Transmission Lines

Basic Course
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Objective

On completion, you should be able to:

- Understand the **characteristics** of different types of **transmission lines**;
- Recognize the types of **connecters** used in Amateur Radio;
- Understand the effects of **Impedance Mismatch** and **SWR**; and
- Troubleshoot RF **transmission line problems**.

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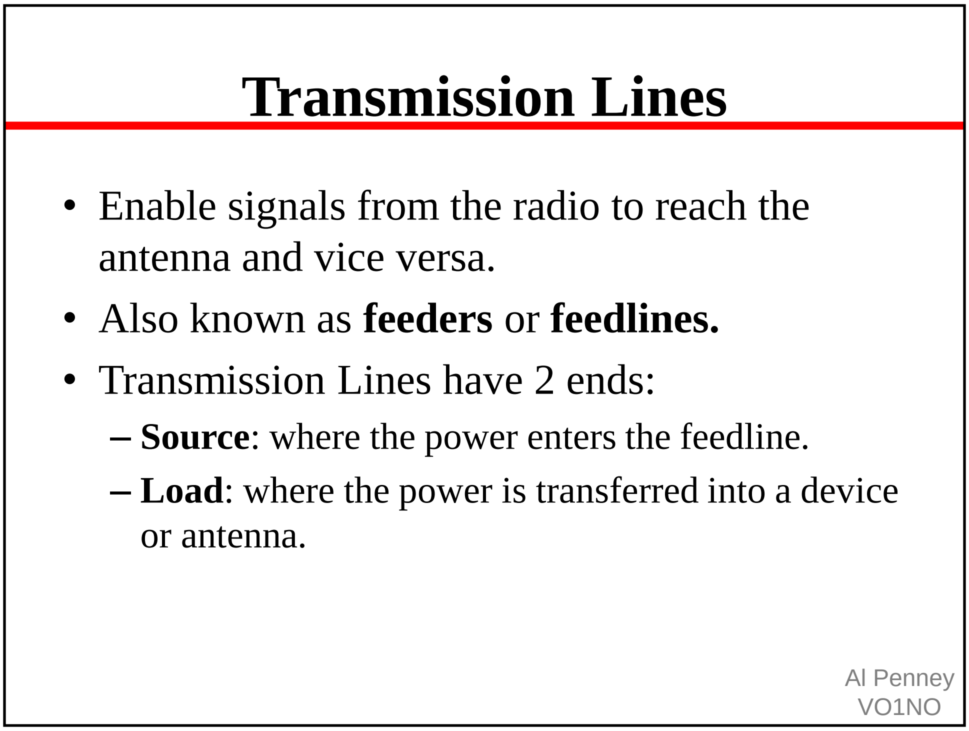

Transmission Lines

- Enable signals from the radio to reach the antenna and vice versa.
- Also known as **feeders** or **feedlines.**
- Transmission Lines have 2 ends:
  - **Source**: where the power enters the feedline.
  - **Load**: where the power is transferred into a device or antenna.

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In radio-frequency engineering, a **transmission line** is a specialized cable or other structure designed to conduct alternating current of radio frequency, that is, currents with a frequency high enough that their wave nature must be taken into account. Transmission lines are used for purposes such as connecting radio transmitters and receivers with their antennas (they are then called feed lines or feeders), distributing cable television signals, trunklines routing calls between telephone switching centres, computer network connections and high speed computer data buses.

Ordinary electrical cables suffice to carry low frequency alternating current (AC), such as mains power, which reverses direction 100 to 120 times per second, and audio signals. However, they cannot be used to carry currents in the radio frequency range, above about 30 kHz, because the energy tends to radiate off the cable as radio waves, causing power losses. **Radio frequency currents also tend to reflect from discontinuities in the cable such as connectors and joints**, and travel back down the cable toward the source. These reflections act as bottlenecks, preventing the signal power from reaching the destination. Transmission lines use specialized construction, and impedance matching, to carry electromagnetic signals with minimal reflections and power losses. The distinguishing feature of most transmission lines is that they have uniform cross sectional dimensions along their length, giving them a uniform *impedance*, called the characteristic impedance, to prevent reflections. Types of transmission line include parallel line (ladder line, twisted pair), coaxial cable, and planar transmission lines such as stripline and microstrip. The higher the frequency of electromagnetic waves moving through a given cable or medium, the shorter the wavelength of the waves. **Transmission lines become necessary when the transmitted frequency's wavelength is sufficiently short that the length of the cable becomes a significant part of a wavelength**.

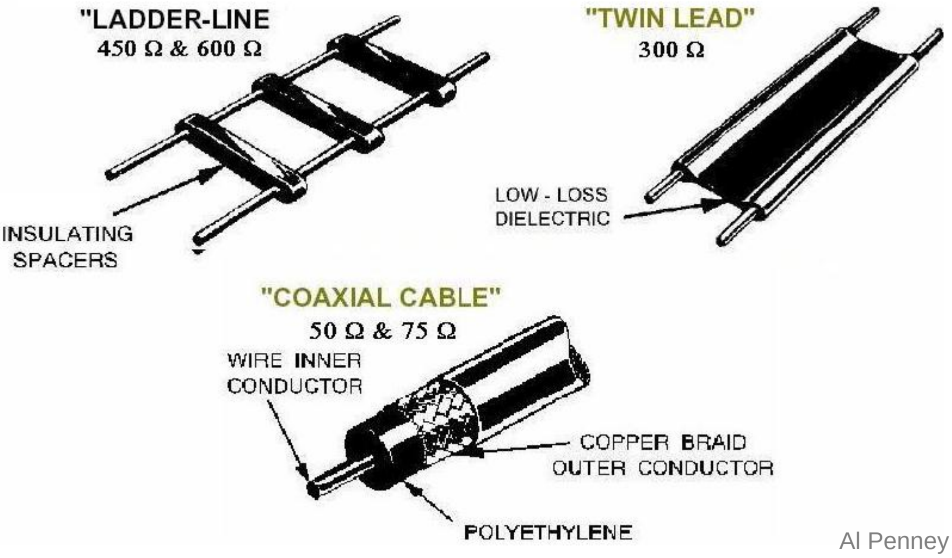
At microwave frequencies and above, power losses in transmission lines become excessive, and waveguides are used instead, which function as "pipes" to confine and guide the electromagnetic waves. Some sources define waveguides as a type of transmission line; however, this article will not include them. At even higher frequencies, in the terahertz, infrared and visible ranges, waveguides in turn become lossy, and optical methods, (such as lenses and mirrors), are used to guide electromagnetic waves.

Optimum Transmission Line

- **Does not radiate** signal from the line itself.
- **No loss** of signal passing through the line.
- **Constant** electrical characteristics throughout its length.

- Unfortunately, there is no such thing as an ideal transmission line!

RF Transmission and Reception Feedline Types



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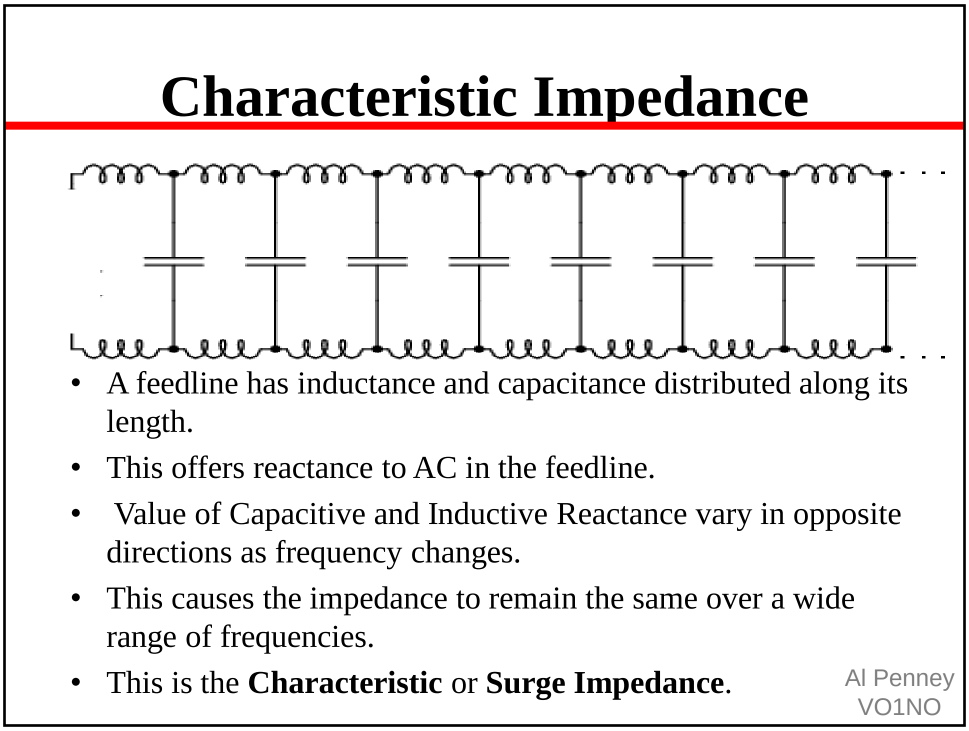

Characteristic Impedance

- A feedline has inductance and capacitance distributed along its length.
- This offers reactance to AC in the feedline.
- Value of Capacitive and Inductive Reactance vary in opposite directions as frequency changes.
- This causes the impedance to remain the same over a wide range of frequencies.
- This is the **Characteristic** or **Surge Impedance**.

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CHARACTERISTIC IMPEDANCE

If the line could be “perfect”—having no resistive losses—a question might arise: What is the amplitude of the current in a pulse applied to this line? Will a larger voltage result in a larger current, or

is the current theoretically infinite for an applied voltage, as we would expect from applying Ohm’s Law to a circuit without resistance? The answer is that the current does depend directly on the voltage,

just as though resistance were present. The reason for this is that the current flowing in the line is something like the charging current that flows when a battery is connected to a capacitor. That is, the line has capacitance. However, it also has inductance. Both of these are “distributed” properties. We may think of the line as being composed of a whole series of small inductors and capacitors, connected as in **the figure**, where each coil is the inductance of an extremely small section of wire, and the capacitance is that existing between the same two sections. Each series inductor acts to limit the rate at which current can charge the following shunt capacitor, and in so doing establishes a very important property of a transmission line: its *surge impedance*, more commonly known as its *characteristic impedance*. This is abbreviated by convention as Z0.

Characteristic Impedance

- Abbreviated $\mathbf{Z_o}$
- Value depends on
  - **the physical dimensions of the line; and**
  - **The relative positions of the conductors.**
- $\mathbf{Z_o}$ = ratio of voltage to current at any given point.
- Value does **not depend on length.**

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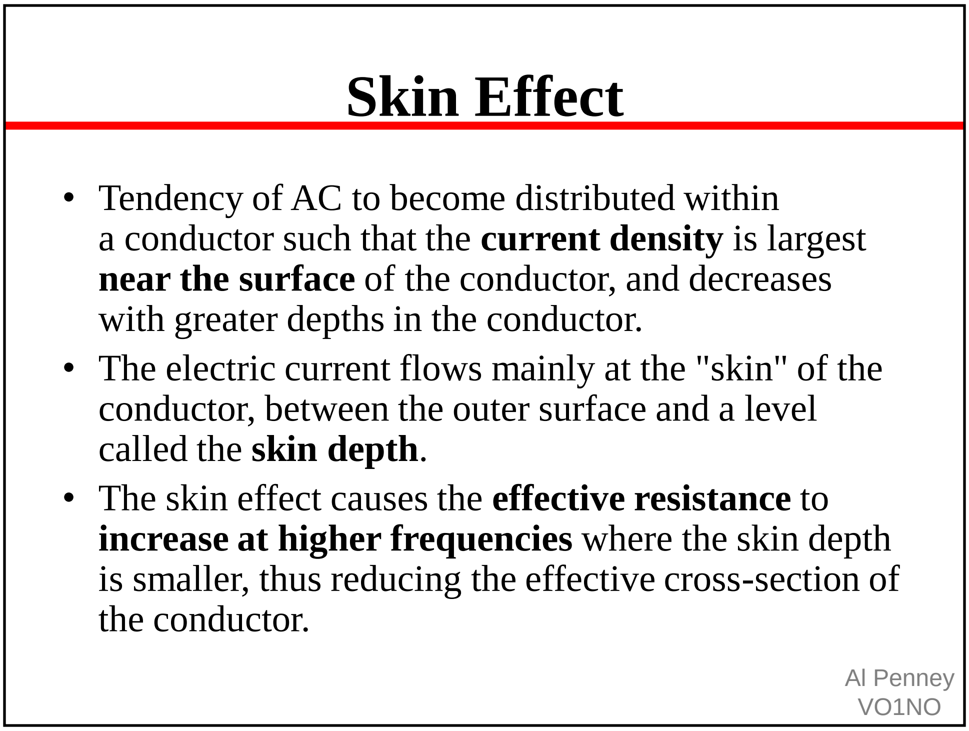
Characteristic Impedance

- Characteristic Impedance is an **AC effect** – you cannot measure it using DC.
- Actual resistance losses are called **Copper Losses**.
- **Skin Effect** causes higher losses as frequency increases.



Skin Effect

- Tendency of AC to become distributed within a conductor such that the **current density** is largest **near the surface** of the conductor, and decreases with greater depths in the conductor.
- The electric current flows mainly at the "skin" of the conductor, between the outer surface and a level called the **skin depth**.
- The skin effect causes the **effective resistance** to **increase at higher frequencies** where the skin depth is smaller, thus reducing the effective cross-section of the conductor.

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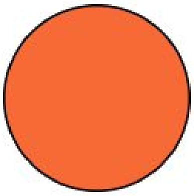
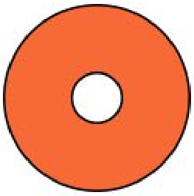
Skin effect is the tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor, and decreases with greater depths in the conductor. The electric current flows mainly at the "skin" of the conductor, between the outer surface and a level called the **skin depth**. The skin effect causes the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller, thus reducing the effective cross-section of the conductor. The skin effect is due to opposing eddy currents induced by the changing magnetic field resulting from the alternating current. At 60 Hz in copper, the skin depth is about 8.5 mm. At high frequencies the skin depth becomes much smaller. Increased AC resistance due to the skin effect can be mitigated by using specially woven litz wire. Because the interior of a large conductor carries so little of the current, tubular conductors such as pipe can be used to save weight and cost.

The skin depth, δ, is defined as the depth where the current density is just 1/e (about 37%) of the value at the surface; it depends on the frequency of the current and the electrical and magnetic properties of the conductor.



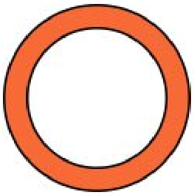
Cross-sectional area of a round conductor available for conducting DC current

“DC resistance”



Cross-sectional area of the same conductor available for conducting low-frequency AC

“AC resistance”



Cross-sectional area of the same conductor available for conducting high-frequency AC

“AC resistance”

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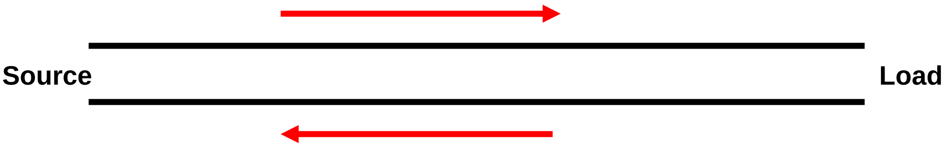
Balanced Transmission Line

- Currents are **equal** but in **opposite direction**.
- This **cancels** the EM field.
- Therefore **very little radiation** from the line.



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At radio frequencies, every conductor that has appreciable length compared with the wavelength in use *radiates* power. Every conductor is an antenna. Special care must be used, therefore, to minimize radiation from the conductors used in RF transmission lines. Without such care, the power radiated by the line may be much larger than that which is lost in the resistance of conductors and dielectrics (insulating materials). Power loss in resistance is inescapable, at least to a degree, but loss by radiation is largely avoidable.

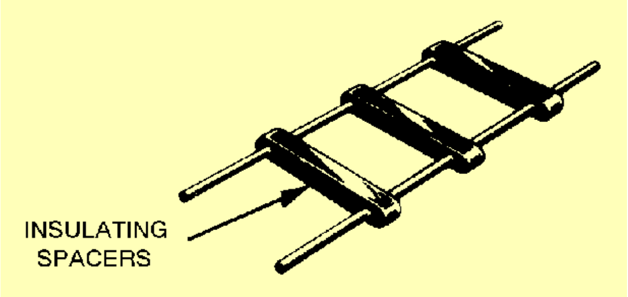
Radiation loss from transmission lines can be prevented by using two conductors arranged and operated so the electromagnetic field from one is balanced everywhere by an equal and opposite field from the other. In such a case, the resultant field is zero everywhere in space - there is no radiation from the line. For example, two parallel conductors having currents I1 and I2 flowing in opposite directions. If the current I1 at point Y on the upper conductor has the same amplitude as the current I2 at the corresponding point X on the lower conductor, the fields set up by the two currents are equal in magnitude. Because the two currents are flowing in opposite directions, the field from I1 at Y is 180° out of phase with the field from I2 at X. However, it takes a measurable interval of time for the field from X to travel to Y. If I1 and I2 are alternating currents, the phase of the field from I1 at Y changes in such a time interval, so at the instant the field from X reaches Y, the two fields at Y are not exactly 180° out of phase. The two fields are exactly 180° out of phase at every point in space only when the two conductors occupy the same space - an obviously impossible condition if they are to remain separate conductors.

The best that can be done is to make the two fields cancel each other as completely as possible. This can be achieved by keeping the distance between the two conductors small enough so the time interval during which the field from X is moving to Y is a very small part of a cycle. When this is the case, the phase difference between the two fields at any given point is so close to 180° that cancellation is nearly complete.

Practical values of d (the separation between the two conductors) are determined by the physical limitations of line construction. A separation that meets the condition of being “very small” at one frequency may be quite large at another. For example, if d is 6 inches, the phase difference between the two fields at Y is only a fraction of a degree if the frequency is 3.5 MHz. This is because a distance of 6 inches is such a small fraction of a wavelength (1 λ = 281 feet) at 3.5 MHz. But at 144 MHz, the phase difference is 26°, and at 420 MHz, it is 77°. In neither of these cases could the two fields be considered to “cancel” each other. Conductor separation must be very small in comparison with the wavelength used; it should never exceed 1% of the wavelength, and smaller separations are desirable. Transmission lines consisting of two parallel conductors as in Fig 1A are called *open-wire lines*, *parallel-conductor lines* or *two-wire lines*.

Open Wire Feedline

- **Two parallel wires** separated (mostly) by air.
- Insulated spacers maintain distance.
- Characteristic Impedances 200 – **600** Ohms.



Parallel feeders go back to the beginnings of radio. By 1930, the "two-wire untuned feeder system" was a standard ARRL *Handbook* feature. The *Jones Radio Handbook* of 1937 provides a table of line losses showing the advantages of open-wire feeders (a 440-Ohm line in the table) over lower impedance twisted-pair feeders (p. 70). The use of 600-Ohm lines was fairly standard, using a spacing of about 6". "To reduce radiation from the feeders to a minimum, the two wires should not be more than 10 to 12 inches apart." (*The Radio Amateur's Handbook*, 7th Ed., ARRL, 1930, p. 162) Rarely did hams exceed the 6" spacing.

Every transmission line has a characteristic impedance, and parallel transmission lines are no exception. The characteristic impedance (Zo) of a line depends on the physical properties of the line. For a 2-wire set, we have only two properties of note (assuming the use of a very conductive material, such as copper): the diameter of the wire and the spacing between the wires.

Twin lead is a form of parallel-wire balanced transmission line. The separation between the two wires in twin-lead is small compared to the wavelength of the radio frequency (RF) signal carried on the wire.[3] The RF current in one wire is equal in magnitude and opposite in direction to the RF current in the other wire. Therefore, in the far field region far from the transmission line, the radio waves radiated by one wire are equal in magnitude but opposite in phase (180° out of phase) to the waves radiated by the other wire, so they superpose and cancel each other. The result is that almost no net radio energy is radiated by the line.

Similarly, any interfering external radio waves will induce equal, in phase RF currents, traveling in the same direction, in the two wires. Since the load at the destination end is connected *across* the wires, only *differential*, oppositely-directed currents in the wires create a current in the load. Thus the interfering currents are canceled out, so twin lead does not tend to pick up radio noise.

However, if a piece of metal is located sufficiently close to a twin-lead line, within a distance comparable to the wire spacing, it will be significantly closer to one wire than the other. As a result, the RF current induced in the metal object by one wire will be greater than the opposing current induced by the other wire, so the currents will no longer cancel. Thus nearby metal objects can cause power losses in twin lead lines, through energy dissipated as heat by induced currents. Similarly, radio noise originating in cables or metal objects located near the twin-lead line can induce unbalanced currents in the wires, coupling noise into the line.

In order to prevent power from being reflected from the load end of the line, causing high SWR and inefficiency, the load must have an impedance which matches the characteristic impedance of the line. This causes the load to appear electrically identical to a continuation of the line, preventing reflections. Similarly, to transfer power efficiently into the line, the source must also match the characteristic impedance. To connect balanced transmission line to unbalanced line like coaxial cable, a device called a balun must be used.

Insulated Twin Lead

- Two parallel conductors enclosed in a **plastic sheath.**
- TV Twin Lead has an impedance of **300 Ohms.**

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win-lead cable is a two-conductor flat cable used as a balanced transmission line to carry radio frequency (RF) signals. It is constructed of two stranded copper or copper-clad steel wires, held a precise distance apart by a plastic (usually polyethylene) ribbon. The uniform spacing of the wires is the key to the cable's function as a transmission line; any abrupt changes in spacing would reflect some of the signal back toward the source. The plastic also covers and insulates the wires.

Twin lead can have significantly lower signal loss than miniature flexible coaxial cable at shortwave and VHF radio frequencies; for example, type RG-58 coaxial cable loses 6.6 dB per 100 m at 30 MHz, while 300 ohm twin-lead loses only 0.55 dB. However, twin-lead is more vulnerable to interference. Proximity to metal objects will inject signals into twin-lead that would be blocked out by coaxial cable. Twin lead therefore requires careful installation around rain gutters, and standoffs from metal support masts. Twin-lead is also susceptible to significant degradation when wet or ice covered, whereas coax is less or not affected in these conditions. For these reasons, coax has largely replaced twin-lead in most uses, except where maximum signal is required.

Ladder Line

- Variant of Insulated Twin Lead.
- To reduce losses, some of the plastic is cut away.
- Characteristic Impedance of **450 Ohms**.

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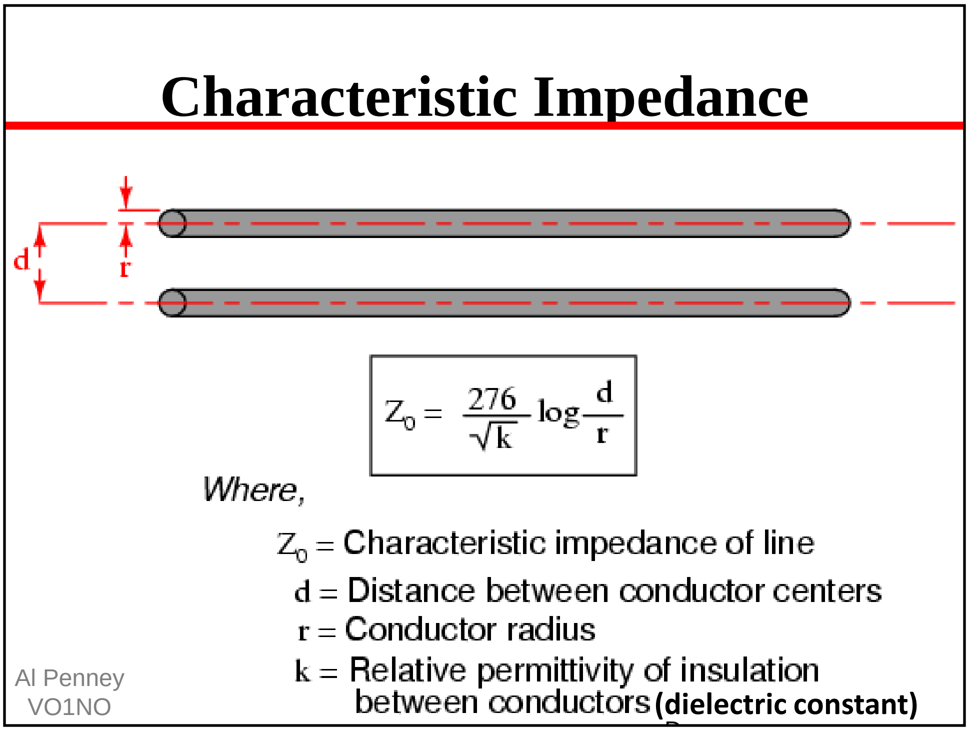
Ladder line or "window line" is a variation of twin lead which is constructed similarly, except that the polyethylene webbing between the wires which holds them apart has rectangular openings ("windows") cut in it. The line consists of two insulated wires with "rungs" of plastic holding them together every few inches, giving it the appearance of a ladder. The advantage of the "windows" is that they lighten the line, and also reduce the amount of surface on which dirt and moisture can accumulate, making ladder line less vulnerable to weather-induced changes in characteristic impedance. The most common type is 450 ohm ladder line, which has a conductor spacing of about an inch.



