which contribute attenuation.

Testing Coaxial Transmission Lines

If one checks the effect of load changes at the antenna end of a line on the s.w.r. indicator at the transmitter end of the line, at least some idea is gained of the s.w.r. reading accuracy. This can be done by simulating different loads with composition resistors (100 ohms for 2:1 s.w.r. on 50 ohm line, 150 ohms for 3:1 s.w.r., *etc.*). A change in s.w.r. reading will not tell, once the line is in use, whether the antenna or line is at fault should an abnormal reading occur. The rechecking of the line by using dummy loading is also rarely possible with ease once the line is in use.

An ohmmeter can be used to determine drastic antenna faults such as opens or shorts but aside from these faults, it is pretty useless for antenna system checks. Various methods are available for checking deterioration in a transmission line. Many depend, however, upon elaborate equipment or having an accurate termination at the far end of the line while testing. One very interesting method is the use of a time domain reflectometer where a step voltage is impressed on the line and returning reflections versus time are displayed on an oscilloscope. Both the general type or fault and its location can be determined. However, about the simplest method to use, which can also be done with the antenna connected as long as the latter does not present a direct d.c. path, is the

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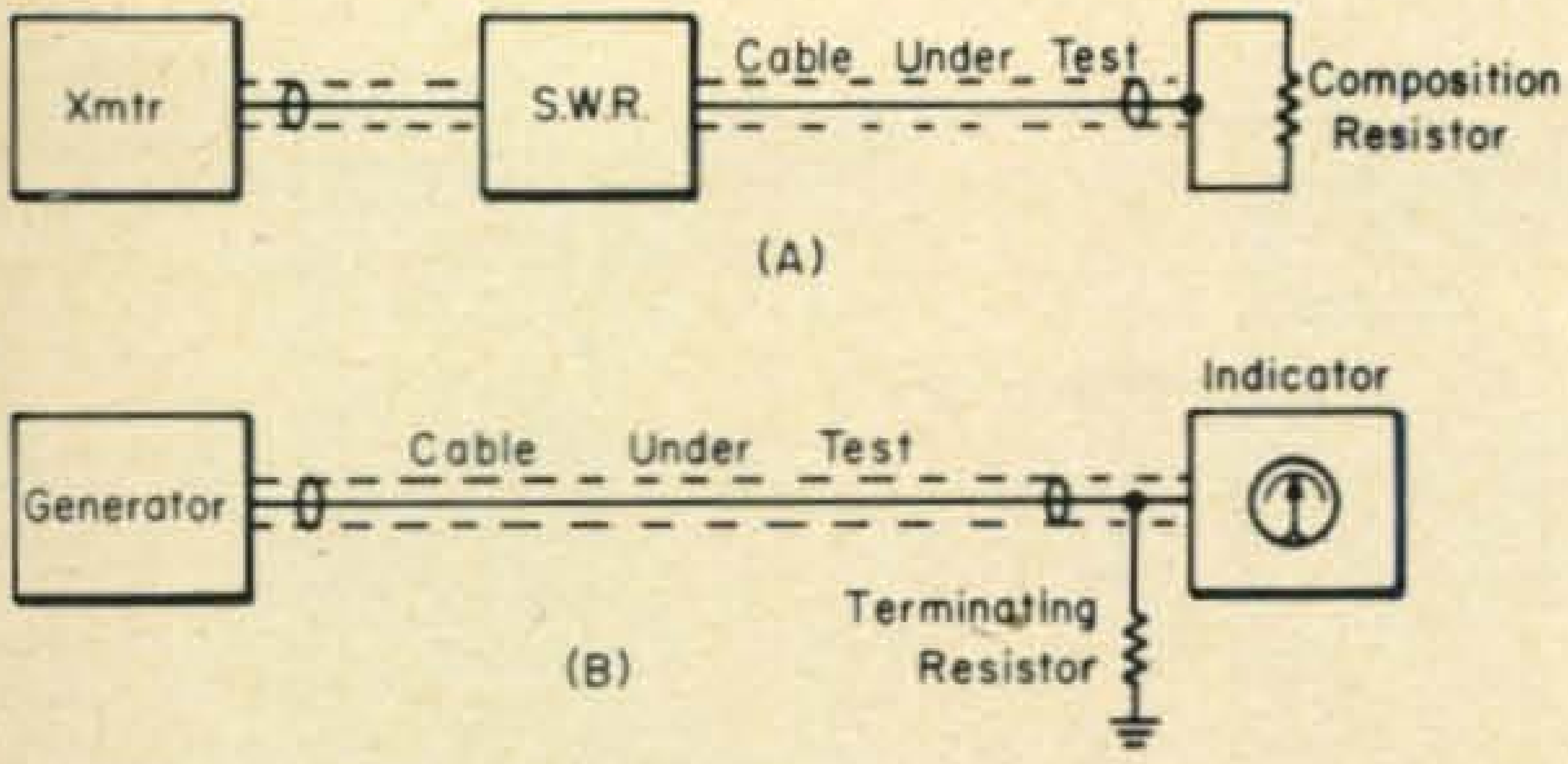

Fig. 4—Generalized methods to measure attenuation. Method (A) creates an artificial s.w.r. and cable loss is calculated from formulas given in text. Method (B) compares output of cable being tested to output available from direct connection between generator and indicator.

measurement of insulation resistance. The method is used widely in commercial and military installations to periodically check the general condition of coaxial lines for the h.f. bands.

