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Feedline Primer

No matter how carefully we try to arrange our station, it's next to impossible to put the antenna and the transmitter in the same place. As luck would have it, antennas must be high off the ground, and clear of surrounding objects that might dampen their power, while the transmitter is usually put indoors where it's convenient to use. The solution to this problem is to use a "transmission line" which is designed to carry the radio-frequency power from one particular place to another.

Ideally, a transmission line should be able to transport power over any distance without letting any escape, but at radio frequencies a wire acts quite differently than it does at the 60 Hz power-line frequency, and it's this difference that makes transmission line more lossy and complex than ordinary wire.

The difference is related to the fact that at 60 Hz a wavelength of wire is on the order of 3100 miles, so that a 100 mile length of line is only an insignificant 1/31st of a wavelength, but at 30 MHz (10 meters) a 100 foot feedline is nearly 3 wavelengths long. Consequently, as discussed later, very different things can be happening at various points along the line. Because of this, the line can begin to lose power, which means that less power will reach the antenna than should.

Before we start, though, it might be a good idea to describe what the ideal line would be like. The ideal "infinite line," as it's called, consists of two perfect conductors placed side-by-side and extending on into infinity. At any one time, the polarity of the current in the first conductor is exactly opposite that in the second conductor. In other words, the two currents are 180 degrees out of phase. As a result, if any radio-frequency energy is lost by one of the conductors, it will be opposite to that lost by the other conductor, and the two fields will cancel each other out. To cancel completely, both losses must be equal in amplitude (the same strength) which would only happen if the two wires occupied *exactly* the same spot in space. Since this cannot take place, there will always be some loss from any line. However, these losses will be negligible so long as the two conductors are spaced at less than 1/100th wavelength.

Characteristic Impedance

In our infinite line, the characteristic impedance, sometimes called "surge impedance," is roughly equal to the square root of the ratio between line inductance and capacitance:

$$Z = \sqrt{L/C}$$

The inductance, while small, is due to the fact that the wire sets up a magnetic field around itself, which in turn induces a current back on the wire that is opposite in direction to the existing current flow. This results in cancellation, the total effect being that of inductance. The capacitance is due to the separation of the two conductors (which act like the two plates of a capacitor), by some type of dielectric such as air, or plastic insulation.

The capacitance, inductance and impedance of a particular line will depend upon the distance between conductors, and their size. The larger the conductors and the closer their spacing, the lower the inductance and the greater the capacitance, and vice versa. A high impedance line will have small conductors widely spaced, while a low impedance line will have large conductors closely spaced. In the infinite line, this impedance is purely resistive, but in a real line there will be some reactive component due to inductive and capacitive effects. It might be noted that characteristic impedance determines the amount of rf current that can flow for any given voltage. Consequently, as the impedance decreases, a higher current will flow for any given power level.

The Practical "Matched" Line

The practical line (one that can really be built) will only try to act like an infinite line if it is terminated by a pure resistance equal to the line's characteristic impedance. If this condition is satisfied, then the line is said to be "matched." In other words, the line acts just like an infinite line delivering all its power to a load (the resistance). In practice, the load would be the antenna, which would radiate all the power presented to it. Consequently, to the radio wave the load only looks like a continuation of the line because it has the same resistance as the line does. In addition, under matched conditions the line's actual impedance (that which can be measured, and is really there) will be equal to its characteristic impedance (that which should be there). As we will soon see, this is

Table A

Attenuation in dB/100 Feet

Type	3.5 MHz	7 MHz	14 MHz	21 MHz	28 MHz	50 MHz	144 MHz
RG-58/U	.78	1.1	1.7	2.2	2.5	3.5	6.3
RG-8/U	.30	.45	.66	.83	.98	1.35	2.5
RG-59/U	.60	.90	1.3	1.6	1.9	2.7	4.8
RG-11/U	.35	.55	.80	.98	1.15	1.5	2.3
Twin-Lead	.19	.28	.41	.52	.60	.85	1.5
Open-Wire	.03	.05	.07	.08	.1	.13	.25

Table B

Type	Impedance	Velocity Factor	30 MHz Power Rating
RG-8/U	52	.66	1700 Watts
RG-58/U	53.5	.66	430 Watts
RG-11/U	75	.66	1400 Watts
RG-59/U	73	.66	680 Watts
RG-17/U	52	.66	5600 Watts
Twin-Lead	300	.82	-----
Open-Wire	-----	.95	-----

Fig. 1. In Table A, attenuation figures may vary from manufacturer to manufacturer. In Table B, the open-wire line impedance will vary depending upon conductor spacing. Wattage capacities of parallel conductor line will depend upon wire size and conductor spacing, there being no "standard" size open-wire line, but many differently built types.