Characteristic Impedance

$$Z_0 = \frac{276}{\sqrt{k}} \log \frac{d}{r}$$

Where,

Z_0 = Characteristic impedance of line
d = Distance between conductor centers
r = Conductor radius
k = Relative permittivity of insulation between conductors **(dielectric constant)**

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Identical units of measurement must be used in both terms of the fraction.

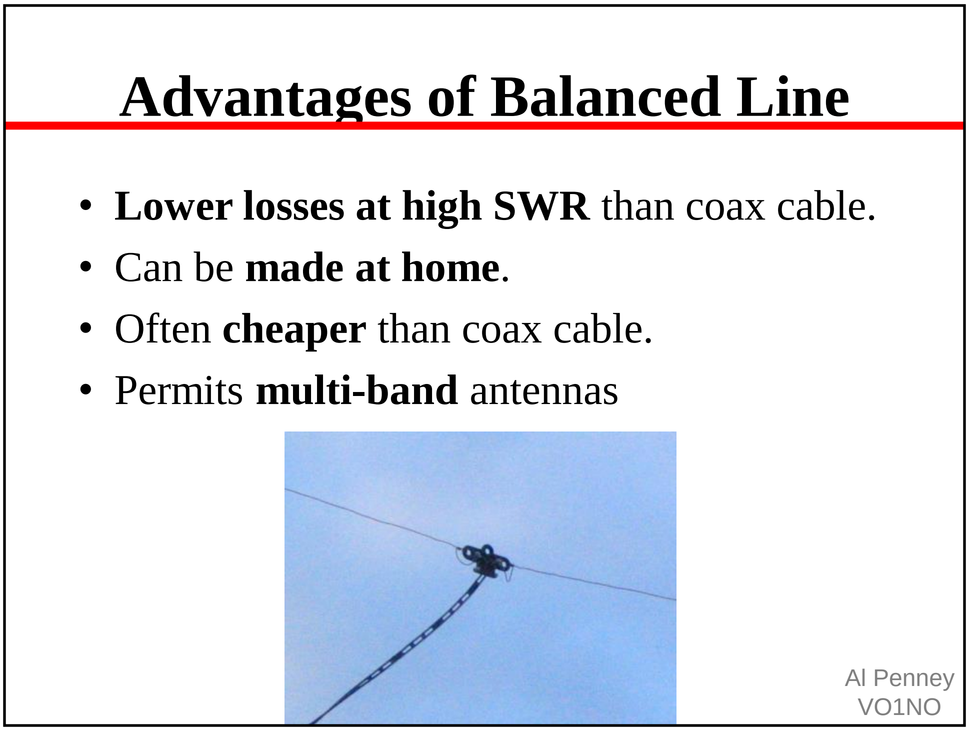
k = dielectric constant of insulation between conductors. For air it is 1.00059 (round off to 1 for practical applications).

The dielectric constant k is the relative permittivity of a dielectric material. It is an important parameter in characterizing capacitors. It is unfortunate that the same symbol k is often used for Coulomb's constant, so one must be careful of this possible confusion.

The **relative permittivity** of a material is its (absolute) permittivity expressed as a ratio relative to the vacuum permittivity.

Permittivity is a material property that affects the Coulomb force between two point charges in the material. Relative permittivity is the factor by which the electric field between the charges is decreased relative to vacuum.

Likewise, relative permittivity is the ratio of the capacitance of a capacitor using that material as a dielectric, compared with a similar capacitor that has vacuum as its dielectric. Relative permittivity is also commonly known as the **dielectric constant**, a term still used but deprecated by standards organizations in engineering as well as in chemistry.



Advantages of Balanced Line

- **Lower losses at high SWR** than coax cable.
- Can be **made at home**.
- Often **cheaper** than coax cable.
- Permits **multi-band** antennas

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Open-wire line has the advantage of both lower loss and lower cost compared to coax. 600-Ω open-wire line at 30 MHz has a matched loss of only 0.1 dB. If you use such open-wire

line with the same 5:1 SWR, the total loss would still be less than 0.3 dB. In fact, even if the SWR rose to 20:1, the total loss would be less than 1 dB. Typical open-wire line sells for about 1/3 the cost of good quality coax cable.

Open-wire line is enjoying a renaissance of sorts with amateurs wishing to cover multiple HF bands with a single-wire antenna. This is particularly true since the bands at 30, 17 and 12 meters

became available in the early 1980s. The 102-foot long “G5RV dipole,” fed with open-wire ladder line into an antenna tuner, has become popular as a simple all-band antenna. The simple 130-foot long flattop

dipole, fed with open-wire 450-Ω “window” ladder-line, is also very popular among all-band enthusiasts.

Despite their inherently low-loss characteristics, open-wire lines are not often employed above about 100 MHz. This is because the physical spacing between the two wires begins to become an

appreciable fraction of a wavelength, leading to undesirable radiation by the line itself. Some form of coaxial cable is almost universally used in the VHF and UHF amateur bands.

Disadvantages of Balanced Line

- **Spacing** must be kept **constant**.
- **Cannot be buried**, laid on ground, or run alongside a conductor.
- **Impedance varies** in rain and with icing.
- **Safety hazard** if touched while transmitting.
- **Impedance higher** than radio antenna terminal, so an impedance matching device is necessary.
- Spacing on VHF/UHF is an appreciable fraction of the wavelength, so line radiates.

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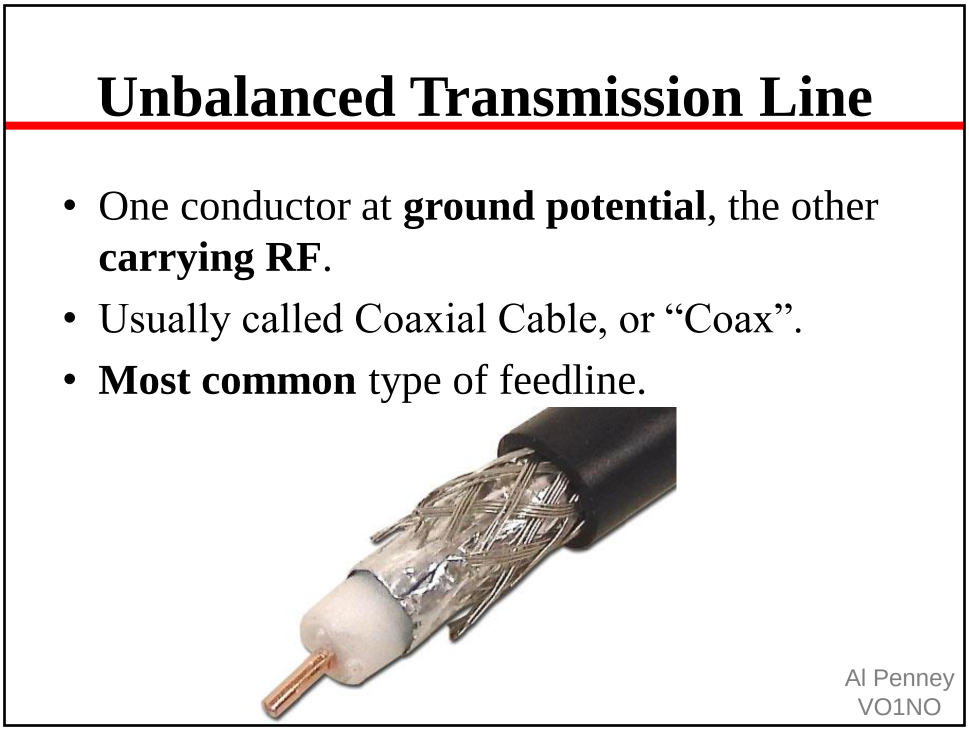

Unbalanced Transmission Line

- One conductor at **ground potential**, the other **carrying RF**.
- Usually called Coaxial Cable, or “Coax”.
- **Most common** type of feedline.

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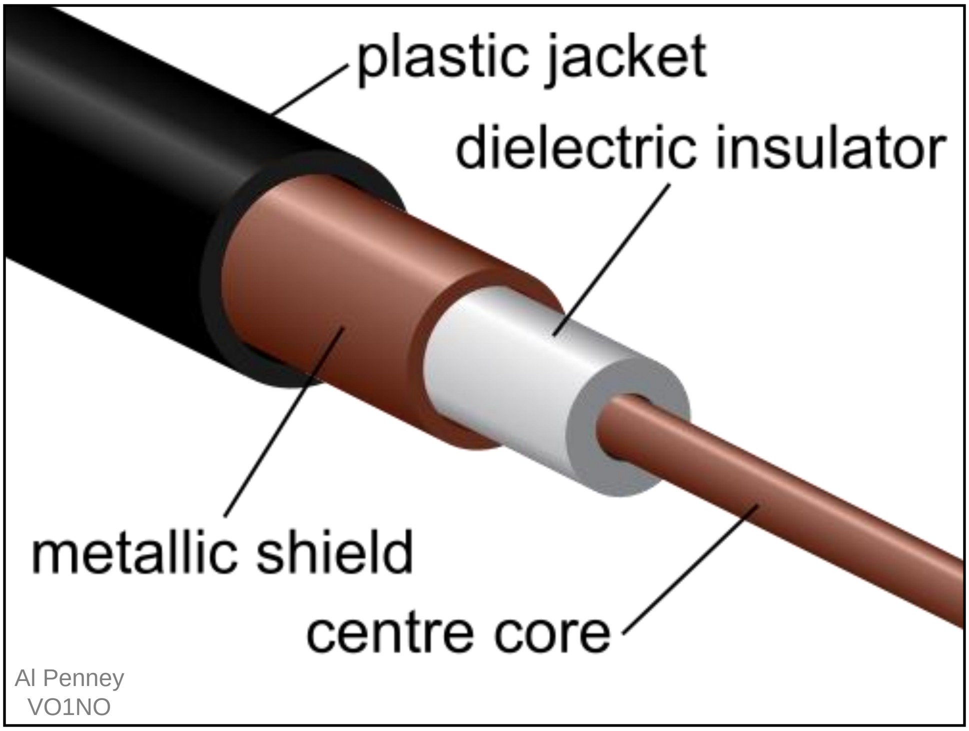
An **unbalanced line** is a transmission line, often coaxial cable, **whose conductors have unequal impedances with respect to ground**; as opposed to a balanced line. Microstrip and single-wire lines are also unbalanced lines.

Any line that has a different impedance of the return path may be considered an unbalanced line. However, **unbalanced lines usually consist of a conductor that is considered the signal line and another conductor that is grounded, or is ground itself.** The ground conductor often takes the form of a ground plane or the screen of a cable. The ground conductor may be, and often is, common to multiple independent circuits. For this reason the ground conductor may be referred to as *common*.

A coaxial line (coax) has a central signal conductor surrounded by a cylindrical shielding conductor. The shield conductor is normally grounded. The coaxial format was developed during World War II for use in radar. It was originally constructed from rigid copper pipes, but the usual form today is a flexible cable with a braided screen. The advantages of coax are a theoretically perfect electrostatic screen and highly predictable transmission parameters. The latter is a result of the fixed geometry of the format which leads to a precision not found with loose wires. Open wire systems are also affected by nearby objects altering the field pattern around the conductor. Coax does not suffer from this since the field is entirely contained within the cable due to the surrounding screen.

Coaxial lines are the norm for connections between radio transmitters and their antennae, for interconnection of electronic equipment where high frequency or above is involved, and were formerly widely used for forming local area networks before twisted pair became popular for this purpose.

Triaxial cable (triax) is a variant of coax with a second shield conductor surrounding the first with a layer of insulation in between. As well as providing additional shielding, the outer conductors can be used for other purposes such as providing power to equipment or control signals. Triax is widely used for the connection of cameras in television studios.



Coaxial cable conducts electrical signal using an inner conductor (usually a solid copper, stranded copper or copper plated steel wire) surrounded by an insulating layer and all enclosed by a shield, typically one to four layers of woven metallic braid and metallic tape. The cable is protected by an outer insulating jacket. Normally, the shield is kept at ground potential and a signal carrying voltage is applied to the center conductor. **The advantage of coaxial design is that electric and magnetic fields are restricted to the dielectric with little leakage outside the shield. Further, electric and magnetic fields outside the cable are largely kept from interfering with signals inside the cable.** This property makes coaxial cable a good choice for carrying weak signals that cannot tolerate interference from the environment or for stronger electrical signals that must not be allowed to radiate or couple into adjacent structures or circuits. Larger diameter cables and cables with multiple shields have less leakage.

Common applications of coaxial cable include video and CATV distribution, RF and microwave transmission, and computer and instrumentation data connections.

The characteristic impedance of the cable is determined by the dielectric constant of the inner insulator and the radii of the inner and outer conductors. In radio frequency systems, where the cable length is comparable to the wavelength of the signals transmitted, a uniform cable characteristic impedance is important to minimize loss. The source and load impedances are chosen to match the impedance of the cable to ensure maximum power transfer and minimum standing wave ratio. Other important properties of coaxial cable include attenuation as a function of frequency, voltage handling capability, and shield quality.

COAXIAL CABLE

Coaxial cable design choices affect physical size, frequency performance, attenuation, power handling capabilities, flexibility, strength, and cost. **The inner conductor might be solid or stranded**; stranded is more flexible. **To get better high-frequency performance, the inner conductor may be silver-plated.** Copper-plated steel wire is often used as an inner conductor for cable used in the cable TV industry.

The insulator surrounding the inner conductor may be solid plastic, a foam plastic, or air with spacers supporting the inner wire. The properties of the dielectric insulator determine some of the electrical properties of the cable. A common choice is a solid polyethylene (PE) insulator, used in lower-loss cables. Solid Teflon (PTFE) is also used as an insulator, and exclusively in plenum-rated cables. Some coaxial lines use air (or some other gas) and have spacers to keep the inner conductor from touching the shield.

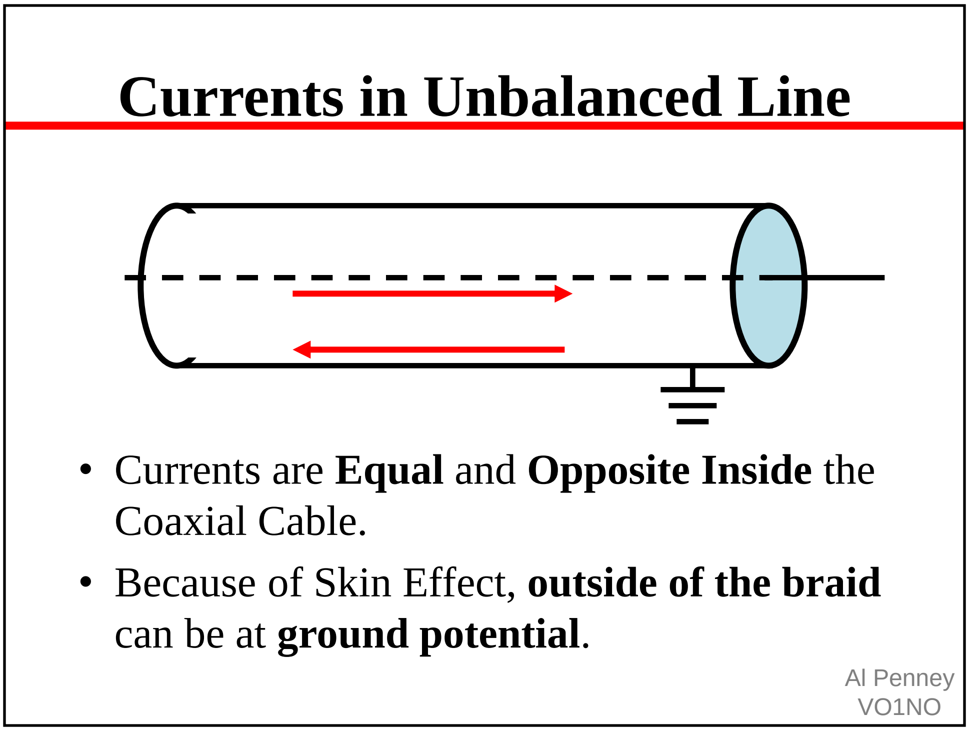
Many conventional coaxial cables use braided copper wire forming the shield. This allows the cable to be flexible, but it also means there are gaps in the shield layer, and the inner dimension of the shield varies slightly because the braid cannot be flat. Sometimes the braid is silver-plated. For better shield performance, some cables have a double-layer shield. The shield might be just two braids, but it is more common now to have a thin foil shield covered by a wire braid. Some cables may invest in more than two shield layers, such as "quad-shield", which uses four alternating layers of foil and braid. Other shield designs sacrifice flexibility for better performance; some shields are a solid metal tube. Those cables cannot be bent sharply, as the shield will kink, causing losses in the cable. When a foil shield is used a small wire conductor incorporated into the foil makes soldering the shield termination easier.

For high-power radio-frequency transmission up to about 1 GHz, coaxial cable with a solid copper outer conductor is available in sizes of 0.25 inch upward. The outer conductor is corrugated like a bellows to permit flexibility and the inner conductor is held in position by a plastic spiral to approximate an air dielectric. One brand name for such cable is *Heliax*.

Coaxial cables require an internal structure of an insulating (dielectric) material to maintain the spacing between the center conductor and shield. The dielectric losses increase in this order: Ideal dielectric (no loss), vacuum, air, polytetrafluoroethylene (PTFE), polyethylene foam, and solid polyethylene. A low relative permittivity allows for higher-frequency usage. An inhomogeneous dielectric needs to be compensated by a non-circular conductor to avoid current hot-spots.

While many cables have a solid dielectric, many others have a foam dielectric that contains as much air or other gas as possible to reduce the losses by allowing the use of a larger diameter center conductor. Foam coax will have about 15% less attenuation but some types of foam dielectric can absorb moisture—especially at its many surfaces — in humid environments, significantly increasing the loss. Supports shaped like stars or spokes are even better but more expensive and very susceptible to moisture infiltration. Still more expensive were the air-spaced coaxials used for some inter-city communications in the mid-20th century. The center conductor was suspended by polyethylene discs every few centimeters. In some low-loss coaxial cables such as the RG-62 type, the inner conductor is supported by a spiral strand of polyethylene, so that an air space exists between most of the conductor and the inside of the jacket. The lower dielectric constant of air allows for a greater inner diameter at the same impedance and a greater outer diameter at the same cutoff frequency, lowering ohmic losses. Inner conductors are sometimes silver-plated to smooth the surface and reduce losses due to skin effect. A rough surface extends the current path and concentrates the current at peaks, thus increasing ohmic loss.

The insulating jacket can be made from many materials. A common choice is PVC, but some applications may require fire-resistant materials. Outdoor applications may require the jacket to resist ultraviolet light, oxidation, rodent damage, or direct burial. Flooded coaxial cables use a water blocking gel to protect the cable from water infiltration through minor cuts in the jacket. For internal chassis connections the insulating jacket may be omitted.



Currents in Unbalanced Line

- Currents are **Equal** and **Opposite Inside** the Coaxial Cable.
- Because of Skin Effect, **outside of the braid** can be at **ground potential**.

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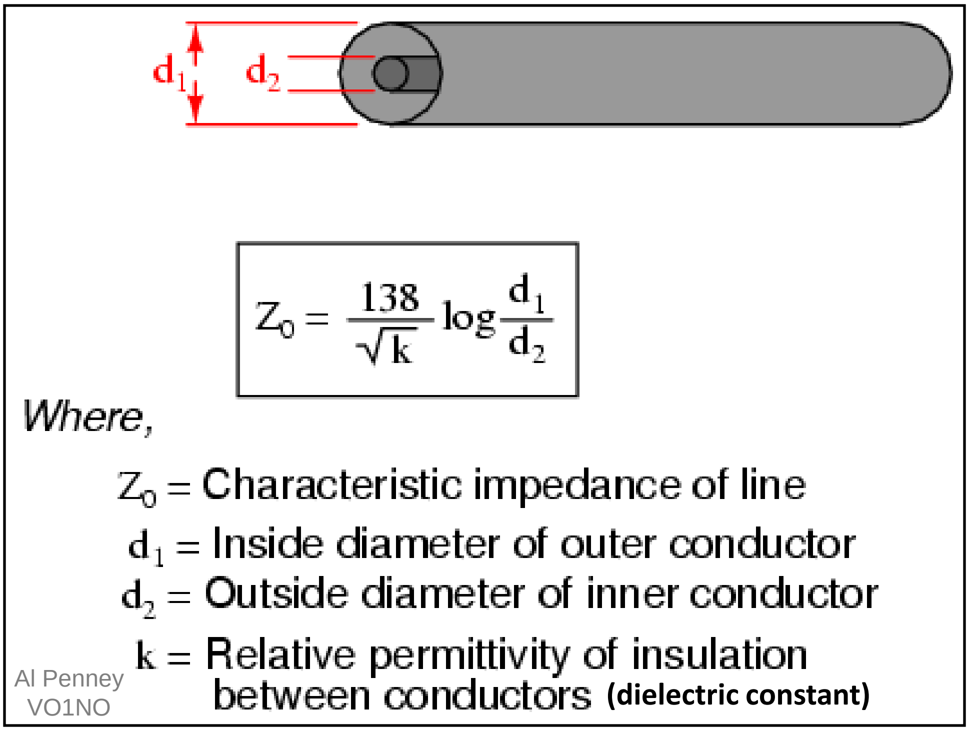
The center and inside of the shield carry equal and opposite direction RF currents. This ALWAYS is the case when the shield is several skin depths thick. We cannot force anything else to happen!

In the drawing above and below, the outside of the shield is isolated by skin effect. It behaves like a separate transmission outer conductor. Skin effect prevents any current, voltage, or field (even magnetic) from penetrating the shield when the shield is many skin depths thick. Only the breaks at the ends connect the inner and outer shield conduction layers.



$$Z_0 = \frac{138}{\sqrt{k}} \log \frac{d_1}{d_2}$$

Where,

Z_0 = Characteristic impedance of line

d_1 = Inside diameter of outer conductor

d_2 = Outside diameter of inner conductor

k = Relative permittivity of insulation between conductors **(dielectric constant)**

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Identical units of measurement must be used in both terms of the fraction.

k = dielectric constant of insulation between conductors. For air it is 1.00059 (round off to 1 for practical applications). For polyethylene it is 2.25.

The dielectric constant k is the relative permittivity of a dielectric material. It is an important parameter in characterizing capacitors. It is unfortunate that the same symbol k is often used for Coulomb's constant, so one must be careful of this possible confusion.

The **relative permittivity** of a material is its (absolute) permittivity expressed as a ratio relative to the vacuum permittivity.

Permittivity is a material property that affects the Coulomb force between two point charges in the material. Relative permittivity is the factor by which the electric field between the charges is decreased relative to vacuum.

Likewise, relative permittivity is the ratio of the capacitance of a capacitor using that material as a dielectric, compared with a similar capacitor that has vacuum as its dielectric. Relative permittivity is also commonly known as the **dielectric constant**, a term still used but deprecated by standards organizations in engineering as well as in chemistry.

Advantages of Unbalanced Line

- Can be **run alongside metal or buried**.
- **Same impedance** as that required by our radios.
- **Convenient** to use.
- **Weatherproof**.