Measuring Insulation Resistance

A megohmmeter is commonly used to measure insulation resistance. It is a form of ohmmeter designed to measure high resistances from 20 to 1,000 megohms. Those amateurs with experience in the electrical power field are probably well acquainted with this instrument. A regular ohmmeter is not useful to measure the insulation resistance between the shield and inner conductor of a coaxial cable since their maximum resistance range is 1 to 10 megohms. The insulation resistance of a coaxial line should normally run from 100 to 200 megohms. When it falls below 100 megohms, it is usually a good indication that moisture has entered the cable, the dielectric is damaged or some other difficulty exists.

The megohmmeter consists essentially of a 500 volt hand-crank generator and a special construction microammeter that requires no "zeroing". However, with care one can use the instruments normally available around the shack to perform the same measurement. A power supply delivering a few hundred volts and a microammeter are necessary. The circuit must be protected against a short by a series protective resistor of sufficient value to protect the power supply and meter. As long as the voltage and current readings across the coaxial line are properly taken, the resistance is easily calculated. (See figure 3.)

This simple measurement will hardly detect some of the complicated chemical changes that could occur in a cable but assuming the cable is in good condition when purchased, it will normally give warning of any drastic change in cable characteristics.

Attenuation Measurements

If cable is used which was not purchased fresh or if cable is being reused from another installation, a check of its attenuation characteristics may be in order. Again, such a measurement can be made with complicated instruments to a high degree of accuracy or with simpler instruments to obtain approximate values. One simple method of measurement is the reverse of the procedure described before to determine cable effect on s.w.r. readings. One calculates what the s.w.r. reading is at the transmitter end of the line from a known, artificially created s.w.r. at the load end of the line. Normalized to attenuation per 100 feet, one can then compare the attenuation of the cable under test to that value given for the cable in a manual. This arrangement is shown in fig. 4(A).

A signal generator can be used in several ways to measure attenuation. The line can be terminated in its characteristic impedance and, with a v.t.v.m., the actual input/output powers calculated. The signal generator must, of course, be carefully matched to the cable. If the generator has a well calibrated output, the amount of increase in db output necessary for the generator to work directly into a load is compared to going through the cable under test to the load will be the attenuation. This assumes the same level across the load as checked by a receiver "S" meter or v.t.v.m. A less accurate but still useful method is to use the receiver "S" meter as a db indicator. The drop in reading is noted as the cable is connected between generator and receiver as compared to a direct connection between generator and receiver as shown in fig. 4(B).

Coaxial Cable Installation

Most faults that occur because of installation methods have to do with poor connections, moisture entering the cable and use of sharp bends. Connections are best made in accordance with the method suggested by the connector manufacturer. These methods are detailed in various manuals and also available in free literature available from most manufacturers. Manufacturers certainly are interested in having their connectors put into service as quickly as possible while still performing properly and there rarely should be reason to deviate from their instructions. In

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spite of this, the use of connectors is often seen with mechanical stress capabilities exceeded and with unduly long discontinuities on the constant impedance coaxial path. Splices in cables should definitely be avoided unless the economics of the situation allow no other choice.

Moisture can do a great deal of damage to a cable. The shield corrodes, the wires become insulated from each other and the efficiency of the shielding is ruined. If the cable is flexed, the shield may open up altogether. Moisture cannot enter a cable along its run unless nicks in the jacket are present. Even small nicks or cuts can allow a great deal of damage to occur and should be sealed with tape or heat shrinkable tubing. Moisture can enter the ends of the cable if they are not sealed off or some cement compound used to waterproof the ends. Most connectors in common use are *not* waterproof types and, again, tape or heat shrinkable tubing should be placed over them.