Additional Loss Due To swr
(In dB)

	swr								
	1.5	**2.0**	**3.0**	**4.0**	**5.0**	**7.0**	**10**	**15**	**20**
.2	*	*	.13	.22	.30	.48	.7	1.2	1.5
.3	*	*	.18	.3	.42	.63	1.0	1.6	2.0
.4	*	.1	.23	.38	.54	.85	1.25	1.9	2.5
.5	*	.13	.27	.47	.65	1.0	1.5	2.3	3.0
.6	*	.14	.32	.54	.75	1.2	1.75	2.6	3.3
.7	*	.15	.36	.6	.85	1.3	2.0	2.8	3.6
.8	*	.18	.4	.69	.95	1.5	2.2	3.0	3.9
.9	*	.19	.45	.75	1.1	1.6	2.3	3.3	4.0
1.0	*	.2	.5	.82	1.2	1.7	2.5	3.5	4.3
1.5	*	.26	.67	1.2	1.5	2.2	3.0	4.3	5.1
2.0	.1	.3	.8	1.3	1.8	2.5	3.5	4.8	5.8
2.5	.13	.35	.9	1.5	1.9	2.8	3.8	5.1	6.0
3.0	.14	.39	1.0	1.55	2.0	3.0	4.0	5.3	6.5
4.0	.15	.41	1.05	1.7	2.3	3.3	4.3	5.8	6.8
5.0	.16	.45	1.1	1.75	2.4	3.4	4.5	6.0	7.0
6.0	.17	.48	1.15	1.8	2.5	3.5	4.6	6.2	7.2
7.0	.18	.49	1.2	1.8	2.5	3.5	4.8	6.4	7.4
8.0	.18	.5	1.2	1.8	2.5	3.6	4.9	6.5	7.4
9.0	.19	.5	1.25	1.9	2.5	3.7	4.9	6.5	7.5
10.0	.19	.5	1.25	1.9	2.5	3.7	4.9	6.5	7.5

*Additional loss is less than .1 dB.

Fig. 2. Find the loss for your cable from Fig. 1, and then locate the nearest dB figure in the left column of this table. Follow that line to the right until you reach the proper vertical column for the swr you have. At this point is the additional loss figure.

not always the case, especially when the line is mismatched.

Standing Waves On A Mismatched Line

As pointed out above, if the line is terminated in a load having the same resistance as the line's characteristic impedance, just about all power is delivered to the termination. But suppose that the load is a different value? In this case, some of the power is reflected backward down the line. This may be visualized by picturing water flowing through a six inch pipe which represents the line. If the pipe is coupled through a reducer to a three inch pipe (representing the load), pressure would be higher in the three inch pipe than in the six. As a result, water would flow backwards at the junction as the pressure tries to equalize. Because of this, both *forward* going and *reflected* power will be present along the line. In some places this power will cancel, while in others it will reinforce, thus causing peaks and valleys (referred to as antinodes and nodes) in the voltage and current distribution. The actual voltage or current at any one point will be equal to the sum of the forward and reflected voltages, or currents, found at that point. Consequently, as you move along the line, if the voltage could be measured, you would find that readings would vary up and down at equal distances coinciding with the maximums and minimums resulting from the sum of the two opposite currents. In a perfectly matched line, the voltage and current will be constant along the line's length because there is only one current traveling through the transmission line, so there is nothing for it to reinforce with.