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Disadvantages of Unbalanced Line

- **Higher losses** than Balanced Feedline
- **Losses increase** with **higher SWR**.
- **Water ingress** a danger to coax cable.
- **Kinking or bending** too sharply can cause damage.
- Some connectors cause **impedance “bumps”.**

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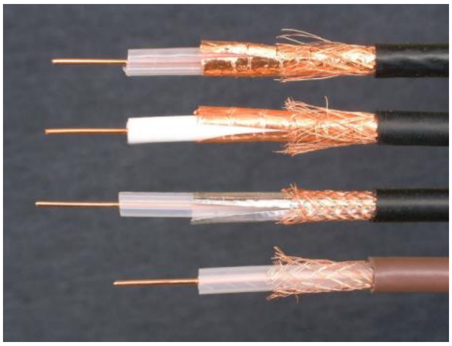
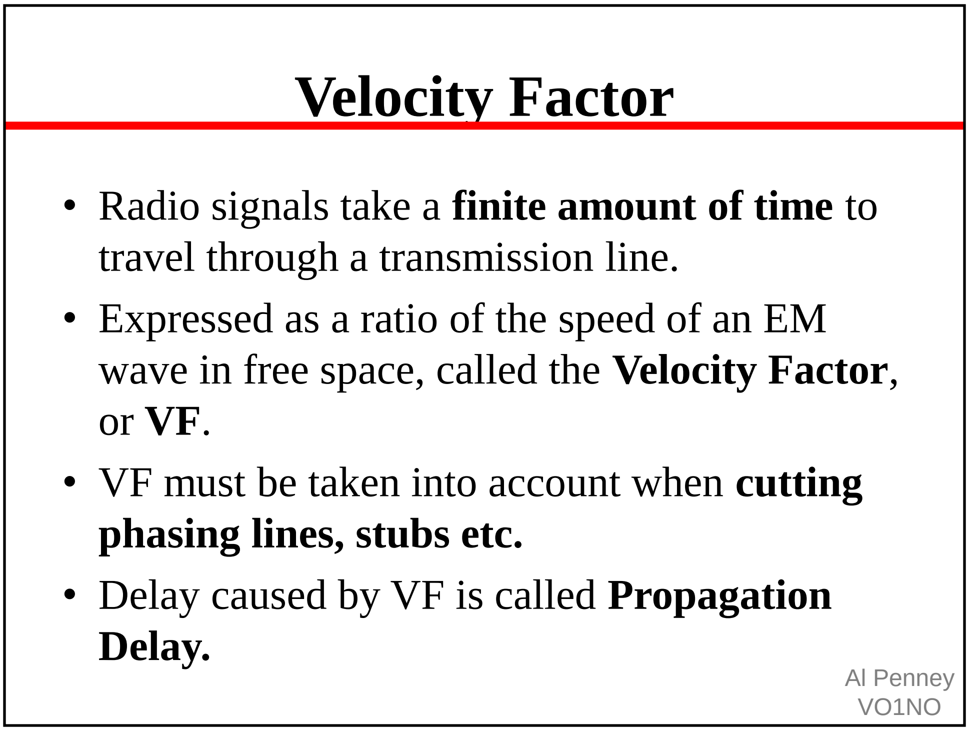
Beware Cheap Coax Cable!

- Poor quality coax has **poor braid coverage**.
- This causes signal attenuation and is susceptible to interference.



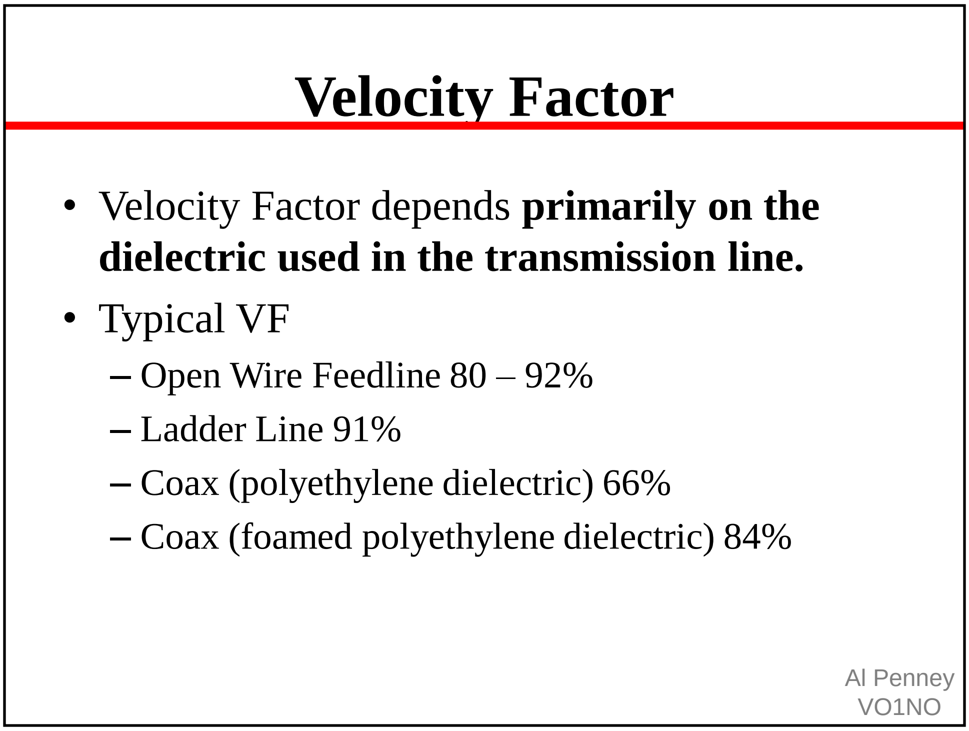


Velocity Factor

- Radio signals take a **finite amount of time** to travel through a transmission line.
- Expressed as a ratio of the speed of an EM wave in free space, called the **Velocity Factor**, or **VF**.
- VF must be taken into account when **cutting phasing lines, stubs etc.**
- Delay caused by VF is called **Propagation Delay.**

The **velocity factor** (**VF**), also called **wave propagation speed** or **velocity of propagation** (**VoP** or) of a transmission medium is the ratio of the speed at which a wavefront (of an electromagnetic signal, a radio signal, a light pulse in an optical fibre or a change of the electrical voltage on a copper wire) passes through the medium, to the speed of light in a vacuum. For optical signals, the velocity factor is the reciprocal of the refractive index.

The speed of radio signals in a vacuum, for example, is the speed of light, and so the velocity factor of a radio wave in a vacuum is unity, or 100%. In electrical cables, the velocity factor mainly depends on the insulating material.



Velocity Factor

- Velocity Factor depends **primarily on the dielectric used in the transmission line.**
- Typical VF
  - Open Wire Feedline 80 – 92%
  - Ladder Line 91%
  - Coax (polyethylene dielectric) 66%
  - Coax (foamed polyethylene dielectric) 84%

Dielectric material codes

•FPE is foamed polyethylene

•PE is solid polyethylen

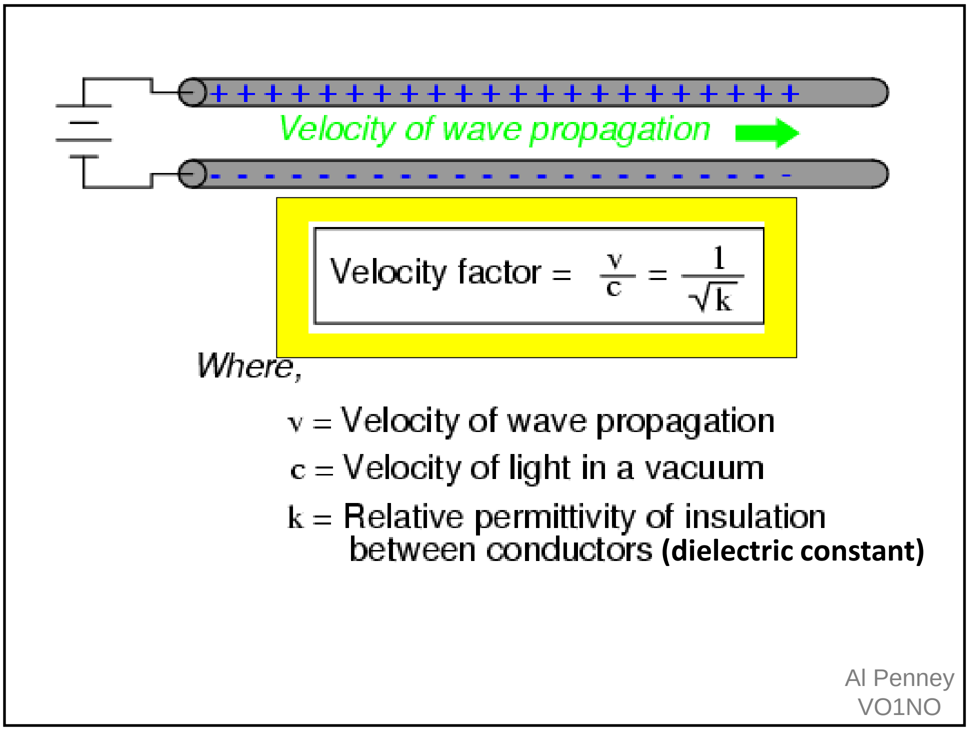
•PF is polyethylene foam

•PTFE is polytetrafluoroethylene;

•ASP is air space polyethylene[

VF is the Velocity Factor

- •VF for solid PE is about 0.66
- •VF for foam PE is about 0.78 to 0.88
- •VF for air is about 1.00
- •VF for solid PTFE is about 0.70
- •VF for foam PTFE is about 0.84



$$\text{Velocity factor} = \frac{v}{c} = \frac{1}{\sqrt{k}}$$

Where,

v = Velocity of wave propagation
c = Velocity of light in a vacuum
k = Relative permittivity of insulation between conductors **(dielectric constant)**

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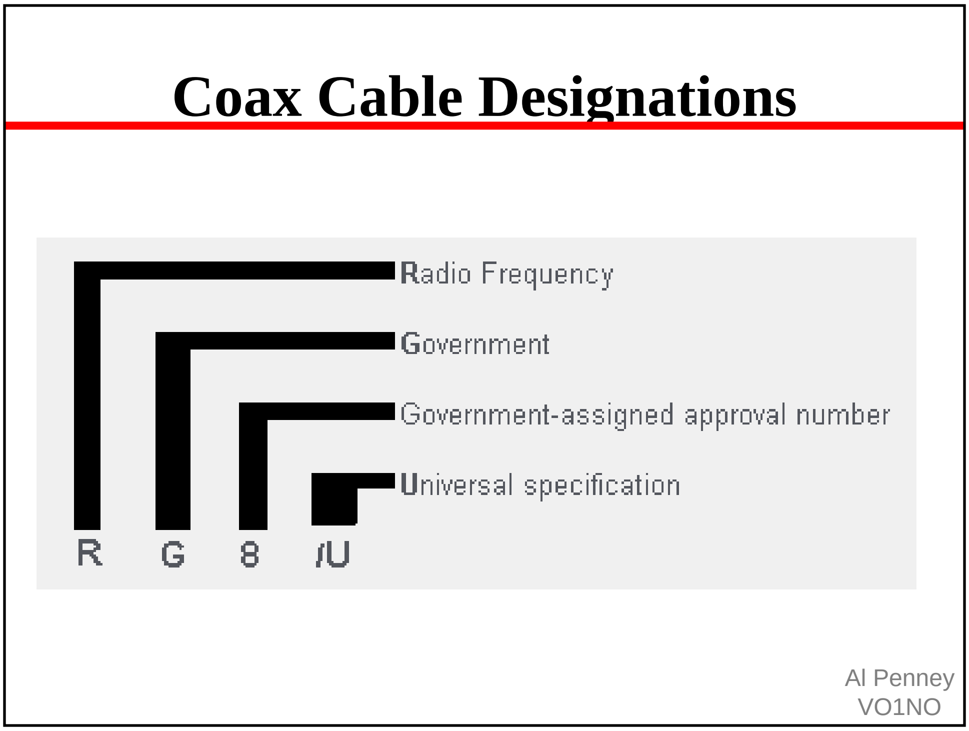
The ratio of a transmission line’s true propagation velocity and the speed of light in a vacuum is called the *velocity factor* of that line. Velocity factor is purely a factor of the insulating material’s relative permittivity (otherwise known as its *dielectric constant*), defined as the ratio of a material’s electric field permittivity to that of a pure vacuum. The velocity factor of any cable type—coaxial or otherwise—may be calculated quite simply by the formula in the slide:



Coax Cable Designations

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Coaxial cables that conform to U.S. Government specifications are identified with an RG designation.
The meaning of the individual components of the designation are:

If the letters A, B or C appear before the slash (/) it indicates a specification-modification or revision. As an example, RG 8/U is superseded by RG 8A/U.

A series of standard types of coaxial cable were specified for military uses, in the form "RG-#" or "RG-#/U". They date from World War II and were listed in *MIL-HDBK-216* published in 1962. These designations are now obsolete. The RG designation stands for Radio Guide; the U designation stands for Universal. The current military standard is MIL-SPEC MIL-C-17. MIL-C-17 numbers, such as "M17/75-RG214", are given for military cables and manufacturer's catalog numbers for civilian applications. **However, the RG-series designations were so common for generations that they are still used, although critical users should be aware that since the handbook is withdrawn there is no standard to guarantee the electrical and physical characteristics of a cable described as "RG-# type".** The RG designators are mostly used to identify compatible connectors that fit the inner conductor, dielectric, and jacket dimensions of the old RG-series cables.

RG-58/U

- 50 Ohm cable.
- Lightweight – diameter of a pencil.
- Okay for HF, but not long runs on VHF/UHF.
- Max power is a few hundred watts.

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RG-58/U is a type of coaxial cable often used for low-power signal and RF connections. The cable has a characteristic impedance of either 50 or 52 Ω. "RG" was originally a unit indicator for bulk RF cable in the U.S. military's Joint Electronics Type Designation System. There are several versions covering the differences in core material (solid or braided wire) and shield (70% to 95% coverage).

The outside diameter of RG-58 is around 0.2 inches (5 mm). RG-58 weighs around 0.025 lb/ft (37 g/m), exhibits approximately 25 pF/ft (82 pF/m) capacitance and can tolerate a maximum of 300 V potential (1800 W). **Plain RG-58 cable has a solid center conductor. The RG-58A/U features a flexible 7- or 19-strand center conductor**.

Most two-way radio communication systems, such as marine, CB radio, amateur, police, fire, WLAN antennas etc., are designed to work with a 50 Ω cable.

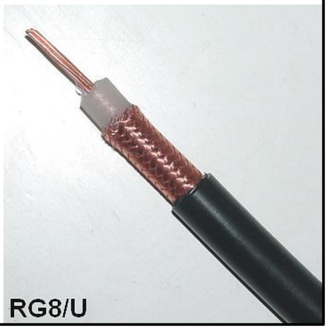
RG-58 cable is often used as a generic carrier of signals in laboratories, combined with BNC connectors that are common on test and measurement equipment such as oscilloscopes.

RG-58 in versions RG-58A/U or RG-58C/U was once widely used in "thin" Ethernet (10BASE2), for which it provides a maximum segment length of 185 meters. However, it has been almost completely replaced by twisted-pair cabling such as Cat 5, Cat 6, and similar cables in data networking applications.

RG-58 cable can be used for moderately high frequencies. Its signal attenuation depends on the frequency, e.g. from 10.8 dB per 100 m (3.3 dB per 100 feet) at 50 MHz to 70.5 dB per 100 m (21.5 dB per 100 feet) at 1 GHz.

RG-8/U

- Used to be the standard 50 Ohm cable.
- Influx of cheap "RG-8 Type" cables caused US Government to change to RG-213 as the standard 50 Ohm cable.
- Diameter ~ 1 cm.
- Much lower loss than RG-58.
- Full legal limit on HF.



RG-213/U

- Quality 50 Ohm cable.
- Full legal limit on HF.
- RG-214/U is identical but has 2 shields.

RG 213 is a flexible coaxial cable that can be used in a number of commercial and military applications. With a 50 Ohm impendance and PVC jacket this RG 213 coax cable has low signal loss and high operation voltage for atenna cable applications. You will find RG 213 in a lot of VHF and UHF applications. Allied Wire & Cable also carries a mil-spec equivalent to RG 213 that can be found at M17/74-RG213.

RG-59/U

- 75 Ohm cable meant primarily for TV.
- Suitable for low power use on HF – 400 watts.
- Also good for specialized receive antennas.
- RG-11 is a higher power version.

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RG-174

- Thin diameter 50 Ohm cable.
- Used for short distance, low power applications.
- Much greater loss than larger cables.

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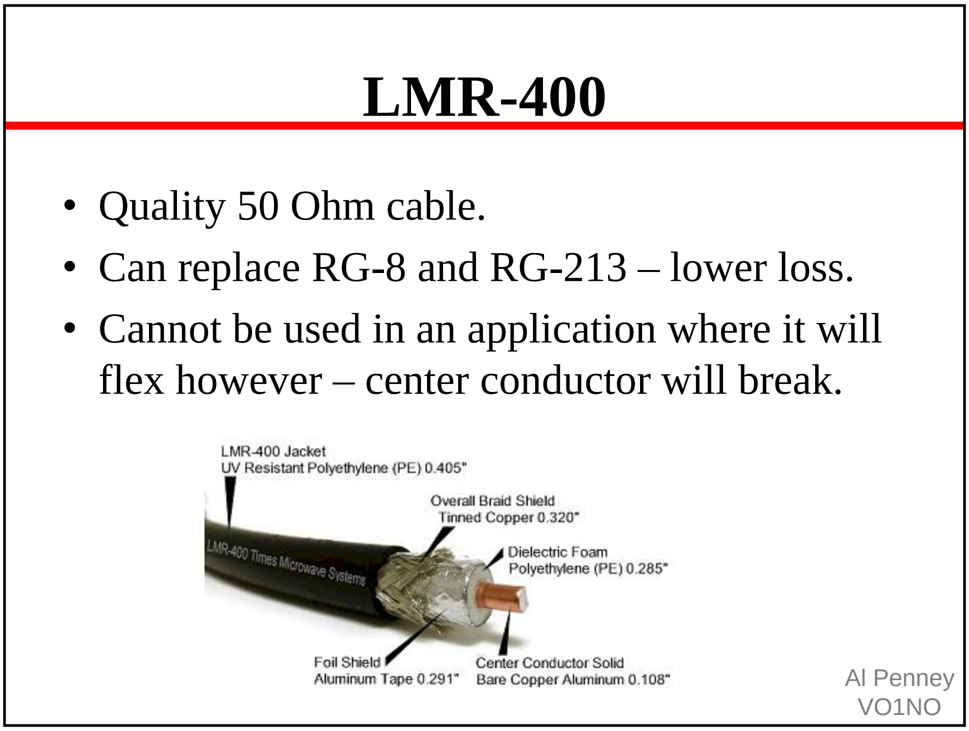
RG174 is an extremely common Coaxial cable type, typically **used in** GPS, WLAN, and cellular communications as its 2.5mm outer diameter allows for the attachment of most micro-coaxial connectors

Low Loss Coax Cable

- Use **foam dielectric** or **plastic spacers** to reduce dielectric losses.
- Also have **larger center conductors** to reduce copper losses.
- Rigid shield cable is called **Hardline**.
- Not required on HF, but necessary for weak signal or high power applications at VHF/UHF and up.



LMR-400

- Quality 50 Ohm cable.
- Can replace RG-8 and RG-213 – lower loss.
- Cannot be used in an application where it will flex however – center conductor will break.

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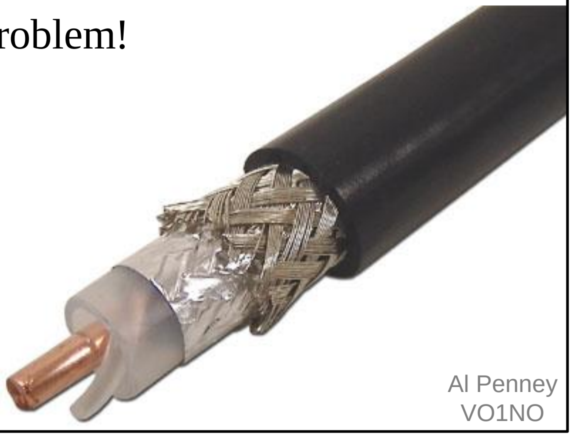
Both **RG8**/X and RG213/U can be used in applications where the cable needs to be "flexed" (i.e. to go around a rotor) whereas **LMR**-**400** has a solid aluminum (flashed with copper) center conductor and therefore will break in a VERY short period of time if used in an application where the cable is "flexed".

LMR(R)-400 Cable also known as Hardline LMR-400 because of its solid center conductor 0.108” (2.74mm) . LMR400 is a flexible Low Loss Communications Coax cable with a minimum bend radius of 1inch and the standard is a UV Resistant Polyethylene outer jacket designed for 20-year outdoor service use.

Belden 9913

- Low loss 50 Ohm coax cable.
- Uses spiral spacer around center conductor.
- Water ingress a problem!



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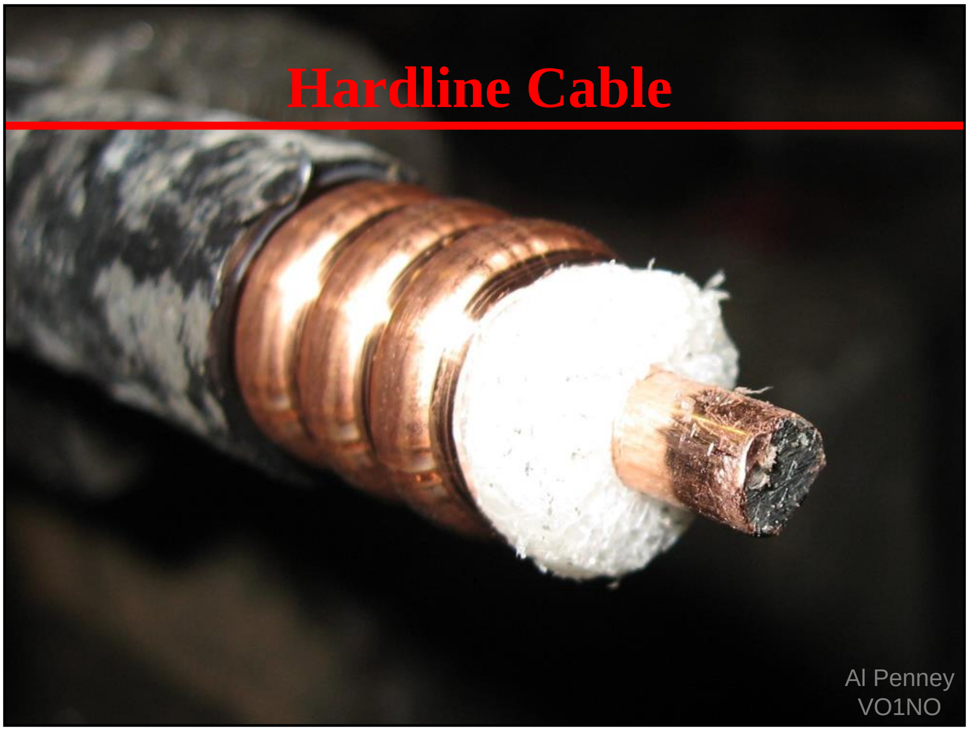

Hardline Cable

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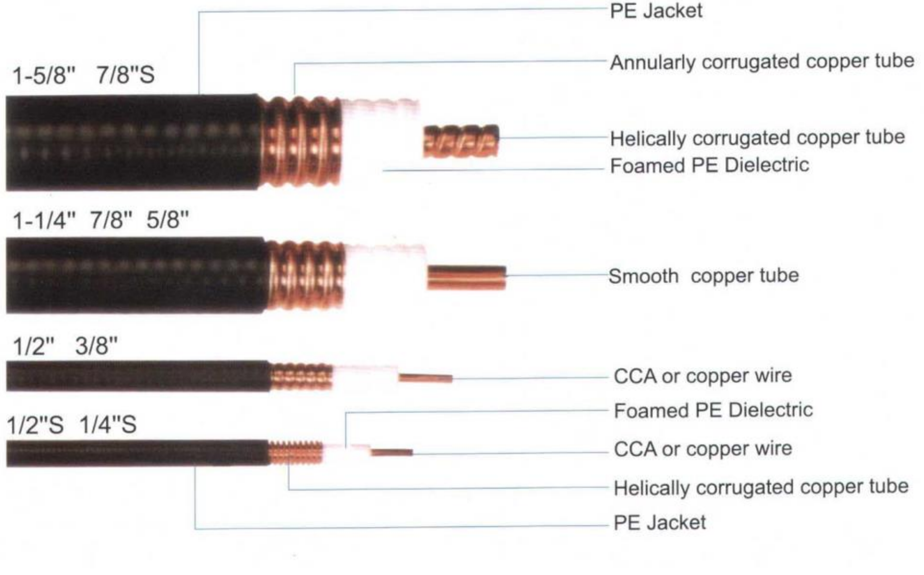
Hard line is used in broadcasting as well as many other forms of radio communication. It is a coaxial cable constructed using round copper, silver or gold tubing or a combination of such metals as a shield. Some lower-quality hard line may use aluminum shielding, aluminum however is easily oxidized and unlike silver oxide, aluminum oxide drastically loses effective conductivity. Therefore, all connections must be air and water tight. The center conductor may consist of solid copper, or copper-plated aluminum. Since skin effect is an issue with RF, copper plating provides sufficient surface for an effective conductor. Most varieties of hardline used for external chassis or when exposed to the elements have a PVC jacket; however, some internal applications may omit the insulation jacket. Hard line can be very thick, typically at least a half inch or 13 mm and up to several times that, and has low loss even at high power. These large-scale hard lines are almost always used in the connection between a transmitter on the ground and the antenna or aerial on a tower.