Coaxial cables were never meant to be bent like hookup wire. If a cable has a very sharp bend in it, the dielectric is strained and it will tend to crack inside the cable as the cable gets older. If the cable is subject to temperature and moisture extremes, such as in outdoor service, the cracking progress is considerably accelerated. In general, a cable should never be bent in a radius less than 10 times the cable diameter (fig. 5). In service where the cable is continually flexed, such as a rotatable beam installation, the minimum radius should be two to three times greater. Coaxial cable was also never meant to be self-supporting

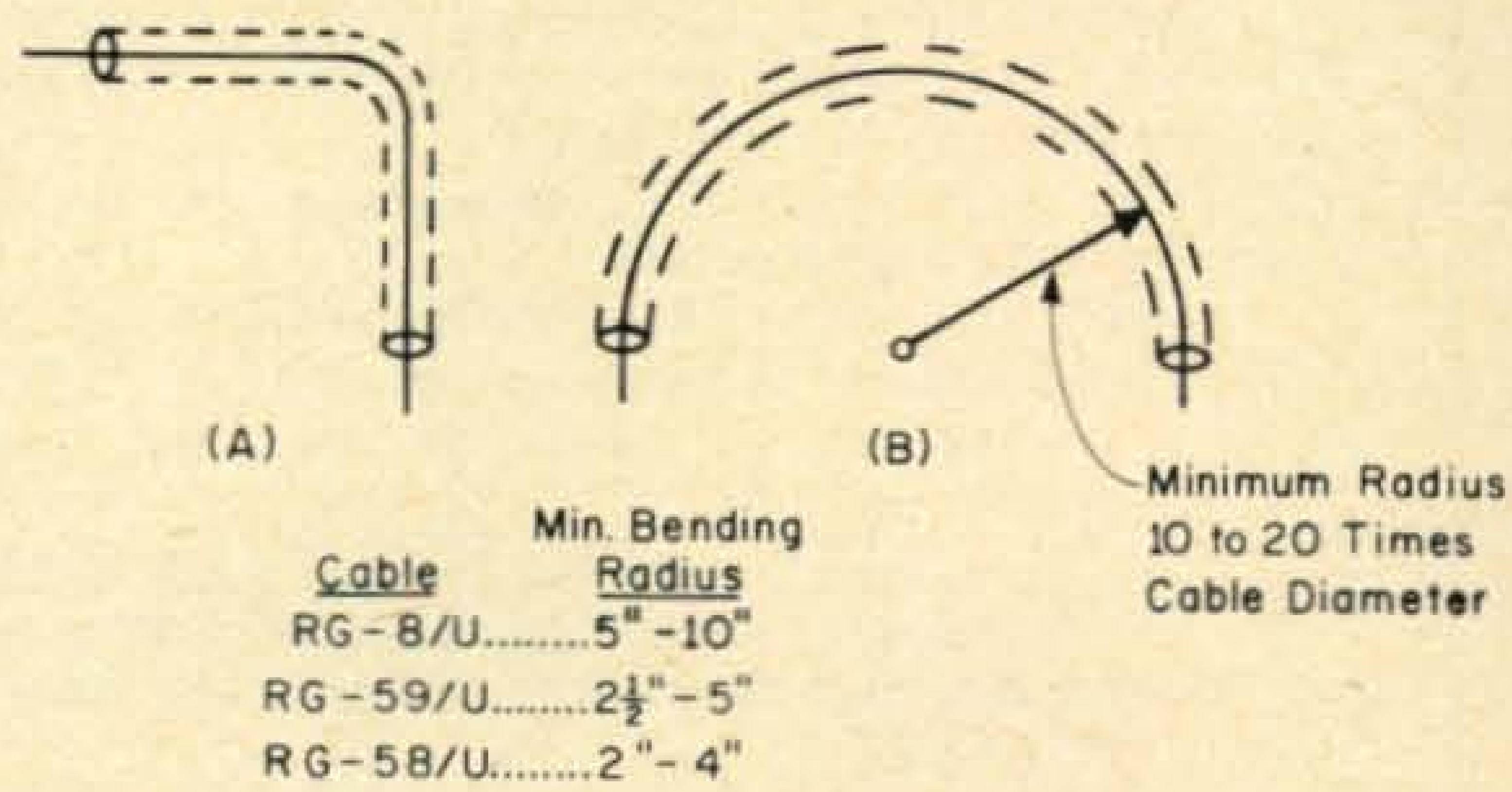

Fig. 5—One common installation fault: sharp bends (A). Cable should be bent gradually (B) to prevent eventual damage to dielectric.

for any great lengths. The distortion in form produced by draping long lengths of cable can effect its performance. The cable manufacturers recommendations should be secured before using any long run of unsupported cable. The use of a hanger wire will often insure a more maintenance free installation.

Summary

This article has tried to present some basic precautions to be observed when reading s.w.r. on a coaxial cable and basic testing and installation methods. Although a careful installation will probably pay most dividends when used for transmitting, receiving conditions will also benefit, especially if proper shielding is useful in preventing local noise pickup. Proper interpretation of s.w.r. meter readings and proper cable installation is not difficult. Certainly, there is no reason to nullify the benefit of having a good radiator by a haphazard transmission line installation. ■