Since the peak voltage found on a line is related to the severity of the mismatch, the ratio of maximum to minimum voltage is used as an indication of how well the transmission line is matched to the load. Current may also be used in this manner. This is called the "standing wave ratio" and it may be expressed either as swr = V_{max}/V_{min} or swr = I_{max}/I_{min}. In a perfectly matched condition, the maximum voltage or current will be equal to the minimum, so the ratio is equal to 1. This is the "ideal" condition that most hams shoot for, but an swr of anywhere from 1.05 to 1.5 is often considered to be hard enough tc obtain, and certainly good enough for most people.

Swr may also be expressed as a quotient between the impedance of the load, and the impedance of the line with the numerator of the fraction being the larger of the two numbers (swr = Z_o/Z_r, or swr = Z_r/Z_o. Z_o = characteristic impedance, Z_r = load impedance). Because the largest number is customarily put on top, the swr can never be less than one.

Since it is easier to measure than either impedance, capacitance or inductance, swr is used more commonly in determining just how well lines are matched. In the average shack, a reflectometer is used to measure the forward and reverse voltages on the line. From these voltages the swr is then calculated by using the equation swr = $(V_o+V_r)/(V_o-V_r)$, in which V_o = forward voltage, and V_r = reverse voltage. Notice that the sum of V_o and V_r will be the maximum voltage that can appear anywhere on the line, and V_o-V_r will be the minimum voltage, so we are back to our original equation, swr = V_{max}/V_{min}. Lest this look like an awful mess to tackle each time you want to find out what your swr is, most reflectometers (swr bridges) have a calibrated swr scale to eliminate the nuisance of repeated calculations.

Input Impedance of Mismatched Lines

As mentioned earlier, the impedance of a line that is perfectly matched to the load is equal to the characteristic impedance of the line. Consequently, a transmitter operating into the line's "input" side would see an input impedance equal to the characteristic impedance. On the other hand, if standing waves are present, the input impedance may vary considerably from the expected characteristic impedance value.

The reason for this variance is the fact that the voltage and current phase relationship found at the input side of the line can change when an swr is present. This will create an impedance that is very different from the characteristic impedance of the line. Remember that impedance is equal to the ratio of voltage to current (Z=E/I) so the input impedance will change in step with whatever voltage and current there is at the input point. Since voltage is not in phase with the current, the voltage to current ratio at different points along a wavelength of line will vary. Correspondingly, since the voltage and current waveform repeats itself at intervals of one-half wavelength, the values of impedance will do the same. It may now be seen that the input impedance of a mismatched line will be very different depending upon how far the input is from the load. If the swr and line length are such that a low voltage and a high current appear at the input, then the input impedance will be lower than the characteristic impedance. High voltage and low current will result in an input impedance higher than the characteristic impedance.

In addition to causing a variation in input impedance, swr also causes it to contain reactance. This effect is present regardless of whether the load is purely resistive or reactive. The presence of a reactive component is due to the out-of-phase relationship between voltage and current caused by swr. If voltage lags current, then the reactance is capacitive; if current lags voltage, it is inductive, just as if a capacitor or inductor were connected across the line. The only exceptions to this effect are at the nodes, where the voltage and current are in phase. At these points, which appear at one-quarter wavelength intervals, the impedance is purely resistive.

Resonant Lines

Many transmitters are capable of operating into a variety of resistive impedances,

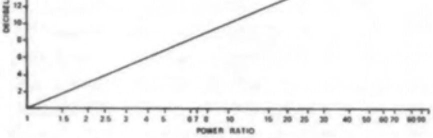

Fig. 3. Chart used to convert decibels to a power ratio. For instance, 7 dB represents a ratio of 5 to 1.

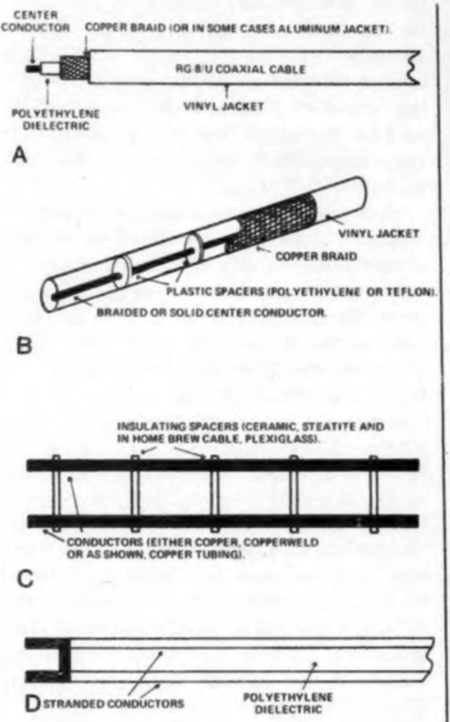

Fig. 4. Four examples of transmission line often used by amateurs.