Hard line may also be known by trademarked names such as Heliax (CommScope), or Cablewave (RFS/Cablewave). Larger varieties of hardline may have a center conductor that is constructed from either rigid or corrugated copper tubing. The dielectric in hard line may consist of polyethylene foam, air, or a pressurized gas such as nitrogen or desiccated air (dried air). In gas-charged lines, hard plastics such as nylon are used as spacers to separate the inner and outer conductors. The addition of these gases into the dielectric space reduces moisture contamination, provides a stable dielectric constant, and provides a reduced risk of internal arcing. Gas-filled hardlines are usually used on high-power RF transmitters such as television or radio broadcasting, military transmitters, and high-power amateur radio applications but may also be used on some critical lower-power applications such as those in the microwave bands. However, in the microwave region, *waveguide* is more often used than hard line for transmitter-to-antenna, or antenna-to-receiver applications.

The various shields used in hardline also differ; some forms use rigid tubing, or pipe, while others may use a corrugated tubing, which makes bending easier, as well as reduces kinking when the cable is bent to conform. Smaller varieties of hard line may be used internally in some high-frequency applications, in particular in equipment within the microwave range, to reduce interference between stages of the device.



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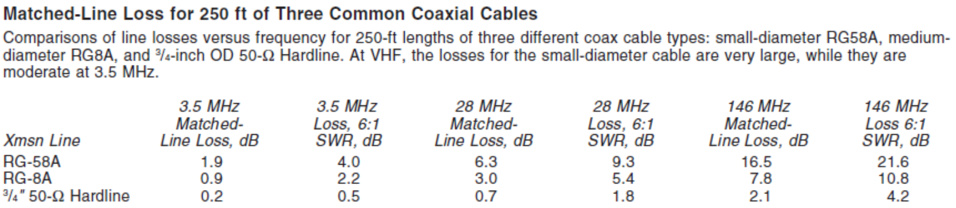
No need for solid center conductors due to skin effect.

Coax Loss



Matched-Line Loss for 250 ft of Three Common Coaxial Cables

Comparisons of line losses versus frequency for 250-ft lengths of three different coax cable types: small-diameter RG58A, medium-diameter RG8A, and ³/₄-inch OD 50-Ω Hardline. At VHF, the losses for the small-diameter cable are very large, while they are moderate at 3.5 MHz.

Xmsn Line	*3.5 MHz Matched-Line Loss, dB*	*3.5 MHz Loss, 6:1 SWR, dB*	*28 MHz Matched-Line Loss, dB*	*28 MHz Loss, 6:1 SWR, dB*	*146 MHz Matched-Line Loss, dB*	*146 MHz Loss 6:1 SWR, dB*
RG-58A	1.9	4.0	6.3	9.3	16.5	21.6
RG-8A	0.9	2.2	3.0	5.4	7.8	10.8
³/₄" 50-Ω Hardline	0.2	0.5	0.7	1.8	2.1	4.2

- Coax loss expressed in **dB per unit length**.
- Loss **increases with frequency**.
- **Longer coax** lengths have **greater loss**.
- **Greater loss** means **less power delivered** to load.

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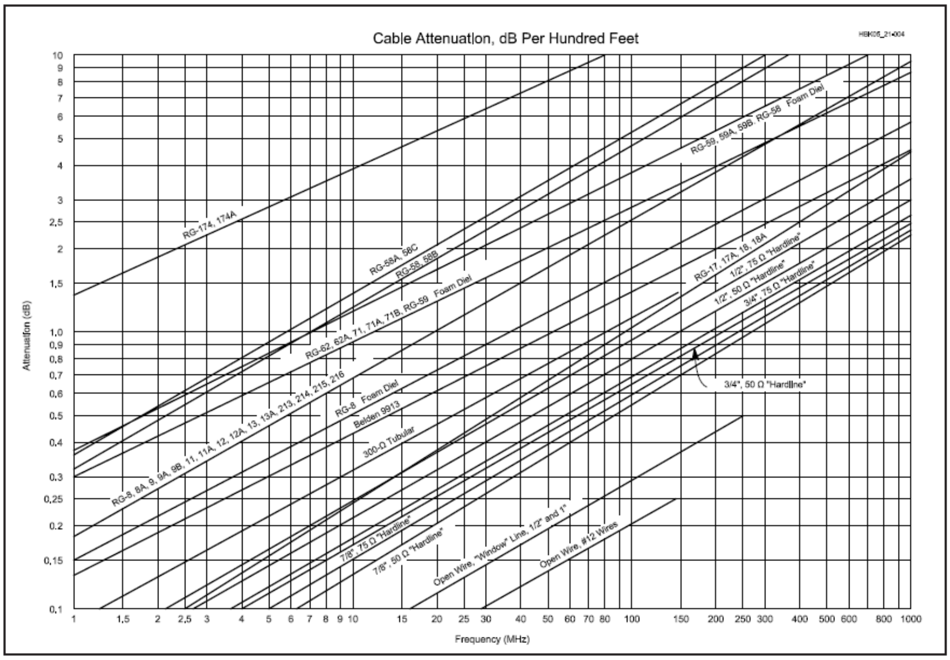

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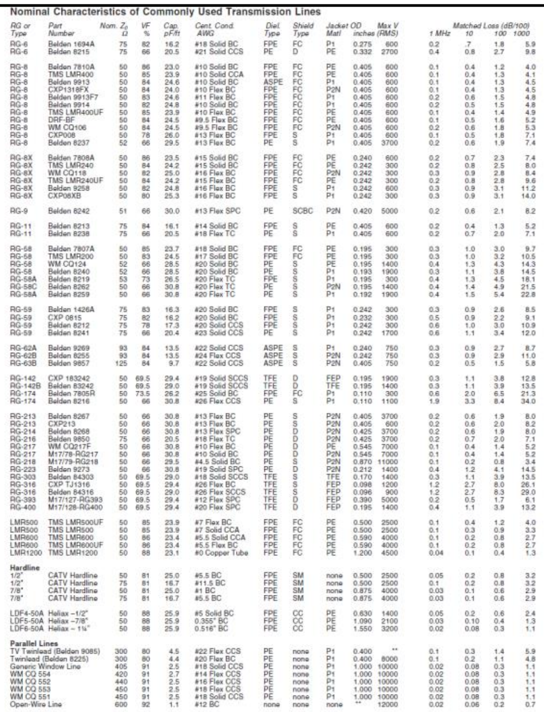

Nominal Characteristics of Commonly Used Transmission Lines

RG or Type	Part Number	Nom. Z_0 Ω	VF %	Cap. pF/ft	Cent. Cond. AWG	Diel. Type	Shield Type	Jacket Matl	OD inches	Max V (RMS)	Matched Loss (dB/100) 1 MHz	10	100	1000
RG-6	Belden 1694A	75	82	16.2	#18 Solid BC	FPE	FC	P1	0.275	600	0.2	.7	1.8	5.9
RG-6	Belden 8215	75	66	20.5	#21 Solid CCS	PE	D	PE	0.332	2700	0.4	0.8	2.7	9.8
RG-8	Belden 7810A	50	86	23.0	#10 Solid BC	FPE	FC	PE	0.405	600	0.1	0.4	1.2	4.0
RG-8	TMS LMR400	50	85	23.9	#10 Solid CCA	FPE	FC	PE	0.405	600	0.1	0.4	1.3	4.1
RG-8	Belden 9913	50	84	24.6	#10 Solid BC	ASPE	FC	P1	0.405	600	0.1	0.4	1.3	4.5
RG-8	CXP1318FX	50	84	24.0	#10 Flex BC	FPE	FC	P2N	0.405	600	0.1	0.4	1.3	4.5
RG-8	Belden 9913F7	50	83	24.6	#11 Flex BC	FPE	FC	P1	0.405	600	0.2	0.6	1.5	4.8
RG-8	Belden 9914	50	82	24.8	#10 Solid BC	FPE	FC	P1	0.405	600	0.2	0.5	1.5	4.8
RG-8	TMS LMR400UF	50	85	23.9	#10 Flex BC	FPE	FC	PE	0.405	600	0.1	0.4	1.4	4.9
RG-8	DRF-BF	50	84	24.5	#9.5 Flex BC	FPE	FC	PE	0.405	600	0.1	0.5	1.6	5.2
RG-8	WM CQ106	50	84	24.5	#9.5 Flex BC	FPE	FC	P2N	0.405	600	0.2	0.6	1.8	5.3
RG-8	CXP008	50	78	26.0	#13 Flex BC	FPE	S	P1	0.405	600	0.1	0.5	1.8	7.1
RG-8	Belden 8237	52	66	29.5	#13 Flex BC	PE	S	P1	0.405	3700	0.2	0.6	1.9	7.4
RG-8X	Belden 7808A	50	86	23.5	#15 Solid BC	FPE	FC	PE	0.240	600	0.2	0.7	2.3	7.4
RG-8X	TMS LMR240	50	84	24.2	#15 Solid BC	FPE	FC	PE	0.242	300	0.2	0.8	2.5	8.0
RG-8X	WM CQ118	50	82	25.0	#16 Flex BC	FPE	FC	P2N	0.242	300	0.3	0.9	2.8	8.4
RG-8X	TMS LMR240UF	50	84	24.2	#15 Flex BC	FPE	FC	PE	0.242	300	0.2	0.8	2.8	9.6
RG-8X	Belden 9258	50	82	24.8	#16 Flex BC	FPE	S	P1	0.242	600	0.3	0.9	3.1	11.2
RG-8X	CXP08XB	50	80	25.3	#16 Flex BC	FPE	S	P1	0.242	300	0.3	0.9	3.1	14.0
RG-9	Belden 8242	51	66	30.0	#13 Flex SPC	PE	SCBC	P2N	0.420	5000	0.2	0.6	2.1	8.2
RG-11	Belden 8213	75	84	16.1	#14 Solid BC	FPE	S	PE	0.405	600	0.2	0.4	1.3	5.2
RG-11	Belden 8238	75	66	20.5	#18 Flex TC	PE	S	P1	0.405	600	0.2	0.7	2.0	7.1
RG-58	Belden 7807A	50	85	23.7	#18 Solid BC	FPE	FC	PE	0.195	300	0.3	1.0	3.0	9.7
RG-58	TMS LMR200	50	83	24.5	#17 Solid BC	FPE	FC	PE	0.195	300	0.3	1.0	3.2	10.5
RG-58	WM CQ124	52	66	28.5	#20 Solid BC	PE	S	PE	0.195	1400	0.4	1.3	4.3	14.3
RG-58	Belden 8240	52	66	28.5	#20 Solid BC	PE	S	P1	0.193	1900	0.3	1.1	3.8	14.5
RG-58A	Belden 8219	53	73	26.5	#20 Flex TC	FPE	S	P1	0.195	300	0.4	1.3	4.5	18.1
RG-58C	Belden 8262	50	66	30.8	#20 Flex TC	PE	S	P2N	0.195	1400	0.4	1.4	4.9	21.5
RG-58A	Belden 8259	50	66	30.8	#20 Flex TC	PE	S	P1	0.192	1900	0.4	1.5	5.4	22.8
RG-59	Belden 1426A	75	83	16.3	#20 Solid BC	FPE	S	P1	0.242	300	0.3	0.9	2.6	8.5
RG-59	CXP 0815	75	82	16.2	#20 Solid BC	FPE	S	P1	0.232	300	0.5	0.9	2.2	9.1
RG-59	Belden 8212	75	78	17.3	#20 Solid CCS	FPE	S	P1	0.242	300	0.6	1.0	3.0	10.9
RG-59	Belden 8241	75	66	20.4	#23 Solid CCS	PE	S	P1	0.242	1700	0.6	1.1	3.4	12.0
RG-62A	Belden 9269	93	84	13.5	#22 Solid CCS	ASPE	S	P1	0.240	750	0.3	0.9	2.7	8.7
RG-62B	Belden 8255	93	84	13.5	#24 Flex CCS	ASPE	S	P2N	0.242	750	0.3	0.9	2.9	11.0
RG-63B	Belden 9857	125	84	9.7	#22 Solid CCS	ASPE	S	P2N	0.405	750	0.2	0.5	1.5	5.8
RG-142	CXP 183242	50	69.5	29.4	#19 Solid SCCS	TFE	D	FEP	0.195	1900	0.3	1.1	3.8	12.8
RG-142B	Belden 83242	50	69.5	29.0	#19 Solid SCCS	TFE	D	TFE	0.195	1400	0.3	1.1	3.9	13.5
RG-174	Belden 7805R	50	73.5	26.2	#25 Solid BC	FPE	FC	P1	0.110	300	0.6	2.0	6.5	21.3
RG-174	Belden 8216	50	66	30.8	#26 Flex CCS	PE	S	P1	0.110	1100	1.9	3.3	8.4	34.0
RG-213	Belden 8267	50	66	30.8	#13 Flex BC	PE	S	P2N	0.405	3700	0.2	0.6	1.9	8.0
RG-213	CXP213	50	66	30.8	#13 Flex BC	PE	S	P2N	0.405	600	0.2	0.6	2.0	8.2
RG-214	Belden 8268	50	66	30.8	#13 Flex SPC	PE	D	P2N	0.425	3700	0.2	0.6	1.9	8.0
RG-216	Belden 9850	75	66	20.5	#18 Flex TC	PE	D	P2N	0.425	3700	0.2	0.7	2.0	7.1
RG-217	WM CQ217F	50	66	30.8	#10 Flex BC	PE	D	PE	0.545	7000	0.1	0.4	1.4	5.2
RG-217	M17/78-RG217	50	66	30.8	#10 Solid BC	PE	D	P2N	0.545	7000	0.1	0.4	1.4	5.2
RG-218	M17/79-RG218	50	66	29.5	#4.5 Solid BC	PE	S	P2N	0.870	11000	0.1	0.2	0.8	3.4
RG-223	Belden 9273	50	66	30.8	#19 Solid SPC	PE	D	P2N	0.212	1400	0.4	1.2	4.1	14.5
RG-303	Belden 84303	50	69.5	29.0	#18 Solid SCCS	TFE	S	TFE	0.170	1400	0.3	1.1	3.9	13.5
RG-316	CXP TJ1316	50	69.5	29.4	#26 Flex BC	TFE	S	FEP	0.098	1200	1.2	2.7	8.0	26.1
RG-316	Belden 84316	50	69.5	29.0	#26 Flex SCCS	TFE	S	FEP	0.096	900	1.2	2.7	8.3	29.0
RG-393	M17/127-RG393	50	69.5	29.4	#12 Flex SPC	TFE	D	FEP	0.390	5000	0.2	0.5	1.7	6.1
RG-400	M17/128-RG400	50	69.5	29.4	#20 Flex SPC	TFE	D	FEP	0.195	1400	0.4	1.1	3.9	13.2
LMR500	TMS LMR500UF	50	85	23.9	#7 Flex BC	FPE	FC	PE	0.500	2500	0.1	0.4	1.2	4.0
LMR500	TMS LMR500	50	85	23.9	#7 Solid CCA	FPE	FC	PE	0.500	2500	0.1	0.3	0.9	3.3
LMR600	TMS LMR600	50	86	23.4	#5.5 Solid CCA	FPE	FC	PE	0.590	4000	0.1	0.2	0.8	2.7
LMR600	TMS LMR600UF	50	86	23.4	#5.5 Flex BC	FPE	FC	PE	0.590	4000	0.1	0.2	0.8	2.7
LMR1200	TMS LMR1200	50	88	23.1	#0 Copper Tube	FPE	FC	PE	1.200	4500	0.04	0.1	0.4	1.3
Hardline														
1/2"	CATV Hardline	50	81	25.0	#5.5 BC	FPE	SM	none	0.500	2500	0.05	0.2	0.8	3.2
1/2"	CATV Hardline	75	81	16.7	#11.5 BC	FPE	SM	none	0.500	2500	0.1	0.2	0.8	3.2
7/8"	CATV Hardline	50	81	25.0	#1 BC	FPE	SM	none	0.875	4000	0.03	0.1	0.6	2.9
7/8"	CATV Hardline	75	81	16.7	#5.5 BC	FPE	SM	none	0.875	4000	0.03	0.1	0.6	2.9
LDF4-50A	Heliax –1/2"	50	88	25.9	#5 Solid BC	FPE	CC	PE	0.630	1400	0.05	0.2	0.6	2.4
LDF5-50A	Heliax –7/8"	50	88	25.9	0.355" BC	FPE	CC	PE	1.090	2100	0.03	0.10	0.4	1.3
LDF6-50A	Heliax – 1¼"	50	88	25.9	0.516" BC	FPE	CC	PE	1.550	3200	0.02	0.08	0.3	1.1
Parallel Lines														
TV Twinlead (Belden 9085)		300	80	4.5	#22 Flex CCS	PE	none	P1	0.400	**	0.1	0.3	1.4	5.9
Twinlead (Belden 8225)		300	80	4.4	#20 Flex BC	PE	none	P1	0.400	8000	0.1	0.2	1.1	4.8
Generic Window Line		405	91	2.5	#18 Solid CCS	PE	none	P1	1.000	10000	0.02	0.08	0.3	1.1
WM CQ 554		420	91	2.7	#14 Flex CCS	PE	none	P1	1.000	10000	0.02	0.08	0.3	1.1
WM CQ 552		440	91	2.5	#16 Flex CCS	PE	none	P1	1.000	10000	0.02	0.08	0.3	1.1
WM CQ 553		450	91	2.5	#18 Flex CCS	PE	none	P1	1.000	10000	0.02	0.08	0.3	1.1
WM CQ 551		450	91	2.5	#18 Solid CCS	PE	none	P1	1.000	10000	0.02	0.08	0.3	1.1
Open-Wire Line		600	92	1.1	#12 BC	none	none	none	**	12000	0.02	0.06	0.2	0.7

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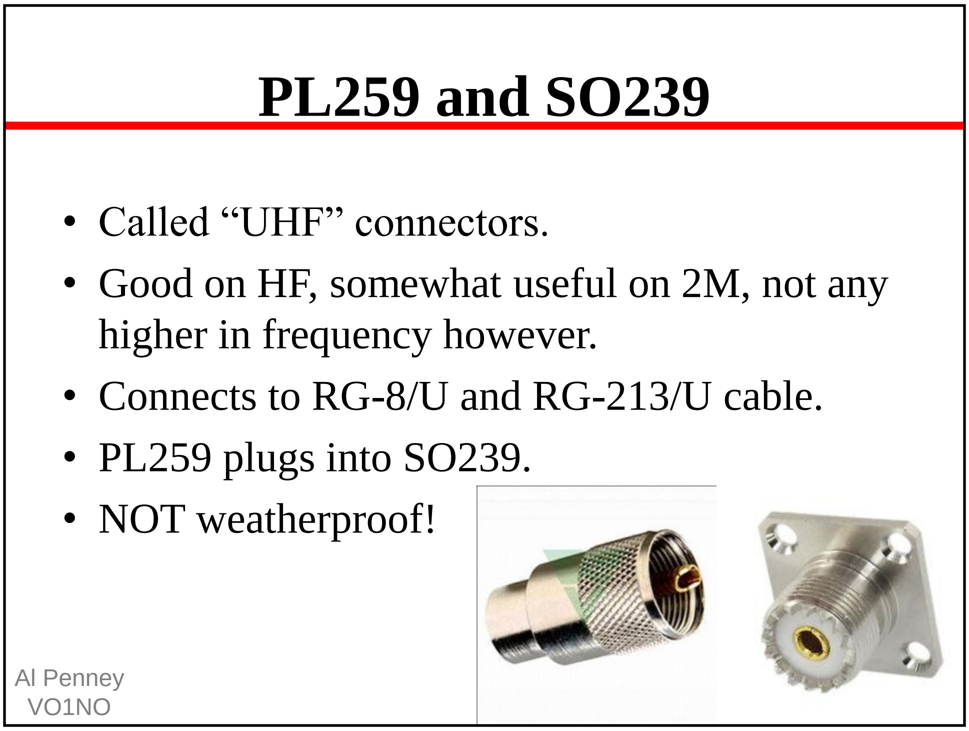
Note: Coax losses shown above are in dB for 100 feet lengths at specified frequencies. Loss is a length multiplier, so a 200 ft length would have twice the loss shown above and a 50 ft length would have half the loss.

Coax Connectors

- Enable coax cable to be connected to devices and antennas.
- Type depends on cable, use and frequency.
- Buy from reputable manufacturers.
- Look for Teflon insulation, silver coating on parts that must be soldered, and gold plating on pieces that mate.



PL259 and SO239

- Called “UHF” connectors.
- Good on HF, somewhat useful on 2M, not any higher in frequency however.
- Connects to RG-8/U and RG-213/U cable.
- PL259 plugs into SO239.
- NOT weatherproof!

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The **UHF connector** is a dated name for a threaded RF connector. The connector design was invented in the 1930s for use in the radio industry, and is a shielded form of the "banana plug. It is a widely used standard connector for HF transmission lines on full-sized radio equipment, with BNC connectors predominating for smaller, hand-held equipment.

The name "UHF" is a source of legitimate confusion, since the name of the connectors did not change when the frequency ranges were renamed. The design was named during an era when "UHF" meant frequencies over 30 MHz. Today Ultra high frequency (UHF) instead refers to frequencies between 300 MHz and 3 GHz and the range of frequencies formerly known as UHF is now called "VHF". Further adding to the confusion, the so-called "UHF" connectors are only well suited for the lower-VHF range and lower; they perform poorly for the higher modern UHF region. A more appropriate name would be "HF" connectors.

There is no active specification or standard governing the mechanical and electrical characteristics of the so-called "UHF" connector system making it effectively a deprecated design.

UHF connectors have a non-constant surge impedance. For this reason, UHF connectors are generally usable through HF and the lower portion of what is now known as the VHF frequency range. Despite the name, the UHF connector is rarely used in commercial applications for today's UHF frequencies, as the non-constant surge impedance creates measurable electrical signal reflections above 100 MHz.

Better quality UHF connectors can handle RF peak power levels well over one kilowatt based on the voltage rating of 500 Volts peak. In practice, a better quality UHF connector will handle over 4 kV peak voltage. Manufacturers typically test UHF jumpers in the 3-5 kV range. UHF connectors are standard on HF amateur amplifiers rated at 1500+ Watts output.

Using PL259 with RG58/U

- An UG175 adaptor is needed to attach a PL259 to RG-58/U.
- Get the right one – similar looking adaptors exist for RG-59, but have a different diameter.

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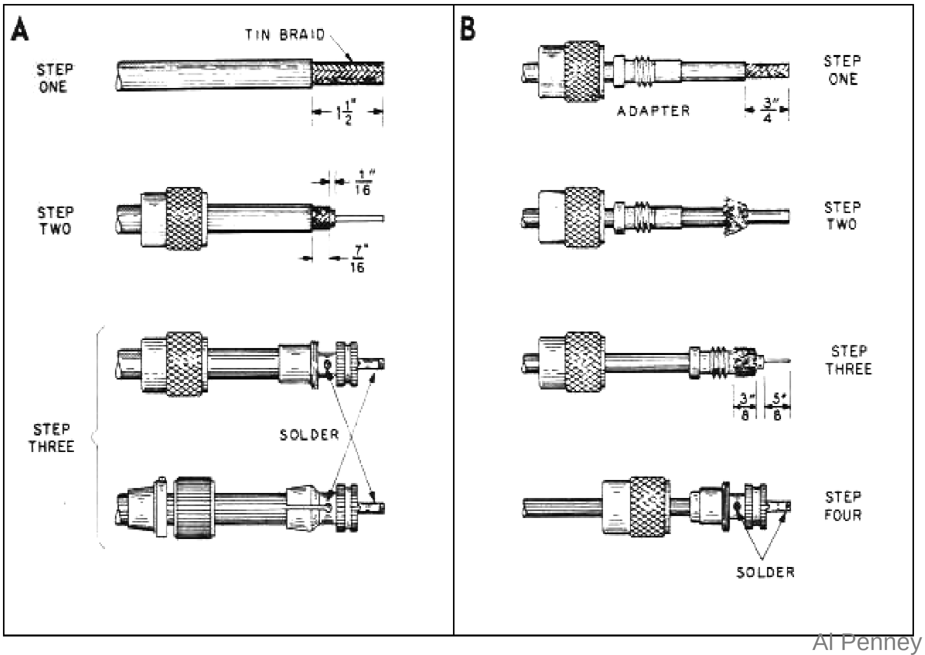

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BNC Connectors

- “Bayonet Neill Concelman”
- Quick connect/disconnect.
- Good to 2 GHz or more, but limited in power handling capability.
- Not weatherproof.

N Connectors

- Named after Paul Neill, of Bell Labs.
- Fits RG-8/U, RG-213/U and other cables.
- Good to 11 GHz or higher, at full legal limit in lower bands.
- Waterproof.

F Connectors

- Used on RG-59 and RG-6 for TV applications.
- Some use them for receive antennas.
- Easy to attach, but not very strong or waterproof.

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SMA Connectors

- **S**ub **M**iniature version **A**
- Used on Handi-Talkis, WiFi equipment.
- DC to 18 GHz
- 50 Ohms.

SMA (*SubMiniature version A*) connectors are semi-precision coaxial RF connectors developed in the 1960s as a minimal connector interface for coaxial cable with a screw-type coupling mechanism. The connector has a 50 Ω impedance. SMA is designed for use from DC (0 Hz) to 18 GHz, and is most commonly used in microwave systems, hand-held radio and mobile telephone antennas, and more recently with WiFi antenna systems and USB software-defined radio dongles. It is also commonly used in radio astronomy, particularly at higher frequencies (5 GHz+).

SMA connectors must not be confused with the standard household 75-ohm type F coax connector (diameters: Male 7⁄16 inch (11 mm) circular or hex; female 3⁄8 in (9.5 mm) external threads), as there is only about a 2 mm difference overall in the specifications. Type F cannot be mated with SMA connectors without the use of an adapter.

Adaptors

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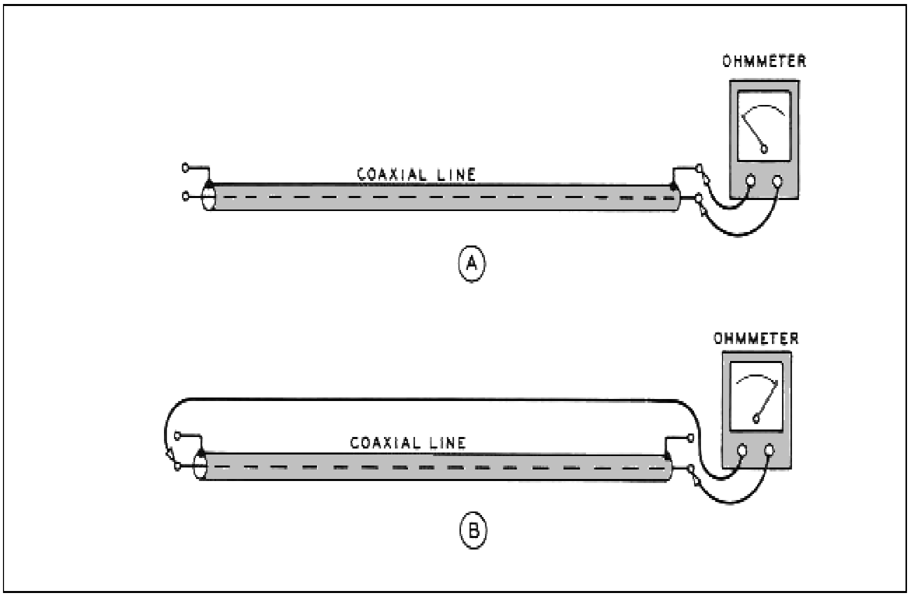

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Always do a continuity check on coax cable after installing connectors (not shown here).

Care of Coax Cable

- **Do not kink or bend** cable too sharply – the center conductor can migrate.
- Minimum bend radius is 5-10 times cable diameter.
- Protect from water ingress!
- Do not drag or step on cable.

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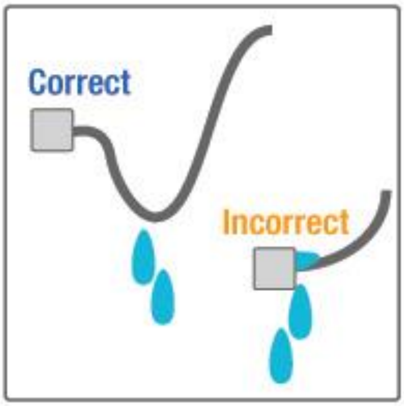
Drip Loop



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Coax seal

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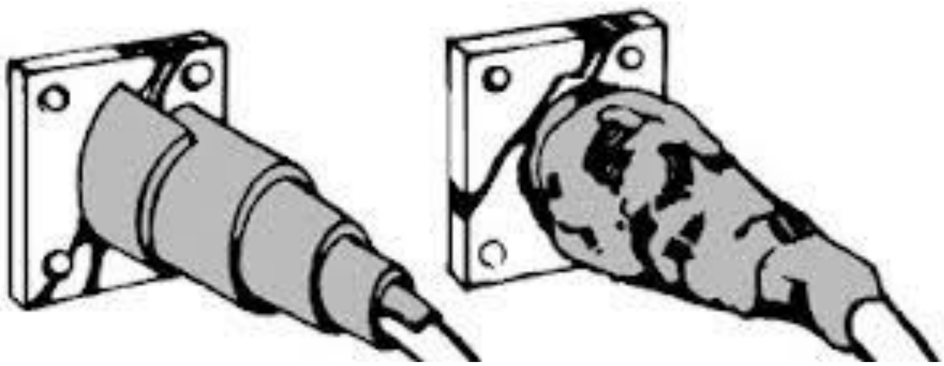

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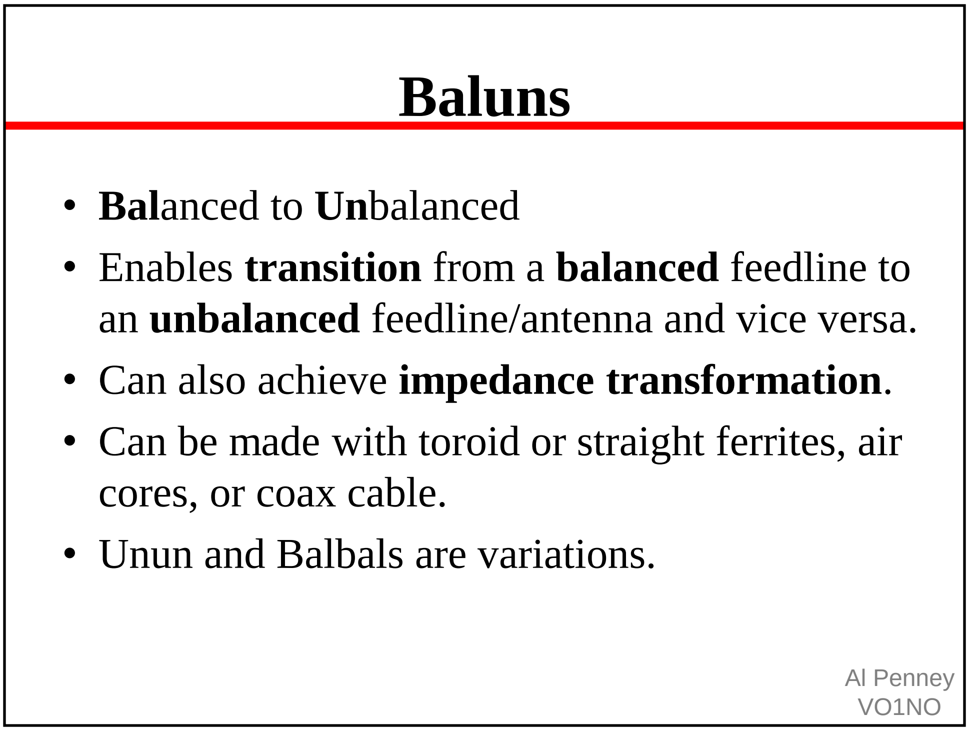
Tape back end of connectors to protect against water ingress and prevent the connector from twisting on the cable.



Baluns

- **Bal**anced to **Un**balanced
- Enables **transition** from a **balanced** feedline to an **unbalanced** feedline/antenna and vice versa.
- Can also achieve **impedance transformation**.
- Can be made with toroid or straight ferrites, air cores, or coax cable.
- Unun and Balbals are variations.

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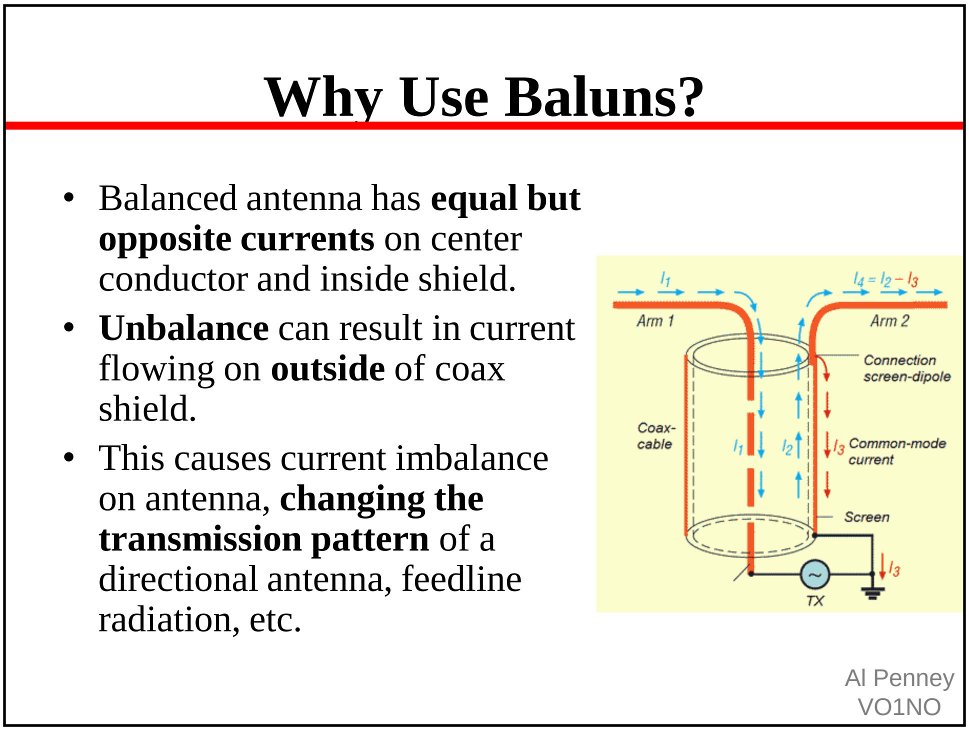
A **balun** (portmanteau of "balanced to unbalanced") is an electrical device that converts between a balanced signal and an unbalanced signal. A balun can take many forms and may include devices that also transform impedances but need not do so. Transformer baluns can also be used to connect lines of differing impedance. Sometimes, in the case of transformer baluns, they use magnetic coupling but need not do so. Common-mode chokes are also used as baluns and work by eliminating, rather than ignoring, common mode signals.

There are two variations of this device - they are:

•the **unun**, which transfers signal from one unbalanced line to another.

•the **balbal**, which transfers signal from one balanced line to another.

A *balun* is a transformer that matches a *bal*anced load (such as a horizontal dipole or Yagi antenna) to an *un*balanced resistive source (such as a transmitter output or a coaxial
feedline).



Why Use Baluns?

- Balanced antenna has **equal but opposite currents** on center conductor and inside shield.
- **Unbalance** can result in current flowing on **outside** of coax shield.
- This causes current imbalance on antenna, **changing the transmission pattern** of a directional antenna, feedline radiation, etc.

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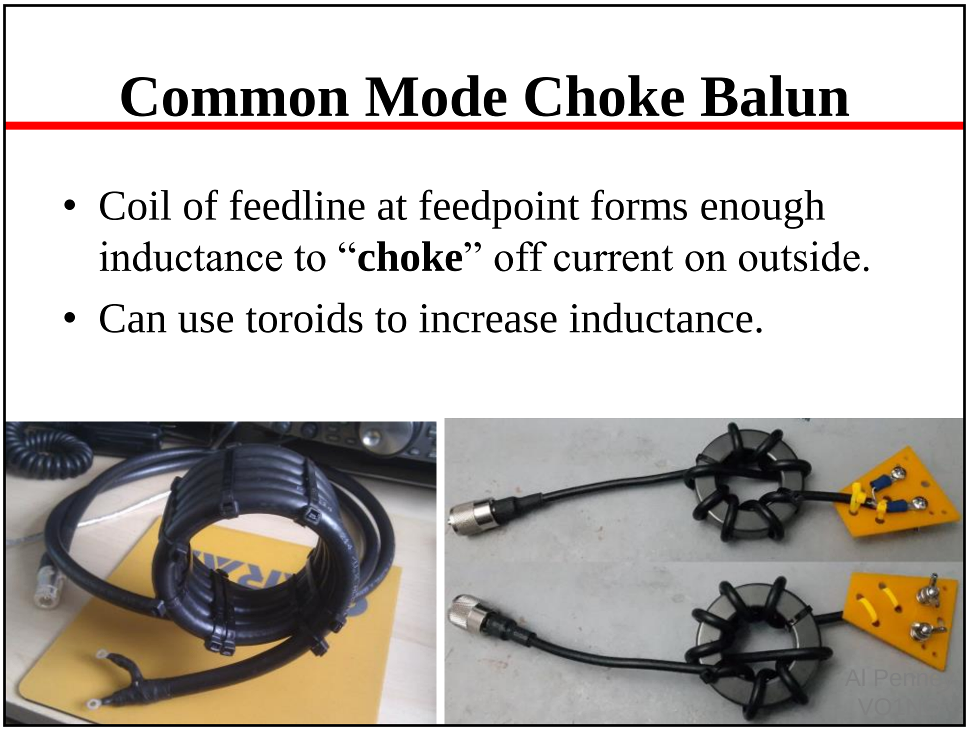
A **Balun** is used to "balance" unbalanced systems - i.e. those where power flows from an unbalanced line to a balanced line (hence, balun derives from *bal*ance to *un*balanced). As an example, consider a coaxial cable connected to a half-wave dipole antenna shown above.

In the Figure, a coaxial cable is connected to a dipole antenna. For a dipole antenna to operate properly, the currents on both arms of the dipole should be equal in magnitude (I1 equals I2, which should equal I4). When a coaxial cable is connected directly to a dipole antenna however, the currents will not necessarily be equal. To see this, note that the current along a transmission line should be of equal magnitude on the inner and outer conductors, as is typically the case. Observe what happens when the coax is connected to the dipole. The current on the center conductor (the red/pink center core of the coax, labeled *I1*) has no where else to go, so must flow along the dipole arm that is connected to it. However, the current that travels along the inner side of the outer conductor (*I2*) has two options: it can travel down the dipole antenna, or down the reverse (outer) side of the outer conductor of the coaxial cable (labeled *I3* in the Figure).

Ideally, the current *I3* should be zero. In that case, the current along the dipole arm connected to the outer conductor of the coax will be equal to the current on the other dipole arm - a desirable antenna characteristic. Because the dipole wants equal or balanced currents along its arms, it is the balanced section. The coaxial cable does not necessarily give this however - some of the current may travel down the outside of the outer coax, leading to unbalanced operation - this is the unbalanced section.

The solution to this problem, however you come up with it, is a balun. A balun forces an unbalanced transmission line to properly feed a balanced component. In Figure 1, this would be done by forcing *I3* to be zero somehow - this is often called choking the current or a current choke.



Common Mode Choke Balun

- Coil of feedline at feedpoint forms enough inductance to “**choke**” off current on outside.
- Can use toroids to increase inductance.

Placing a “common-mode choke” whose reactance is + *j*1000 οημσ at the antenna’s feed point removes virtually all trace current on the outside of the braid. This is always true for the simple case where the feedline was dressed symmetrically, directly down under the feed point. Certain slanted-feedline lengths required additional common-mode chokes, placed at λ/4 intervals down the transmission line from the feed point.

The simplest method to create a common-mode choke balun with coaxial cable is to wind up some of it into a coil at the feed point of the antenna. The normal transmission-line currents inside the coax are unaffected by the coiled configuration, but common mode currents trying to flow on the outside of the coax braid are “choked off” by the reactance of the coil. This coax-coil choke could also be referred to as an “air-wound” choke, since no ferrite-core material is used to help boost the common-mode reactance at low frequencies.

A coax choke can be made like a flat coil— that is, like a coil of rope whose adjacent turns are carefully placed side-by-side to reduce inter-turn distributed capacity, rather than in a “scramble-wound” fashion. Sometimes a coil form made of PVC is used to keep things orderly.

This type of choke shows a broad resonance due to its inductance and distributed capacity that can easily cover three amateur bands. See **Fig 30**. Some geometries are reasonably effective over the entire HF range. If particular problems are encountered on a single band, a coil that is resonant at that band may be added. The coils shown in **Table 3** were designed to have a high impedance at the indicated frequencies, as measured with an impedance meter. Many other geometries can also be effective. This construction technique is not effective with twin-lead because of excessive coupling between adjacent turns.

This choke-type of balan is sometimes referred to as a “current balun” since it has the hybrid properties of a tightly coupled transmission-line transformer (with a 1:1 transformation ratio) and a coil. The transmission- line transformer forces the current at the output terminals to be equal, and the coil portion chokes off common-mode currents.

Choke Baluns

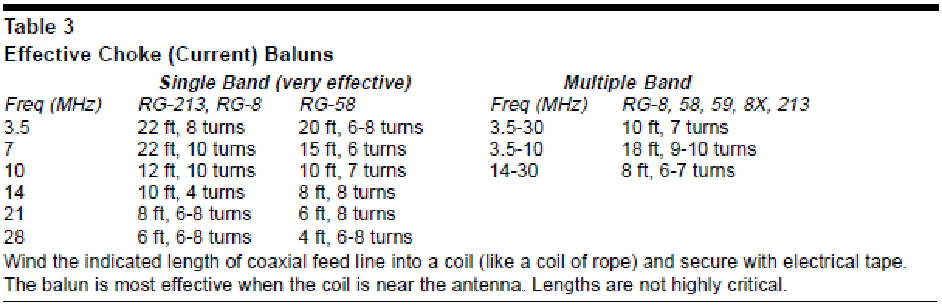


Table 3

Effective Choke (Current) Baluns

	Single Band (very effective)		*Multiple Band*	
Freq (MHz)	*RG-213, RG-8*	*RG-58*	*Freq (MHz)*	*RG-8, 58, 59, 8X, 213*
3.5	22 ft, 8 turns	20 ft, 6-8 turns	3.5-30	10 ft, 7 turns
7	22 ft, 10 turns	15 ft, 6 turns	3.5-10	18 ft, 9-10 turns
10	12 ft, 10 turns	10 ft, 7 turns	14-30	8 ft, 6-7 turns
14	10 ft, 4 turns	8 ft, 8 turns		
21	8 ft, 6-8 turns	6 ft, 8 turns		
28	6 ft, 6-8 turns	4 ft, 6-8 turns		

Wind the indicated length of coaxial feed line into a coil (like a coil of rope) and secure with electrical tape. The balun is most effective when the coil is near the antenna. Lengths are not highly critical.

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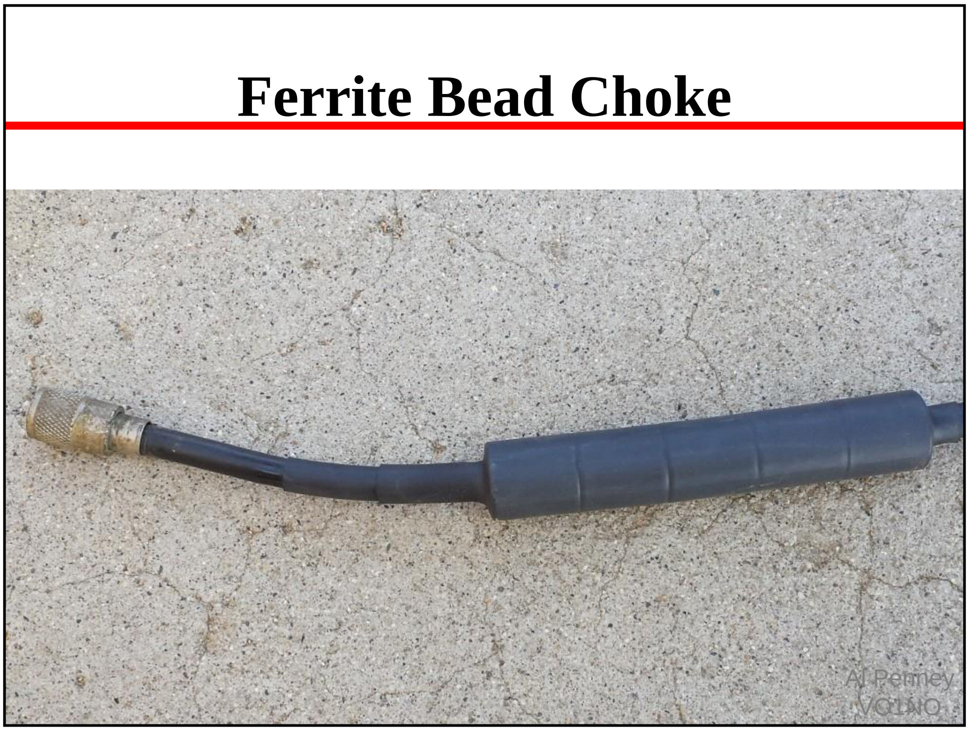

Ferrite Bead Choke

Ferrite beads are used for RF decoupling and parasitic suppression. When placed over a **wire**, **cable** or **coaxial cable** they suppresses common mode current flowing on the **wire** or **wire** bundle or the outside of the **coax** shield but does not affect the signal inside the **coax cable** or **wire** (differential current).

Transformer Baluns

- Two or more windings on an air or ferrite core.
- Can provide a **broadband match** between transmission line and antenna.
- In addition to converting balanced to unbalanced they can provide 1:1, 4:1 and many other impedance shifts.
- Also provide electrical isolation.