but they cannot tolerate reactance. Consequently, it is possible to load up into a mismatched line only so long as the input is at one of the nodes. When a feedline is cut to benefit from this situation the line is said to be "resonant" or "tuned." A line with a low swr, and a fairly uniform impedance that falls close to the characteristic impedance regardless of line length, is called "nonresonant" or "flat."

A flat line is usually considered to be one having an swr of 2:1 (i.e.,2.0 or 2 to 1) or less, and can be as long as necessary. When the swr rises above 3 to 1, the line falls into the "resonant" category, because it can only be used efficiently if its length is adjusted so that the input is at a node.

As a rule, the lower the swr the better, so a "flat" line is generally the objective. In most cases, a resonant line is resorted to only if there is a bad mismatch between the line and the load, and neither can be adjusted to straighten everything out.

Velocity Factor

In the common types of available transmission line, polyethylene insulation is used between the two parallel conductors. The plastic is used both to separate the conductors, and to keep them at a fixed distance from each other. However, the use of this insulation has two drawbacks: It causes power loss, and it reduces the speed at which power may pass through the line because electromagnetic fields travel more slowly through solid materials than through free space. This means that for the same frequency, the wavelength in a transmission line is shorter than it would be in air. In other words, the wave doesn't travel quite as far during one cycle because it has been slowed down.

Throughout this article, when reference has been made to a "wavelength" of line, it is the so-called "electrical" wavelength that has been meant. To convert from physical to electrical length, the "velocity factor" must be used. The velocity factor is the ratio of wave velocity within the line to wave velocity in free space. The equivalent physical length of a wavelength of line may be calculated by using the equation: length in feet = $(984V)/F$, F = frequency in megahertz, and V = velocity factor.

The velocity factors for several popular types of cable are given in Fig. 1, Table B.

Transmission Line Losses

Coming back to the perfectly matched transmission line, there are three major ways in which power may be lost: by I^2R losses in the wire (heating of conductors), by heating of the insulation (dielectric heating), and by radiation.

To a small extent, heating of the conductors is due to the inherent resistance of the wire. These are usually referred to as I^2R losses because they follow the power formula $P = I^2R$. Major heating is caused by the conductors' inductive reactance. Unlike resistance, the reactance increases with frequency, so that losses become quite considerable at high frequencies. Conductor losses also increase as the characteristic impedance decreases, because higher currents may flow for a given voltage in a low impedance line. Dielectric losses are just the opposite: They increase as voltage increases, so greater loss occurs on a high impedance line. Dielectric losses also increase with frequency.

Radiation losses, in a perfectly matched line, are due to stray coupling of rf from the antenna. This rf may be phased in such a manner as to cancel part of the existing wave on either conductor, and it is in this way that much of the loss takes place. Any additional radiation loss is caused by the small uncancelled leakage caused by the slight separation of conductors.

Swr And Line Losses

As swr increases, it is normally assumed that line losses become severe, and efficiency falls below acceptable values. As we have seen previously, tuned or resonant lines may be operated under mismatched conditions. In fact, a low swr is not necessarily all that important. Whether swr related losses are serious or not depends upon the inherent line loss under perfectly matched conditions. If the original line is air-insulated, for instance, the inherent loss is low because of the absence of a lossy dielectric, so the swr related loss is also small. However, if the line has polyethylene insulation, there is a much greater dielectric loss, hence a high swr related loss. Since dielectric and conductor losses increase with frequency, so will the losses due to swr. Consequently, an acceptable swr at 14 MHz may well be unacceptable at 28 MHz, because of increased inherent loss. For this reason, low loss air-insulated transmission line is often used to feed a multiband antenna, which has a wide variety of swr values across different bands, so that swr related losses will be nearly as insignificant on 10 meters as on 80, no matter what happens to the swr.

When computing total line losses, take the inherent loss for the cable you are using from Fig. 1, Table B, and *add* it to the swr caused loss from Fig. 2. Accuracies in Fig. 2 are ± .05 dB for losses less than 1 dB and ± .5 dB for loss values greater than 1 dB. Remember that the inherent loss is shown in dB per 100 feet, so the dB figure must be corrected for the length of cable you are using. For example, if you were using 50 feet of line, you would multiply the appropriate dB value by 1/2, for a 75 foot piece you would multiply by 3/4, and so on. Fig. 3 may be used to convert the dB figure into an actual power ratio.

In addition to increasing line losses, swr also affects the power handling capabilities of a transmission line. All lines will have a voltage limitation imposed by the voltage breakdown, or arc voltage for air-dielectric lines, between the two parallel conductors. The current limitation is dependent upon conductor diameter and metallic composition, and the melting or ignition point of any insulation that is used. The amount of power that can be safely handled when an swr is present is inversely proportional to the standing wave ratio (reduced power handling capacity = original capacity/swr). In other words, if the line was originally able to handle 1000 Watts, an swr of 5 to 1 will reduce this capability to 200 Watts.

Coaxial Cable

Several types of transmission lines fall into the coaxial cable group, but by far the most common is the solid dielectric type. In this form, as seen in Fig. 4, at A, a solid or stranded center conductor is surrounded by polyethylene insulation. A shield of braided copper follows, forming the second conductor, and a waterproof vinyl protective cover encircles the braid. For low power handling capabilities, the center conductor is usually #18 copper, single conductor.

Copperweld, comprising of a steel inner wire bonded to an outer coating of copper, is used to increase strength in the center conductor. However, both hard and soft-drawn copper (though more easily broken), are 7 times more conductive than steel. The only reason that copperweld can be used effectively is that at radio frequencies inductance in the wire's center will tend to force the rf into the outer copper layer, where resistance is lower. It is for this reason that cable used at high frequencies, where efficiency must be at a maximum, often has silver plated conductors. Silver is about 6%

more conductive than copper, which may not seem very impressive, but every little bit counts when dielectric and reactive losses approach 2 dB/100 feet, such as one might find at 432 MHz.

In cables intended for use at high powers (1000 Watts and above), a stranded center conductor is used instead of a solid copper, or copperweld conductor. Unfortunately, the spiraling of the stranding creates a spiraling of the rf, resulting in a longer rf path. Also, there is a higher center conductor resistance because of the contact resistance between each strand and its neighbor. This resistance contributes to a higher total attenuation in this type of cable.

As mentioned before, solid polyethylene, with a dielectric constant of 2.3, is the insulation used in most coaxial cable. The ideal cable would be an inner conductor suspended exactly in the middle of the outside conductor, with air as the only dielectric. In this case, the dielectric constant would be that of air (1.0) which is the "ultimate" (except for a vacuum) and provides the lowest attenuation. This is impossible in practice, because supporting material must be used to maintain proper spacing between conductors. Therefore, a compromise can be made between the high constant of polyethylene and the low constant of air. In some cables a foamed polyethylene dielectric having countless encapsulated air bubbles is used, resulting in a dielectric constant of 1.5 or thereabouts. With such cables, attenuation figures at 100 MHz are at least 1.5 dB better than regular cable, and even greater at higher frequencies.

Another method of lowering the dielectric constant is shown in Fig. 4, at B. During production, the areas between each spacer are filled with air so that a high percentage of the dielectric is of a low loss nature. Since this type of cable must be pressurized as it is extruded, it is more costly to manufacture and not frequently used in amateur applications. Another disadvantage is the fact that cables of this nature are not very flexible. Also, in the areas between spacers, the distances between conductors can vary, causing different impedances to be present. All of these small mismatches can add an swr of as much as 4 to 1 at some frequencies.