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Toroid Impedance Matching Transformers

The toroidal transformer is capable of providing a broadband match between antenna and transmission line, or between transmission line and transmitter or receiver. Many other matching methods are frequency sensitive and must be readjusted whenever the operating frequency is changed by even a small percentage. Although

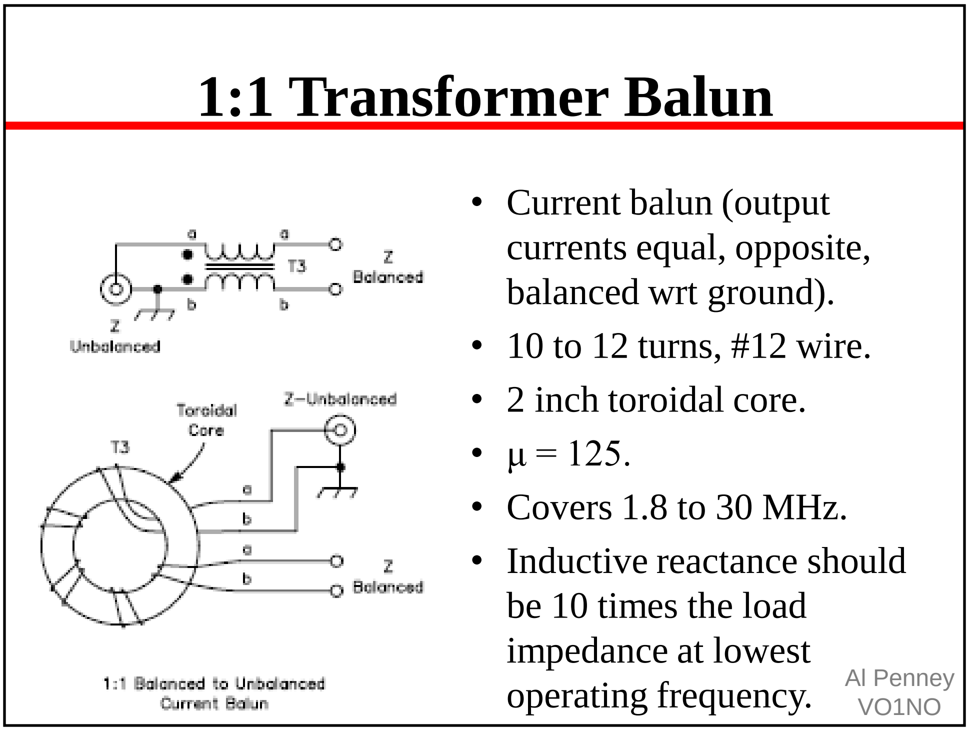
this problem is of no great concern to fixed frequency radio stations, it is of critical importance to stations that operate on a variety of frequencies or widely separated bands of frequencies.

In classical transformers, there are two electrically separate windings of wire coils around the transformer's core. The advantage of transformer-type over other types of balun is that the electrically separate windings for input and output allow these baluns to connect circuits whose ground-level voltages are subject to ground loops or are otherwise electrically incompatible; for that reason they are often called *isolation transformers*.

This type is sometimes called a *voltage balun*. The *primary* winding receives the input signal, and the *secondary* winding puts out the converted signal. The core that they are wound on may either be empty (air core) or, equivalently, a magnetically neutral material like a porcelain support, or it may be a material which is good magnetic conductor like ferrite in modern high-frequency (HF) baluns, or soft iron as in the early days of telegraphy.

The electrical signal in the primary coil is converted into a magnetic field in the transformer's core. When the electrical current through the primary reverses, it causes the established magnetic field to collapse. The collapsing magnetic field then induces an electric field in the secondary winding.

The ratio of loops in each winding and the efficiency of the coils' magnetic coupling determines the ratio of electrical potential (voltage) to electrical current and the total power of the output. For idealized transformers, although the ratio of voltage to current will change in exact proportion to the square of the winding ratio, the power (measured in watts) remains identical. In real transformers, some energy is lost inside to heating of the metallic core of the transformer, and lost outside to the surrounding environment because of imperfect magnetic coupling between the two coils.



1:1 Transformer Balun

- Current balun (output currents equal, opposite, balanced wrt ground).
- 10 to 12 turns, #12 wire.
- 2 inch toroidal core.
- µ = 125.
- Covers 1.8 to 30 MHz.
- Inductive reactance should be 10 times the load impedance at lowest operating frequency.

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A Current balun is one whose output currents are equal and opposite (balanced with respect to ground). This 1:1 balun excepted, they are usually more difficult and expensive to build than voltage baluns

Typically, 10 to 12 turns of #12 wires wound on 2.0-inch toroidal cores with µ = 125 will cover the whole range from 1.8 to 30 MHz.

Ferrite Core Inductors

The word *ferrite* refers to any of several examples of a class of materials that behave similarly to powdered iron compounds and are used in radio equipment as the cores for

inductors and transformers. Although the materials originally employed were of powdered iron (and indeed the name *ferr*ite still implies iron), many modern materials are

composed of other compounds. According to literature from Amidon Associates, ferrites with a *relative permeability,* or *µr,* of 800 to 5000 are generally of the manganese-zinc

type of material, and cores with relative permeabilities of 20 to 800 are of nickel-zinc. The latter are useful in the 0.5-A� to 100-A�MHz range.

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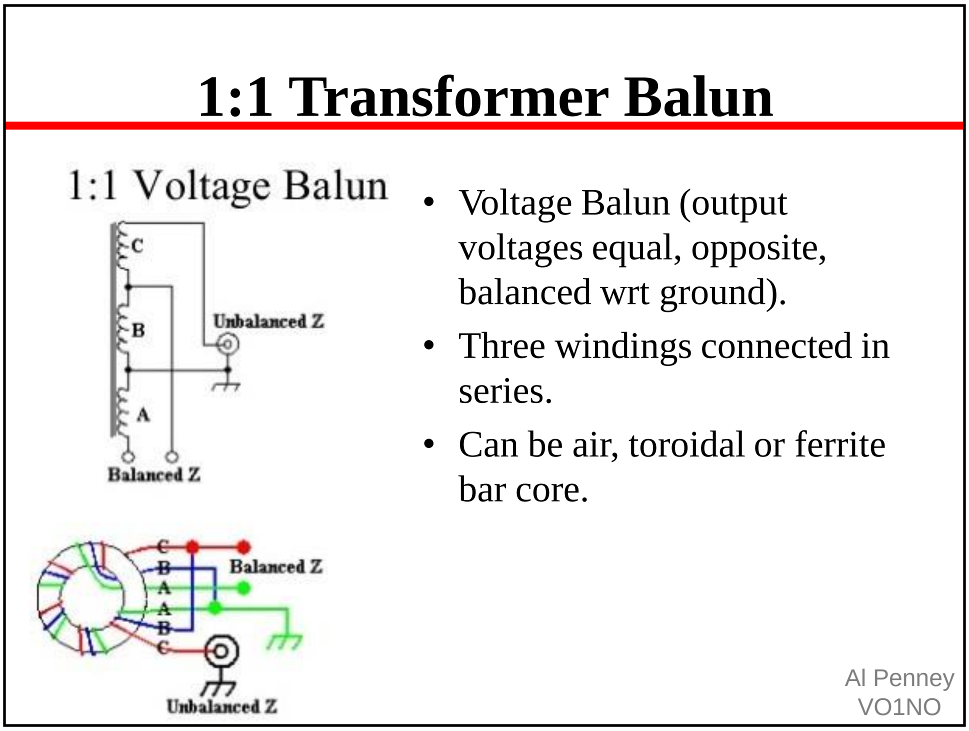

1:1 Transformer Balun

- Voltage Balun (output voltages equal, opposite, balanced wrt ground).
- Three windings connected in series.
- Can be air, toroidal or ferrite bar core.

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A Voltage balun is one whose output voltages are equal and opposite (balanced with respect to ground).


Power Antenna Co
1:1 Current / Choke Bal
5KW: 160 to 10 Meter
del number: BL 10-160
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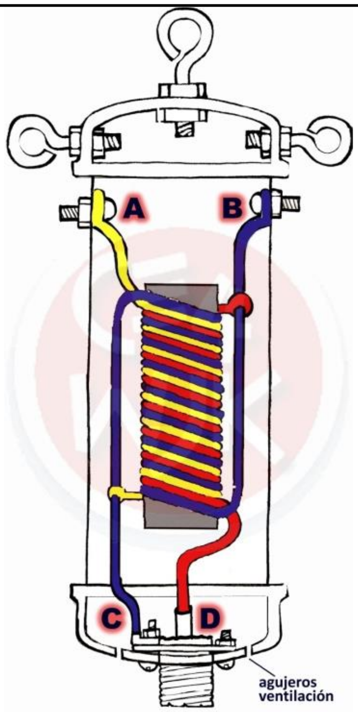

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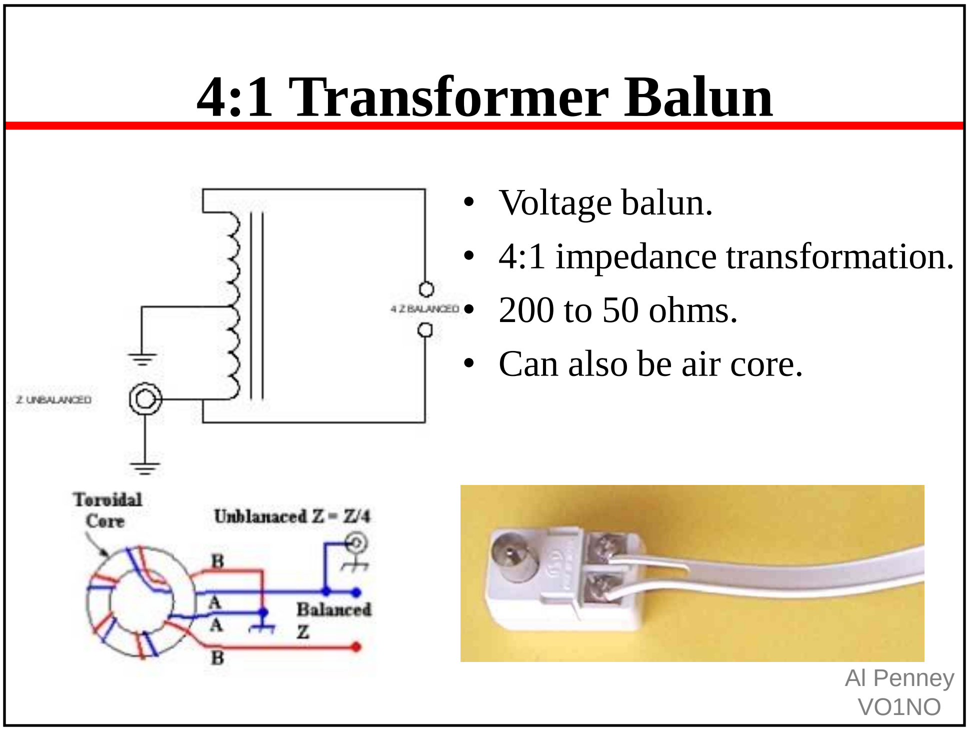

4:1 Transformer Balun

- Voltage balun.
- 4:1 impedance transformation.
- 200 to 50 ohms.
- Can also be air core.

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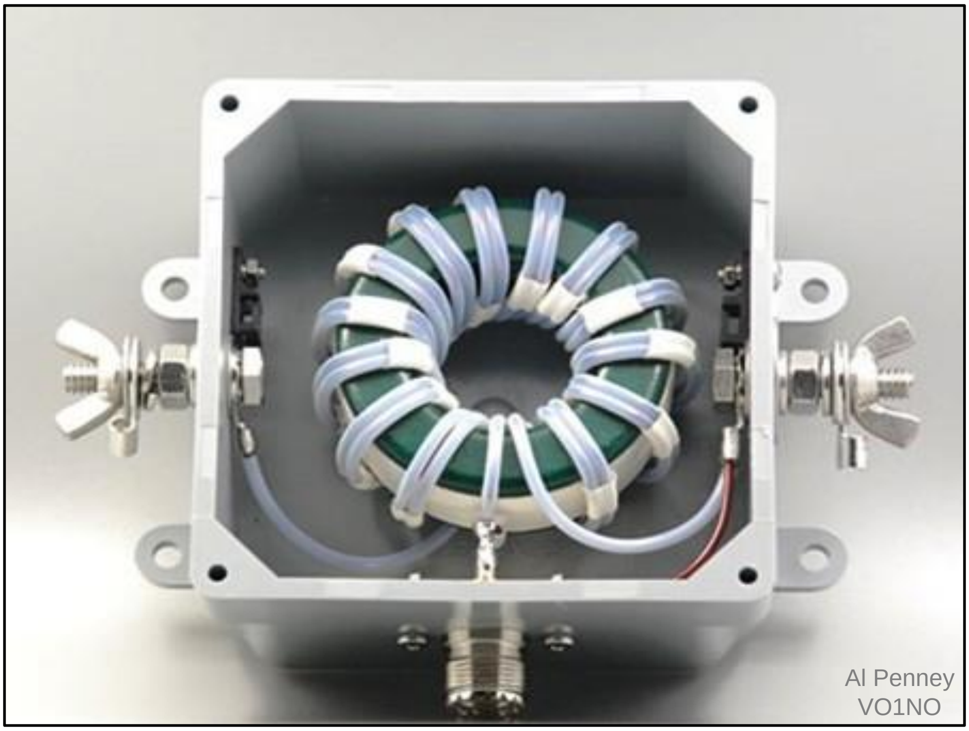
A Voltage balun is one whose output voltages are equal and opposite (balanced with respect to ground).



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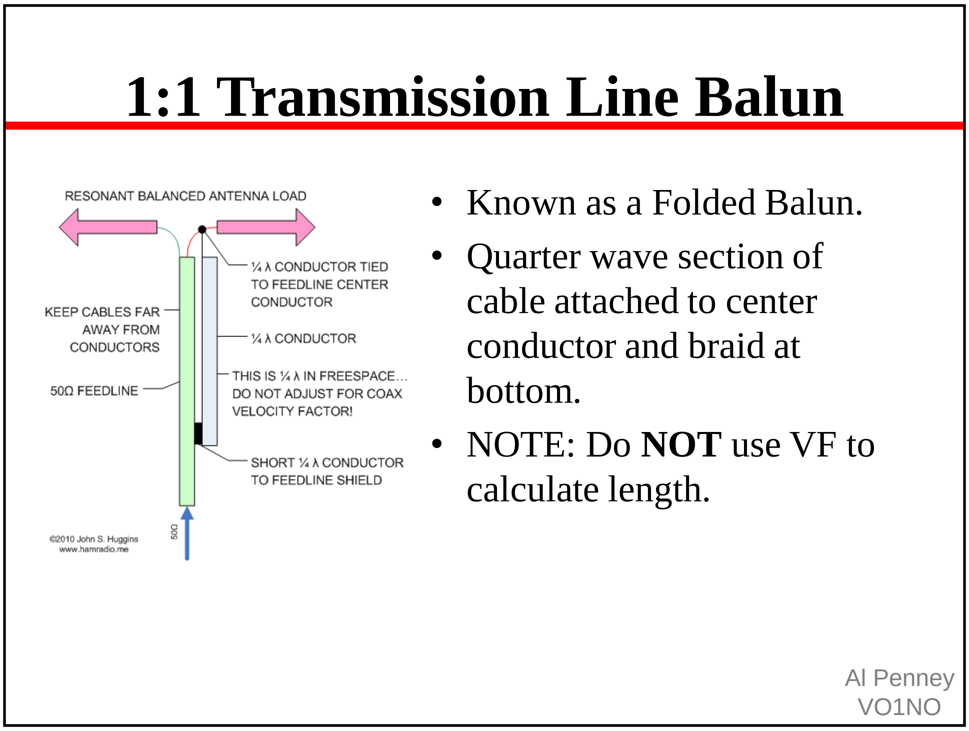

1:1 Transmission Line Balun

- Known as a Folded Balun.
- Quarter wave section of cable attached to center conductor and braid at bottom.
- NOTE: Do **NOT** use VF to calculate length.

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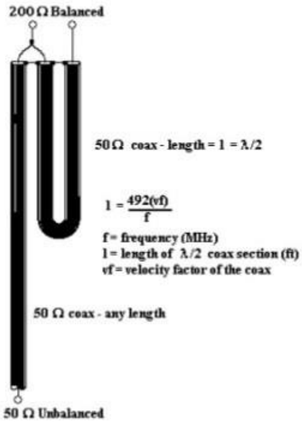
Folded Balun

aka *Pawsey Stub* and *1/4 Wave Coaxial Balun*
Figure shows the idea behind the Pawsey stub which is known in Electrical Engineering circles as a variant of the Folded Balun. While the Gray conductor in the Figure only needs to be a wire of similar size to the coaxial cable feedline, it is often made from a scrap piece of the same cable. Each end of the outer shield of the stub is connected to the feed system. A common thought of many is since this is coaxial cable, we need velocity factor adjustments. Since the electric and magnetic fields (of the stub system) are in air, I think velocity factor does not apply.

4:1 Transmission Line Balun



- Voltage Balun.
- Uses half wavelength section of coaxial cable (factor in the VF).
- Suitable for one band only.
- Often used on VHF/UHF Yagis.
- **75 ohm cable gives 300 ohms**.

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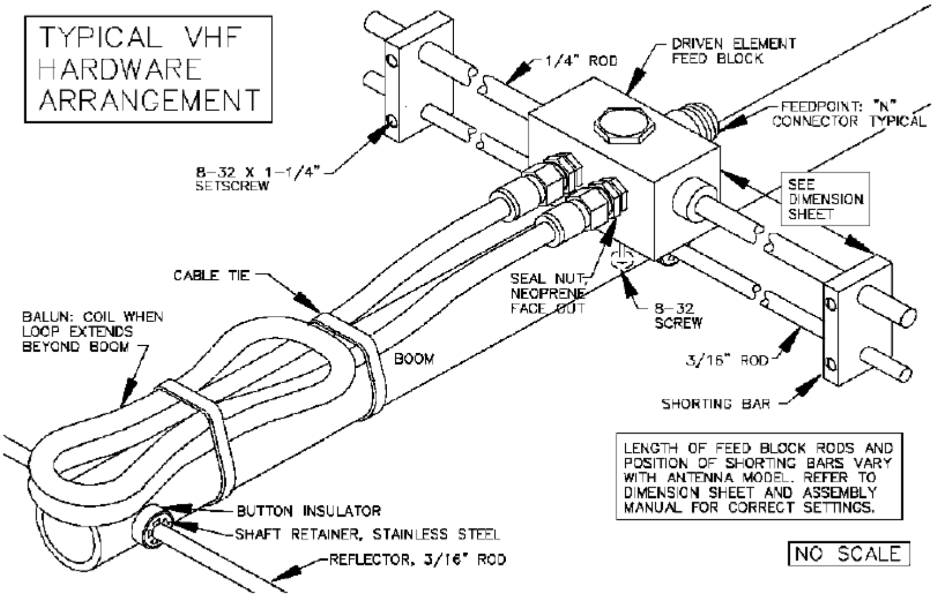

LENGTH OF FEED BLOCK RODS AND POSITION OF SHORTING BARS VARY WITH ANTENNA MODEL. REFER TO DIMENSION SHEET AND ASSEMBLY MANUAL FOR CORRECT SETTINGS.

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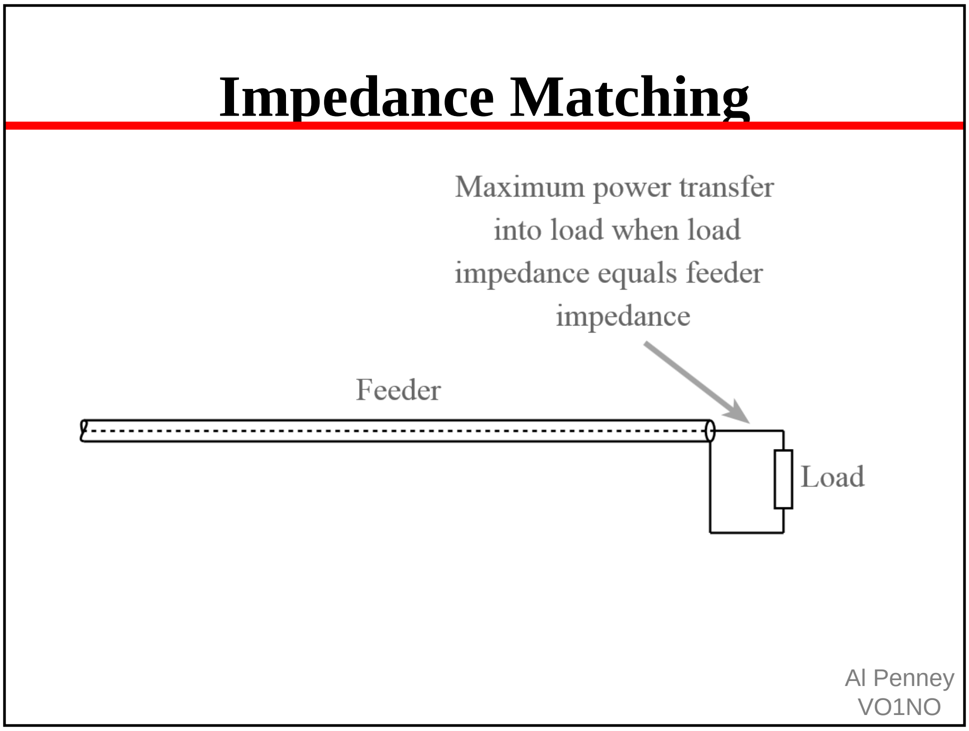

Impedance Matching

Maximum power transfer into load when load impedance equals feeder impedance

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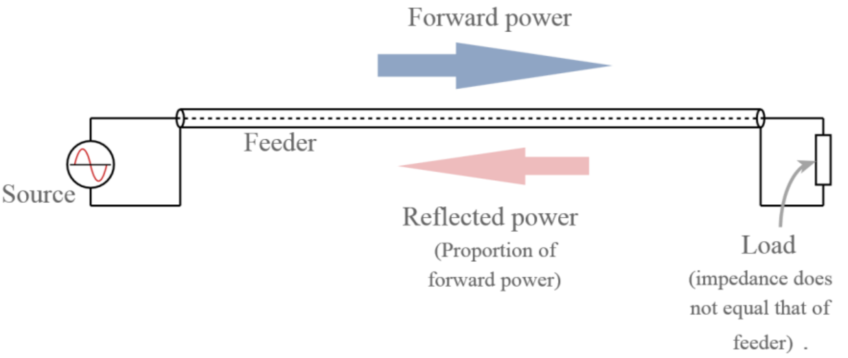
When looking at systems that include transmission lines it is necessary to understand that sources, transmission lines / feeders and loads all have a characteristic impedance. 50Ω is a very common standard for RF applications although other impedances may occasionally be seen in some systems.

In order to obtain the maximum power transfer from the source to the transmission line, or the transmission line to the load, be it a resistor, an input to another system, or an antenna, the impedance levels must match.

In other words for a 50Ω system the source or signal generator must have a source impedance of 50Ω, the transmission line must be 50Ω and so must the load.

Impedance Matching



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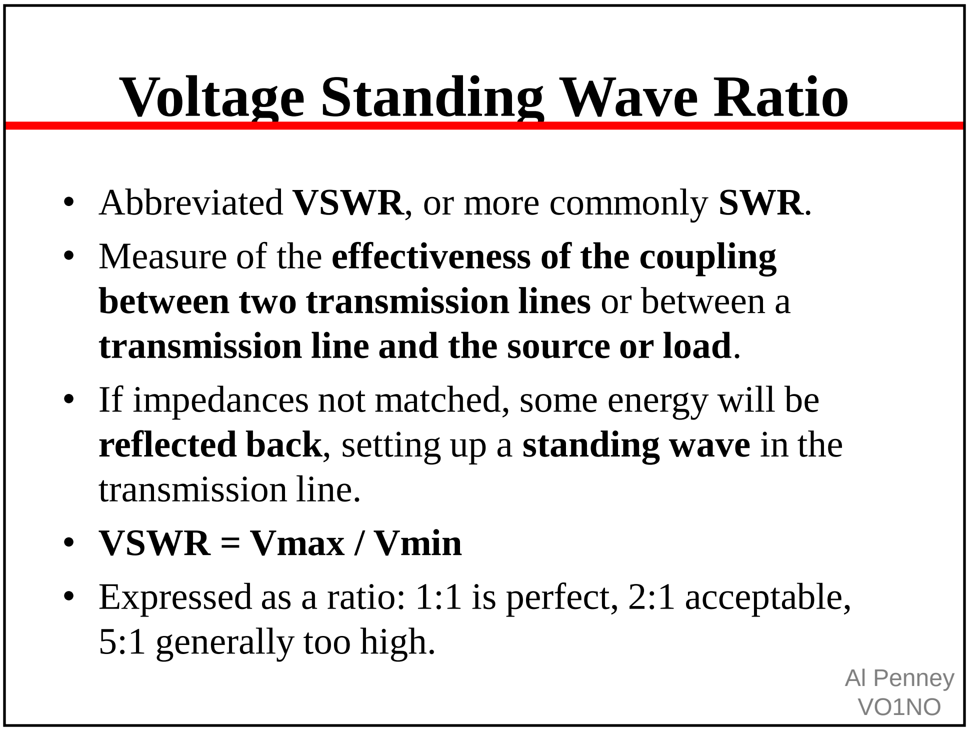
Issues arise when power is transferred into the transmission line or feeder and it travels towards the load. If there is a mismatch, i.e. the load impedance does not match that of the transmission line, then it is not possible for all the power to be transferred.