Table of Coax Data

RG #	Imp.	Cap.	Max. Volts
5B/U	50	29.5	3000
8/U	50	29.5	5000
8A/U	52	29.5	5000
9/U	50	30.0	5000
9B/U	50	30.0	5000
11/U	75	20.5	5000
11A/U	75	20.5	5000
14A/U	52	29.5	7000
17A	52	29.5	11000
22/U	95	—	—
54A/U	58	—	—
55B/U	53.5	28.5	1900
58/U	53.5	28.5	1900
58A/U	50	29.5	1900
58C/U	50	29.5	1900
59/U	73	21.0	2300
59A/U	75	20.5	2300
59B/U	75	20.5	2300
62/U	93	13.5	750
62A/U	93	13.5	750
63B/U	125	10.0	1000
71/U	95	13.5	750
71A/U	95	13.5	750
71B/U	125	13.5	—
79B/U	125	10.0	1000
108A	78	20.0	1000
141/U	50	29.0	1900
174/U	50	30.0	1500
178/U	50	29.0	1000
179B/U	75	19.9	1200
187/U	75	19.3	1200
187A/U	75	19.5	1200
188/U	50	29.0	1200
188A/U	50	29.0	1200
195/U	95	15.2	1500
196A/U	50	29.0	1000
212/U	50	29.5	3000
213/U	50	30.5	3000
214/U	50	30.5	3000
215/U	50	30.5	3000
217/U	50	29.5	7000
223/U	50	30.0	1900

Fig. 5. These figures may vary slightly from manufacturer to manufacturer.

In most cable the shield is made up of many fine wires braided into a tube that surrounds the insulation. Since there are a large number of individual wires, there is a considerable total contact resistance. Also, the shield is not 100% efficient, because rf can leak out through small chinks between each wire. Cable is available that replaces the braid with a seamless aluminum shield having much better shielding characteristics.

With this type of transmission line, radiation is eliminated and isolation figures approaching 100 dB may be achieved. The shield also serves as a protective jacket, and as such, weight is reduced 1/2 pound per 100 feet over conventional cable.

Most flexible coaxial cables use vinyl as the jacket material. As polyvinylchloride is brittle, plasticizers are added to make a more flexible material. Under exposure to heat and sunlight, these plasticizers tend to leach out, or migrate through the braid and into the polyethylene dielectric. This migration results in an increase in dielectric constant with an abrupt increase in attenuation, and with the leaving of the plasticizers, the vinyl becomes brittle and cracked. This allows moisture to enter the cable and causes the dielectric constant to deteriorate even more. At this point, which may take anywhere from five to ten years, the cable must be replaced. Much of the cable now available uses resinous plasticizers that will not migrate, resulting in a cable having a lifetime well in excess of 10 years.

Another type of jacket material called Xelon does not contain plasticizers at all, so life expectancies of over 25 years may be realized. Xelon jackets also allow direct burial and submersion in water for those really exotic antenna systems.

Solid dielectric coax is available in impedances ranging from 50 to 75 Ohms. Other impedances are available, but they do not match the feedpoint resistance of the antenna systems that are in common use by hams, so they are to be avoided in most cases. Unfortunately, it is this "mongrel" cable that's often sold "cheap" by surplus houses.

Parallel Conductor Lines

There are two major types of parallel conductor lines: Open-wire line shown in Fig. 4, at C, and twin-lead shown at D. Open-wire line is constructed of either #12 or #14 copper (or copperweld), separated at intervals by spacers. In commercially made lines, these spacers range from 1 to 6 inches long and are made of ceramic, porcelain, or steatite. The shorter spacers are used at high frequencies to prevent incomplete cancellation. The characteristic impedance of most open-wire line is on the order of 400-600 Ohms, depending upon wire size and spacing.

Although the absence of a lossy dielectric, except at the insulators, allows this line to have lower attenuation than coax, there is a fly in the ointment. The problem stems from the fact that open-wire line must be balanced. In other words, the current in one conductor must be exactly out of phase with, but the same amplitude as, its neighbor in the other conductor, if full cancellation is to take place. These conditions are not as important in the "unbalanced" coaxial cable where one conductor is completely surrounded by the other. Because of this, open-wire line must be kept away from metal objects that might couple to one conductor more than the other, causing imbalance. For this reason, open-wire line should run for a quarter wavelength at right angles to the antenna it is feeding. Don't let this influence your choice of a type of feeder. Open-wire line can be operated at much higher standing wave ratios than coax, an advantage that may prove to out-weigh quite a number of disadvantages.