As power cannot disappear, the power that is not transferred into the load has to go somewhere and there it travels back along the transmission line back towards the source.

When this happens the voltages and currents of the forward and reflected waves in the feeder add or subtract at different points along the feeder according to the phases. In this way standing waves are set up.

The way in which the effect occurs can be demonstrated with a length of rope. If one end is left free and the other is moved up an down the wave motion can be seen to move down along the rope. However if one end is fixed a standing wave motion is set up, and points of minimum and maximum vibration can be seen.



Voltage Standing Wave Ratio

- Abbreviated **VSWR**, or more commonly **SWR**.
- Measure of the **effectiveness of the coupling between two transmission lines** or between a **transmission line and the source or load**.
- If impedances not matched, some energy will be **reflected back**, setting up a **standing wave** in the transmission line.
- **VSWR = Vmax / Vmin**
- Expressed as a ratio: 1:1 is perfect, 2:1 acceptable, 5:1 generally too high.

Al Penney
VO1NO

VSWR Definition

Voltage standing wave ratio (VSWR) is defined as the ratio between transmitted and reflected voltage standing waves in a radio frequency (RF) electrical transmission system. It is a measure of how efficiently RF power is transmitted from the power source, through a transmission line, and into the load. A common example is a power amplifier connected to an antenna through a transmission line.

SWR is, thus, the ratio between transmitted and reflected waves. A high SWR indicates poor transmission-line efficiency and reflected energy, which can damage the transmitter and decrease transmitter efficiency. Since SWR commonly refers to the voltage ratio, it is usually known as voltage standing wave ratio (VSWR).

VSWR and System Efficiency

In an ideal system, 100% of energy is transmitted from the power stages to the load. This requires an exact match between the source impedance (the characteristic impedance of the transmission line and all its connectors), and the load impedance. The signal's AC voltage will be the same from end to end since it passes through without interference.

In a real system, mismatched impedances cause some of the power to be reflected back toward the source (like an echo). These reflections cause constructive and destructive interference, leading to peaks and valleys in the voltage, varying with time and distance along the transmission line. VSWR quantifies these voltage variances, hence another commonly used definition for Voltage Standing Wave Ratio is that it is the ratio of the highest voltage to the lowest voltage, at any point on the transmission line.

For an ideal system, voltage does not vary. Therefore, its VSWR is 1.0 (or more usually expressed as a ratio of 1:1). When reflections occur, voltages vary and VSWR is higher, for example 1.2 (or 1.2: 1). Increased VSWR correlates with reduced transmission line (and therefore overall transmitter) efficiency.

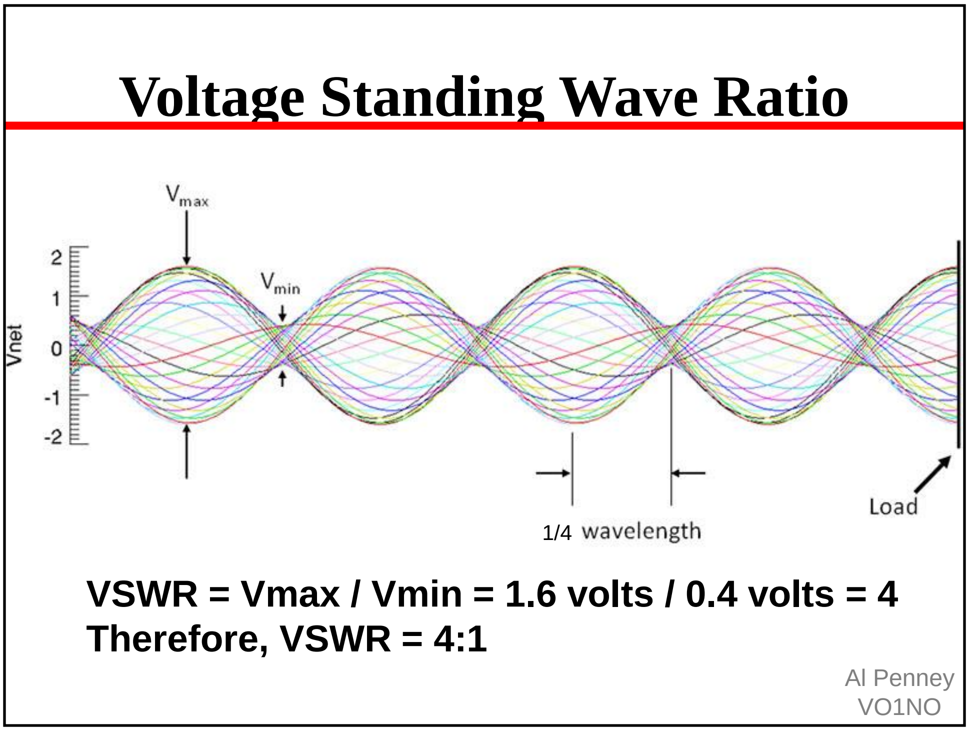
For a radio (transmitter or receiver) to deliver power to an antenna, the impedance of the radio and transmission line must be well matched to the antenna's impedance. The parameter **VSWR** is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.

VSWR stands for **Voltage Standing Wave Ratio**, and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna.

The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1:1 (“one to one”). In this case, no power is reflected from the antenna, which is ideal.

In radio engineering and telecommunications, **standing wave ratio** (**SWR**) is a measure of impedance matching of loads to the characteristic impedance of a transmission line or waveguide. Impedance mismatches result in standing waves along the transmission line, and SWR is defined as the ratio of the partial standing wave's amplitude at an antinode (maximum) to the amplitude at a node (minimum) along the line.

The SWR is usually thought of in terms of the maximum and minimum AC voltages along the transmission line, thus called the **voltage standing wave ratio** or **VSWR** (sometimes pronounced "vizwar". For example, the VSWR value 1.2:1 denotes an AC voltage due to standing waves along the transmission line reaching a peak value 1.2 times that of the minimum AC voltage along that line. The SWR can as well be defined as the ratio of the maximum amplitude to minimum amplitude of the transmission line's currents, electric field strength, or the magnetic field strength. Neglecting transmission line loss, these ratios are identical.



Voltage Standing Wave Ratio

VSWR = Vmax / Vmin = 1.6 volts / 0.4 volts = 4
Therefore, VSWR = 4:1

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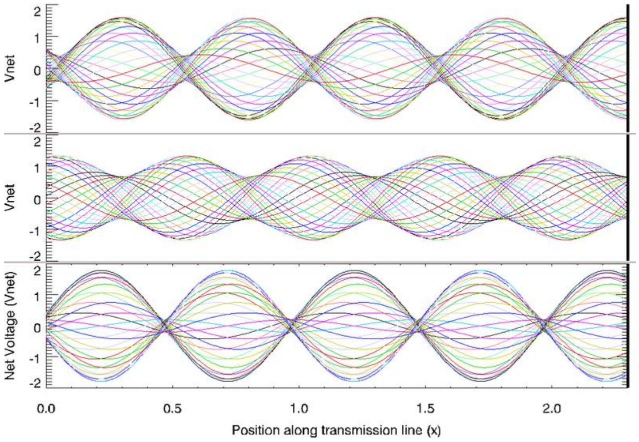
Standing waves on a transmission line, with the resulting voltages (VNET) shown in different colors during one complete cycle of the applied voltage. The generated wave with an amplitude of 1 travels from left to right and is partially reflected by the load at right. SWR = V_{MAX} / V_{MIN} = 1.6 / 0.4 = 4.0. *(Graphic created by Wikipedia contributor, Interferometrist and is used under the Creative Commons Attribution-Share Alike 4.0 International license.)*

VSWR is determined from the voltage measured along a transmission line leading to an antenna. VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave, as seen in the following Figure:

When an antenna is not matched to the receiver, power is reflected. This causes a "reflected voltage wave", which creates standing waves along the transmission line. The result are the peaks and valleys as seen in Figure 1. If the VSWR = 1:1, there would be no reflected power and the voltage would have a constant magnitude along the transmission line.

VSWR



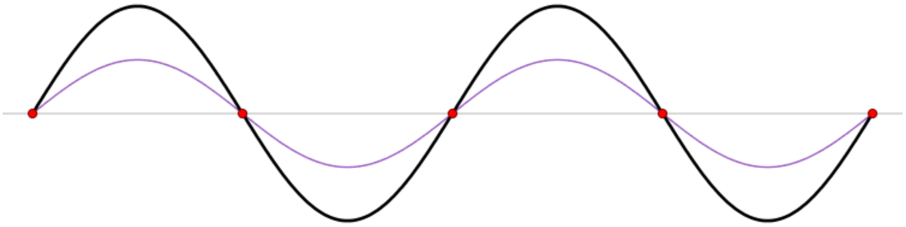
VSWR = 4:1

VSWR = 2:1

VSWR = 9:1

Standing waves on transmission line, net voltage shown in different colors during one period of oscillation. Incoming wave from left (amplitude = 1) is partially reflected with (top to bottom) Γ = 0.6, −0.333, and 0.8 ∠60°. Resulting SWR = 4, 2, 9.

Voltage Standing Wave Ratio



Incident wave (blue) is fully reflected (red wave) out of phase at short-circuited end of transmission line, creating a net voltage (black) standing wave where the SWR = ∞.

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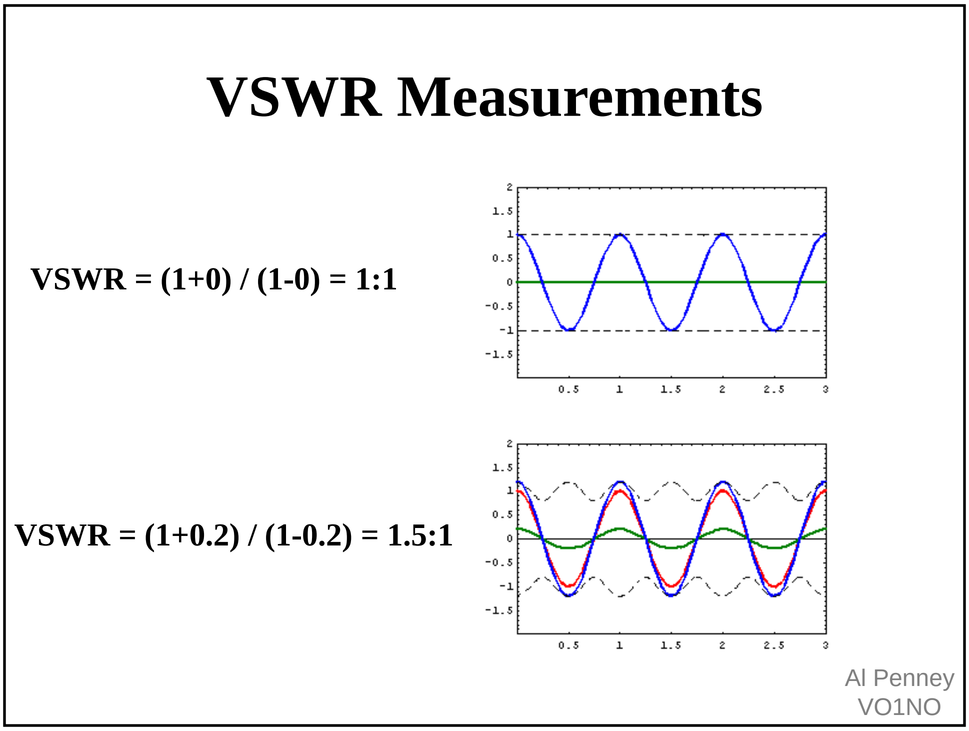
Impedance matching

SWR is used as a measure of impedance matching of a load to the characteristic impedance of a transmission line carrying radio frequency (RF) signals. This especially applies to transmission lines connecting radio transmitters and receivers with their antennas, as well as similar uses of RF cables such as cable television connections to TV receivers and distribution amplifiers. Impedance matching is achieved when the source impedance is the complex conjugate of the load impedance. The easiest way of achieving this, and the way that minimizes losses along the transmission line, is for the imaginary part of the complex impedance of both the source and load to be zero, that is, pure resistances, equal to the characteristic impedance of the transmission line. When there is a mismatch between the load impedance and the transmission line, part of the forward wave sent toward the load is reflected back along the transmission line towards the source. The source then sees a different impedance than it expects which can lead to lesser (or in some cases, more) power being supplied by it, the result being very sensitive to the electrical length of the transmission line.

Such a mismatch is usually undesired and results in standing waves along the transmission line which magnifies transmission line losses (significant at higher frequencies and for longer cables). The SWR is a measure of the depth of those standing waves and is, therefore, a measure of the matching of the load to the transmission line. A matched load would result in an SWR of 1:1 implying no reflected wave. An infinite SWR represents complete reflection by a load unable to absorb electrical power, with all the incident power reflected back towards the source.

It should be understood that the match of a load to the transmission line is different from the match of a *source* to the transmission line or the match of a source to the load *seen through* the transmission line. For instance, if there is a perfect match between the load impedance Z_{load} and the source impedance $Z_{source}=Z^*_{load}$, that perfect match will remain if the source and load are connected through a transmission line with an electrical length of one half wavelength (or a multiple of one half wavelengths) using a transmission line of *any* characteristic impedance Z_0. However the SWR will generally not be 1:1, depending only on Z_{load} and Z_0. With a different length of transmission line, the source will see a different impedance than Z_{load} which may or may not be a good match to the source. Sometimes this is deliberate, as when a quarter-wave matching section is used to improve the match between an otherwise mismatched source and load.

However typical RF sources such as transmitters and signal generators are designed to look into a purely resistive load impedance such as 50Ω or 75Ω, corresponding to common transmission lines' characteristic impedances. In those cases, matching the load to the transmission line, $Z_{load}=Z_0$, *always* ensures that the source will see the same load impedance as if the transmission line weren't there. This is identical to a 1:1 SWR. This condition ($Z_{load}=Z_0$) also means that the load seen by the source is independent of the transmission line's electrical length. Since the electrical length of a physical segment of transmission line depends on the signal frequency, violation of this condition means that the impedance seen by the source through the transmission line becomes a function of frequency (especially if the line is long), even if Z_{load} is frequency-independent. So in practice, a good SWR (near 1:1) implies a transmitter's output seeing the exact impedance it expects for optimum and safe operation.



VSWR Measurements

VSWR = (1+0) / (1-0) = 1:1

VSWR = (1+0.2) / (1-0.2) = 1.5:1

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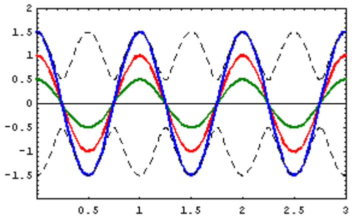
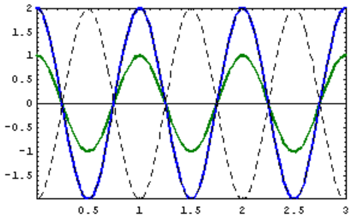
http://www.takuichi.net/hobby/edu/em/standing/onedim/index.html

VSWR Measurements

VSWR = (1+0.5) / (1-0.5) = 3:1



VSWR = (1+1) / (1-1) = ∞



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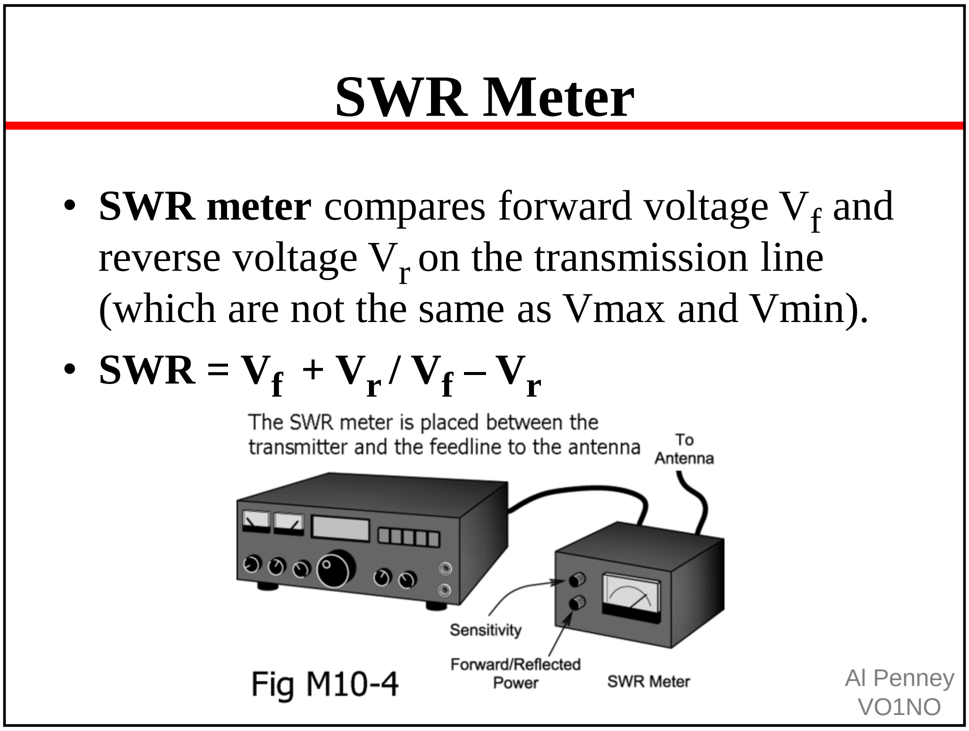
http://www.takuichi.net/hobby/edu/em/standing/onedim/index.html



SWR Meter

- **SWR meter** compares forward voltage V_f and reverse voltage V_r on the transmission line (which are not the same as Vmax and Vmin).
- **SWR =** $V_f + V_r / V_f - V_r$

The SWR meter is placed between the transmitter and the feedline to the antenna

Fig M10-4

A directional SWR meter measures the magnitude of the forward and reflected waves by sensing each one individually, with directional couplers. A calculation then produces the SWR.

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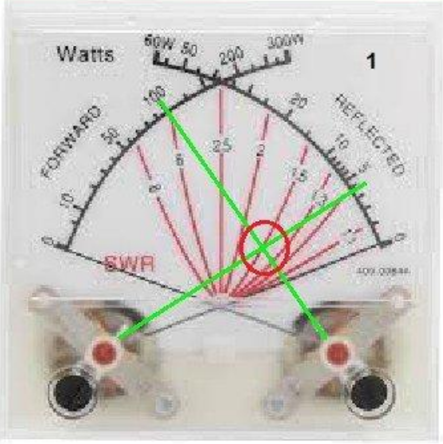
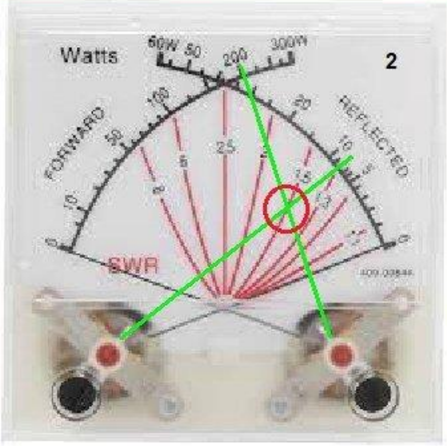
Power SWR meter, using crossed needles.

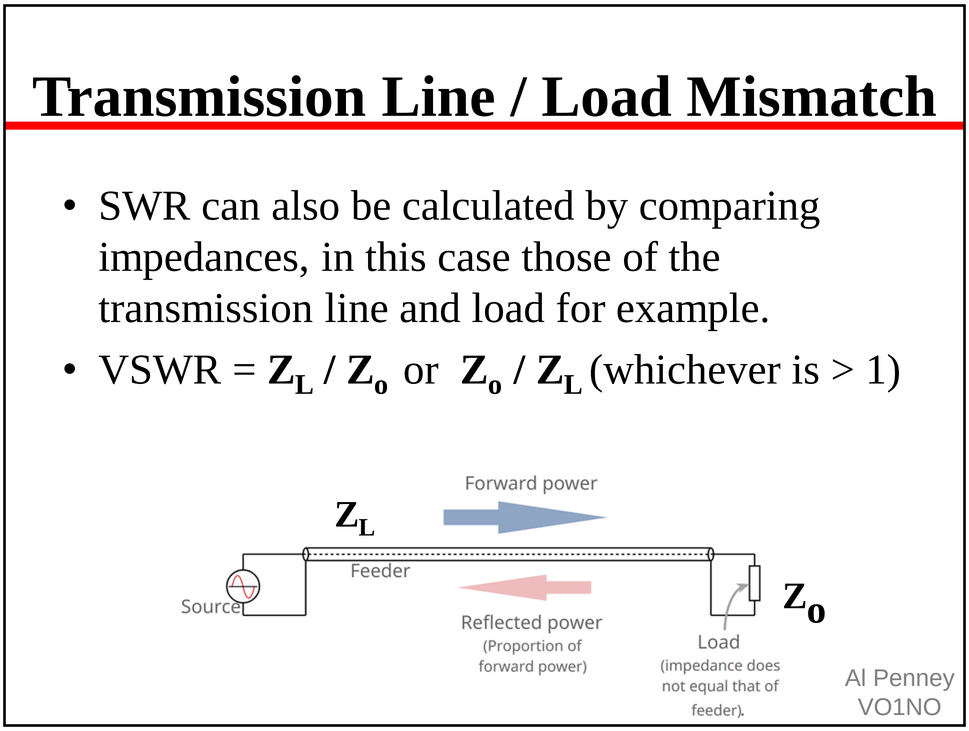


100W OUT, 4W REFLECTED, 1.5:1 SWR



200W OUT, 8W REFLECTED, 1.5:1 SWR

This is how you read a cross needle swr/power meter. Notice meter 1 shows 100 watts out, about 4 watts reflected, and where the 2 needles crosses at the red line showing a 1.5:1 swr. Then skip to meter number 2 where it shows 200 watts out, 8 watts reflected power, and the 2 needles still cross each other at the red, 1.5:1 swr line showing that as forward power increases, reflected power also increses, but the swr stays the same. SWR is not read from the end of the reflected power needle and reflected power and swr are 2 totally different readings but are related. The 1.5:1 is merely a ratio of forward power verses reflected power.



Transmission Line / Load Mismatch

- SWR can also be calculated by comparing impedances, in this case those of the transmission line and load for example.
- VSWR = $\mathbf{Z_L / Z_o}$ or $\mathbf{Z_o / Z_L}$ (whichever is > 1)

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Can also be calculated by comparing impedances of the load Z_O and the line Z_L

SWR = Z_O / Z_L or Z_L / Z_O (whichever gives an answer greater than 1).

Line / Load Mismatch Example

- Driven Element on a 2M Yagi has impedance of 200 Ohms. What is SWR if fed with 50 Ohm coax cable?

Line / Load Mismatch Example

- Driven Element on a 2M Yagi has impedance of 200 Ohms. What is SWR if fed with 50 Ohm coax cable?

- VSWR = $\mathbf{Z_L / Z_o}$ or $\mathbf{Z_o / Z_L}$ (whichever is > 1)
- VSWR = $\mathbf{Z_L / Z_o = 200/50 = 4:1}$

- Question – How could we feed this antenna with 50 Ohm coax cable and have an acceptable SWR?