Several types of television type lines are made that can be used in ham applications. The first is called "ladder line," and is a close-spaced (1/2 to 1 inch) version of open-wire line. The second type is twin-lead. Twin-lead is more lossy than ladder line, but it still has a considerable edge over coax. It is also very flexible, being only a thin, small ribbon, and is inexpensive due to its simplicity.

Characteristic Impedance

At this point, on the chance you may have occasion to use it, a quick mention should be made of how to calculate the characteristic impedance of various types of transmission line.

The impedance of air dielectric coax is given by the equation $Z_o = 138 \log_{10} (D/d)$, D= inner diameter of shield, and d= wire diameter. The impedance of solid dielectric coax is given by the equation:

$$Z_o = (138/\sqrt{K}) \log_{10} (D/d),$$

where both D and d are the same as above, and K = the dielectric constant of the material between conductors. Finally, the characteristic impedance of air-insulated parallel conductor line is given by the formula $Z_o = 276 \log_{10} (b/a)$, where b = the center-to-center distance between conductors, and a = the conductor radius. In all of the above, the measurements may be in any convenient unit, so long as all measurements are in the same unit, with the exception of K, of course.

Choosing A Transmission Line

Important factors involved in choosing a transmission line include antenna impedance, operating frequency, feedline length and where the cable will be used.

Fig. 5 gives the pertinent characteristics of about 40 types of cable found on the new and surplus market. Although this table doesn't cover the entire RG series, it should prove helpful in finding out the impedance of military and other surplus cables. If low cost is important, surplus should be strongly considered, though it would be good to keep in mind that military surplus may have been stored for a long time. In this respect, surplus cable might be a bit less flexible than new cable, but all-in-all surplus is in good shape.

When choosing your transmission line, the first consideration is the feedpoint impedance of your antenna. Today, commercial antennas have been standardized to either 50 or 75 Ohms. For 50 Ohms RG–8/U (or RG–8A/U) is used for high power (over 400 Watts) purposes. For low power applications, particularly below 30 MHz, either RG–58/U or RG–58A/U are used. The 75 Ohm counterpart of RG–8/U is RG–11/U and the counterpart of RG–58U is RG–59/U.

As a point of reference as to what transmission line to use, dipoles have impedances ranging from 60 to 70 Ohms, so either of the above mentioned cables may be used. Verticals have impedance values of 30 Ohms, making 50 Ohm cable suitable. Folded dipoles are 300 Ohm, making TV ladder line and twin-lead a good choice. For the most part, all antennas will have some type of corresponding cable that will serve your purposes.

Above 100 MHz, either low-loss coax or

open-wire line should be used, especially if you're operating low power. Both RG–8/U and RG–11/U are acceptable, but when even lower losses are desired, coax with foamed polyethylene and seamless aluminum jacket should be put into service. Below 30 MHz, unless the feedline will be hundreds of feet long, any type of cable is adequate, including open-wire line. Long runs of coax, covering more than 200 feet, can be detrimental even at 3.5 MHz, meaning that more efficient types of coax will be necessary. Other than that, the five coaxial cables and two parallel conductor feedlines shown in Fig. 1 should hold you in good stead.

The final consideration in your choice of transmission line, and one that is not worried about very much, is jacket material. As we mentioned back under "Coaxial Cable," the average coax is good for around 10 years, at best, when used under bright sunlight or warm temperatures. If 10 years sounds long enough, then regular coax is for you, but for lifetimes approaching 15 years, coax intended for outside *rigorous* conditions should be purchased. This coax has resinous plasticizers mixed with the vinyl and is often called semi-contaminating, which may help you to identify this cable from the short descriptions given in most catalogs. If you really want to get your money's worth, coax with a Xelon jacket will provide over 25 years of service, even under conditions that would hasten the deterioration of ordinary cable. Xelon is also your best bet for long-term burial or submersion in water.

Conclusion

Now that you probably know more than you ever wanted to about transmission lines, believe it or not, there's plenty more. But even though many facets have not been covered in this article, it is hoped that enough has been presented to allow you to choose the proper line for your installation. In any case, a knowledge of transmission lines is valuable for the FCC exams and will put you in a position where you can understand and use them whenever necessary.

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