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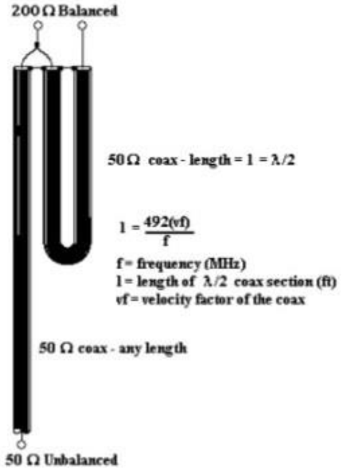
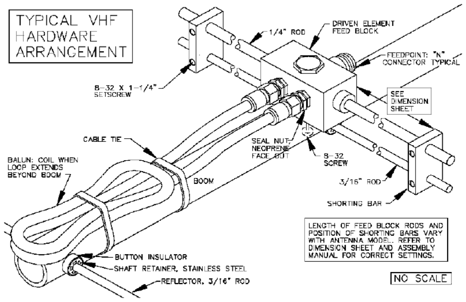
With a 4:1 Coax Balun Of Course!





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Impact of SWR

- High SWR may cause the transmitter to **load incorrectly.**
- It may cause **high voltages** to exist in the transmitter, damaging components.
- It may also cause the transmitter to **draw too much current** and overheat.
- Modern solid state radios have SWR sensing circuits that **fold power back** when high SWR exists.

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Practical implications of SWR

The most common case for measuring and examining SWR is when installing and tuning transmitting antennas. When a transmitter is connected to an antenna by a feed line, the driving point impedance of the antenna must match the characteristic impedance of the feed line in order for the transmitter to see the impedance it was designed for (the impedance of the feed line, usually 50 or 75 ohms).

The impedance of a particular antenna design can vary due to a number of factors that cannot always be clearly identified. This includes the transmitter frequency (as compared to the antenna's design or resonant frequency), the antenna's height above and quality of the ground, proximity to large metal structures, and variations in the exact size of the conductors used to construct the antenna.

When an antenna and feed line do not have matching impedances, the transmitter sees an unexpected impedance, where it might not be able to produce its full power, and can even damage the transmitter in some cases. The reflected power in the transmission line increases the average current and therefore losses in the transmission line compared to power actually delivered to the load. It is the interaction of these reflected waves with forward waves which causes standing wave patterns, with the negative repercussions we have noted.

Tom Rauch on SWR

Reflected power in our systems sets up a standing wave. The standing wave stands and causes a change in impedance along the length of the mismatched transmission line system. It does not run around causing all sorts of mischief.

Reflected power itself, the way we measure it, isn't even reflected power. The readings we take are just another way of expressing impedance mismatch or deviation from a calibrated target impedance value...like SWR or transmission loss or return loss.

The danger in the transmitter is the PA stage sees an impedance it was not designed for, and that deviation can change the load line seen by the output device.

1.) If the impedance error makes the impedance at the output device go lower than normal, the device draws more current and gets hotter.

2.) If the impedance at the output device increases, the voltage can increase and we risk arcing or voltage breakdown, but the device runs cooler and becomes non-linear.

I can have a 10:1 SWR on a transmission line and a perfectly happy power amplifier, or I can have a perfectly matched line with no "reflected power" or standing wave issues and it can be the wrong impedance for a transmitter.

We absolutely want transmitters and amplifiers to "see" the impedance they were designed to run into, so we generally want a SWR meter (normalized for the transmitter's design impedance) at the output to show no error or "mismatch", but let's not kid ourselves into thinking it is power bouncing around and landing in the PA. The real problem is the wrong impedance, like putting 16 ohm speakers on a 4 ohm audio amp and cranking up the volume.

Impact of SWR

- High SWR also causes **additional losses in the transmission line.**
- These losses are caused by **dielectric and conductor heat losses.**
- This means **less power gets to antenna.**
- In some cases, high SWR can cause the **coax to get hot**, especially with **lossy coax**.

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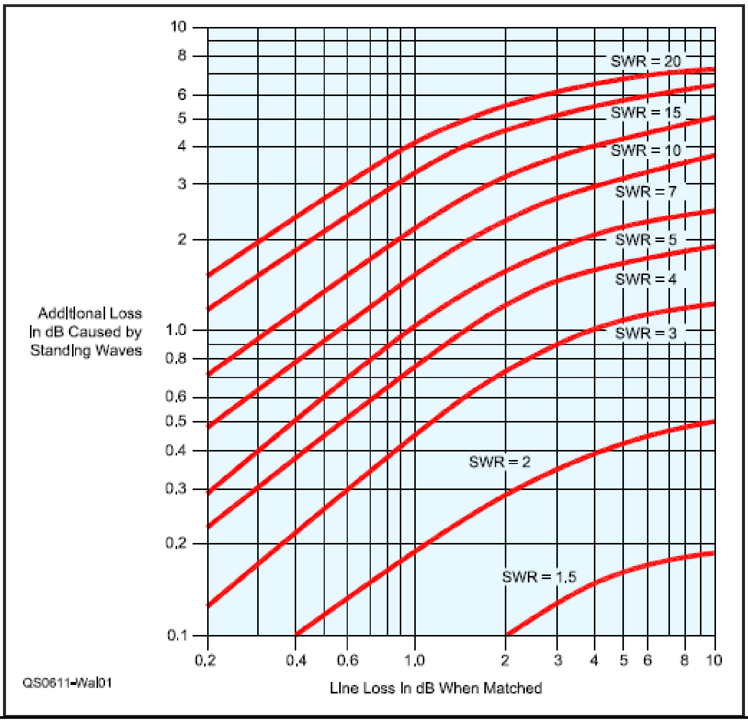
Matching the impedance of the antenna to the impedance of the feed line can sometimes be accomplished through adjusting the antenna itself, but otherwise is possible using an antenna tuner, an impedance matching device. Installing the tuner between the feed line and the antenna allows for the feed line to see a load close to its characteristic impedance, while sending most of the transmitter's power (a small amount may be dissipated within the tuner) to be radiated by the antenna despite its otherwise unacceptable feed point impedance. Installing a tuner in between the transmitter and the feed line can also transform the impedance seen at the transmitter end of the feed line to one preferred by the transmitter. However, in the latter case, the feed line still has a high SWR present, with the resulting increased feed line losses unmitigated.

The magnitude of those losses are dependent on the type of transmission line, and its length. They always increase with frequency. For example, a certain antenna used well away from its resonant frequency may have an SWR of 6:1. For a frequency of 3.5 MHz, with that antenna fed through 75 meters of RG-8A coax, the loss due to standing waves would be 2.2 dB. However the same 6:1 mismatch through 75 meters of RG-8A coax would incur 10.8 dB of loss at 146 MHz. Thus, a better match of the antenna to the feed line, that is, a lower SWR, becomes increasingly important with increasing frequency, even if the transmitter is able to accommodate the impedance seen (or an antenna tuner is used between the transmitter and feed line).

Certain types of transmissions can suffer other negative effects from reflected waves on a transmission line. Analog TV can experience "ghosts" from delayed signals bouncing back and forth on a long line. FM stereo can also be affected and digital signals can experience delayed pulses leading to bit errors. Whenever the delay times for a signal going back down and then again up the line are comparable to the modulation time constants, effects occur. For this reason, these types of transmissions require a low SWR on the feedline, even if SWR induced loss might be acceptable and matching is done at the transmitter.



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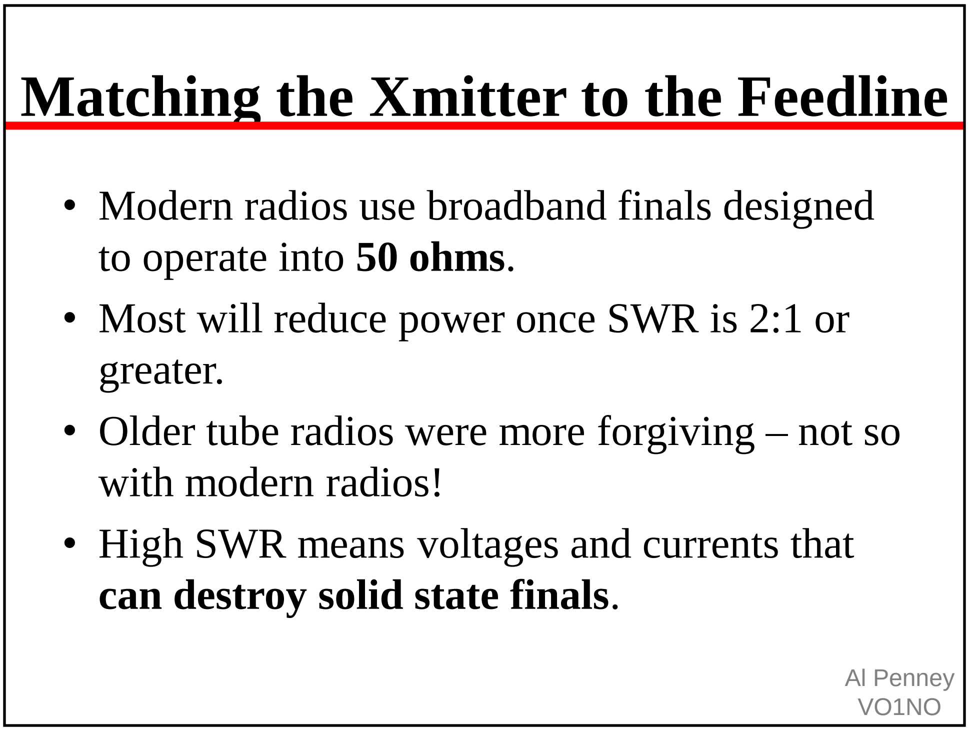
ADDITIONAL POWER LOSS DUE TO SWR

The power lost in a given line is least when the line is terminated in a resistance equal to its characteristic impedance, and as stated previously, that is called the *matched-line loss*. There is however an *additional loss* that increases with an increase in the SWR. This is because the effective values of both current and voltage become greater on lines with standing waves. The increase in effective current raises the ohmic losses (I2R) in the conductors, and the increase in effective voltage increases the losses in the dielectric (E2/R).

The increased loss caused by an SWR greater than 1:1 may or may not be serious. If the SWR at the load is not greater than 2:1, the additional loss caused by the standing waves, as compared with the loss when the line is perfectly matched, does not amount to more than about 1/2 dB, even on very long lines. One-half dB is an undetectable change in signal strength. Therefore, it can be said that, from a practical standpoint in the HF bands, an SWR of 2:1 or less is every bit as good as a perfect match, so far as additional losses due to SWR are concerned.

However, above 30 MHz, in the VHF and especially the UHF range, where low receiver noise figures are essential for effective weak-signal work, matched-line losses for commonly available types of coax can

be relatively high. This means that even a slight mismatch may become a concern regarding overall transmission line losses. At UHF one-half dB of additional loss may be considered intolerable!



Matching the Xmitter to the Feedline

- Modern radios use broadband finals designed to operate into **50 ohms**.
- Most will reduce power once SWR is 2:1 or greater.
- Older tube radios were more forgiving – not so with modern radios!
- High SWR means voltages and currents that **can destroy solid state finals**.

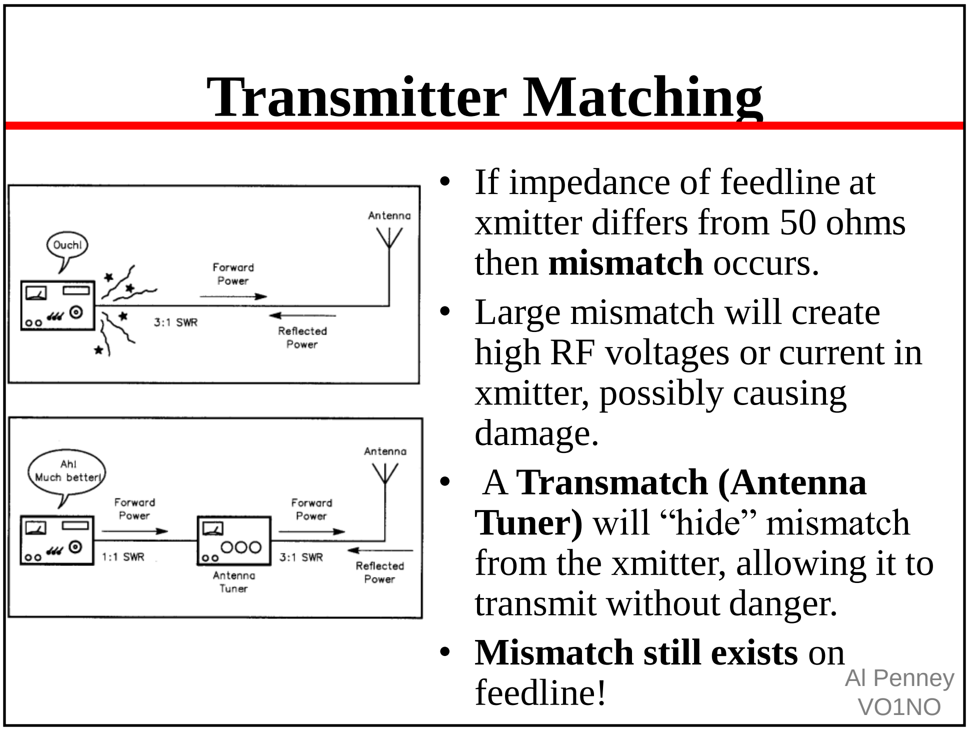
Al Penney
VO1NO

Modern amateur transceivers use broadband, untuned solid-state final amplifiers, designed to operate into 50 οημσ. Such a transmitter is able to deliver its rated output power—at its rated level of distortion—only when it is operated into the load for which it was designed. An SSB transmitter that is “splattering” is often being driven hard into the wrong load impedance.

Further, modern radios often employ protection circuitry to reduce output power automatically if the SWR rises to more than about 2:1. Protective circuits are needed because solid-state devices can

almost instantly destroy themselves trying to deliver power into the wrong load impedance. Modern solid-state transceivers often include built-in antenna tuners (often at extra cost) to match impedances

when the SWR isn’t 1:1. Older vacuum-tube amplifiers were a lot more forgiving than solid-state devices—they could survive momentary overloads without being instantly destroyed. The pi-networks used to tune and load old-fashioned vacuum-tube amplifiers were able to match a fairly wide range of impedances.



Transmitter Matching

- If impedance of feedline at xmitter differs from 50 ohms then **mismatch** occurs.
- Large mismatch will create high RF voltages or current in xmitter, possibly causing damage.
- A **Transmatch (Antenna Tuner)** will “hide” mismatch from the xmitter, allowing it to transmit without danger.
- **Mismatch still exists** on feedline!

Al Penney
VO1NO

MATCHING THE LINE TO THE TRANSMITTER

The impedance at the input of a transmission line is uniquely determined by a number of factors: **the frequency, the characteristic impedance Z0 of the line, the physical length,**

velocity factor and the matched-line loss of the line, plus the impedance of the load (the antenna) at the output end of the line. If the impedance at the input of the transmission line connected to the transmitter differs appreciably from the load resistance into which the transmitter output circuit is designed to operate, an impedance-matching network must be inserted between the transmitter and the line input terminals.

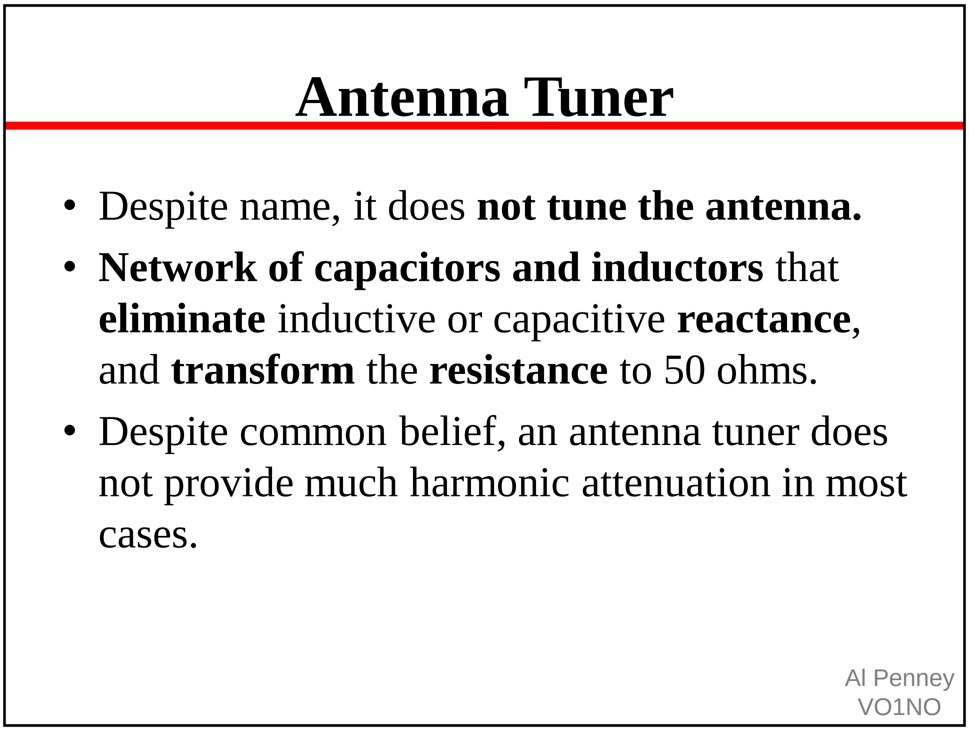
In older ARRL publications, such an impedance-matching network was often called a *Transmatch*. This is a coined word, referring to a “Transmitter Matching” network. Nowadays, radio amateurs commonly

call such a device an *antenna tuner*.

The function of an antenna tuner is to transform the impedance at the input end of the transmission line—whatever it may be—to the 50 οημσ needed to keep the transmitter loaded properly. An antenna

tuner does *not* alter the SWR on the transmission line going to the antenna. It only ensures that the transmitter sees the 50-οημ load for which it was designed.

http://www.arrl.org/files/file/Technology/tis/info/pdf/9401070.pdf



Antenna Tuner

- Despite name, it does **not tune the antenna.**
- **Network of capacitors and inductors** that **eliminate** inductive or capacitive **reactance**, and **transform** the **resistance** to 50 ohms.
- Despite common belief, an antenna tuner does not provide much harmonic attenuation in most cases.

Al Penney
VO1NO

What an "antenna tuner" actually tunes

Despite its name, an antenna "tuner" does not actually tune the antenna. It matches the complex impedance of the transmitter to that of the input end of the feedline. The input impedance of the transmission line will be different than the characteristic impedance of the feedline if the impedance of the antenna on the other end of the line does not match the line's characteristic impedance. The consequence of the mismatch is standing waves on the feedline that alter the line's impedance at every point along the line.

If both the tuner and the feedline were lossless, tuning at the transmitter end would indeed produce a perfect match at every point in the transmitter-feedline-antenna system. However, in practical systems lossy feedlines limit the ability of the antenna tuner to change the antenna's resonant frequency. If the loss of power is low in the line carrying the transmitter's signal to the antenna, a tuner at the transmitter end can produce a worthwhile degree of matching and tuning for the antenna and feedline network as a whole. But with lossy, low-impedance feedlines like the commonly used 50 Ohm coaxial cable, maximum power transfer only occurs if matching is done at the antenna in conjunction with a matched transmitter and feedline, producing a match at both ends of the line.

In any case, regardless of its placement, an ATU does not alter the gain, efficiency, or directivity of the antenna, nor does it change the internal complex impedance of the antenna itself.

Efficiency and SWR

If there is still a high standing wave ratio (SWR) in the feedline beyond the ATU, any loss in that part of the feedline is typically increased by the transmitted waves reflecting back and forth between the tuner and the antenna, causing resistive losses in the wires and possibly the insulation of the transmission line. Even with a matching unit at both ends of the feedline – the near ATU matching the transmitter to the feedline and the remote ATU matching the feedline to the antenna – losses in the circuitry of the two ATUs will slightly reduce power delivered to the antenna.

Hence, operating an antenna far from its design frequency and compensating with an ATU between the transmitter and the feedline is not as efficient as using a resonant antenna with a matched-impedance feedline, nor as efficient as a matched feedline from the transmitter to a remote antenna tuner attached directly to the antenna.

Harmonic Attenuation in an Antenna Tuner

One potentially desirable characteristic of an antenna tuner is the degree of extra harmonic attenuation it can provide. While this is desirable in

theory, it is not always achieved in practice. For example, if an antenna tuner is used with a single, fixed-length antenna on multiple bands, the impedances presented to the tuner at the fundamental

frequency and at the harmonics will often be radically different, thus attenuating harmonics. There are some situations in Amateur Radio where the impedance at the second harmonic is essentially the same as that for the fundamental however, providing little attenuation to harmonics. This often involves "trapped" antenna systems or wideband log-periodic designs. For example, a system used by many amateurs is a "tribander" Yagi that works on 20, 15 and 10 meters. The second harmonic of a 20-meter transmitter feeding such a tribander can be objectionably strong for nearby amateurs operating on 10 meters. This is despite the approximately 60 dB of attenuation of the second harmonic provided by the low-pass filters built into modern solid state transceivers. A linear amplifier can exacerbate the problem, since its second harmonic may be suppressed only about 46 dB by the typical pi-network output circuit used in most amplifiers. Even in a trapped antenna system, most amateur antenna tuners will not attenuate the 10-meter harmonic much at all, especially if the tuner uses a high-pass T-network. This is the most common network used commercially because of the wide range of impedances it will match. Some T-network designs have attempted to improve the harmonic attenuation using parallel inductors and capacitors instead of a single inductor for the center part of the T. Unfortunately, this often leads to more loss and more critical tuning at the fundamental, while providing little, if any, additional harmonic suppression in actual installations.

Harmonics and Pi-Network Tuners

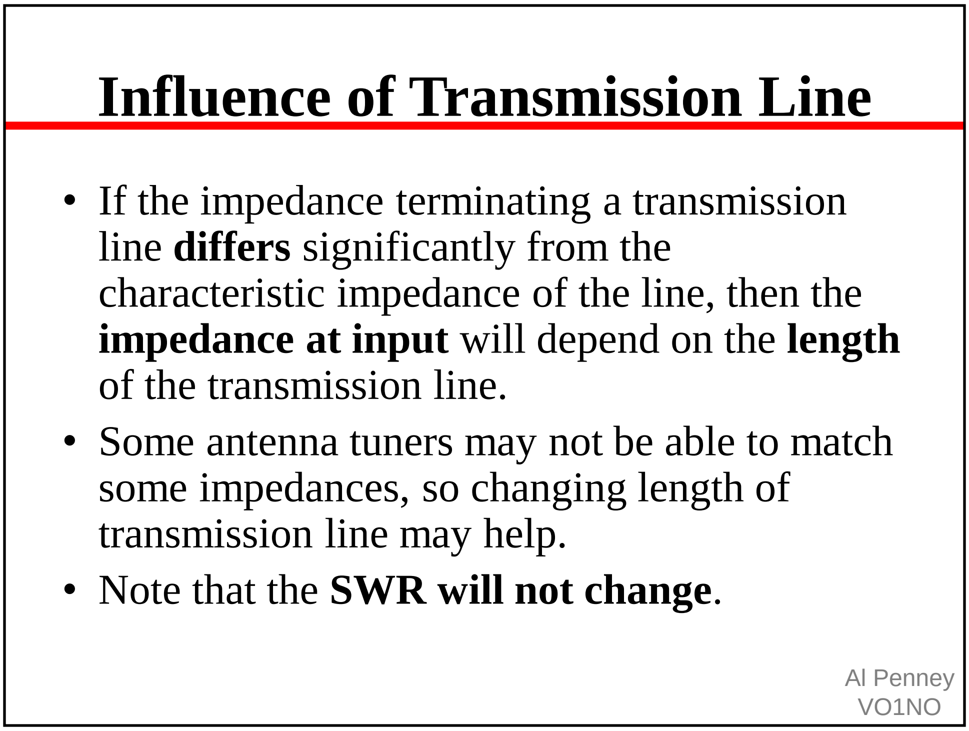
In a trapped antenna system, if a different network is used for an antenna tuner (such as a lowpass Pi network), there will be additional attenuation of harmonics, perhaps as much as 30 dB for a

loaded Q of 3. The exact degree of harmonic attenuation, however, is often limited due to the stray inductance and capacity present in most tuners at harmonic frequencies. Further, the matching range

for a Pi-network tuner is fairly limited because of the range of input and output capacitance needed for widely varying loads.

Harmonics and Stubs

Far more reliable suppression of harmonics can be achieved using shorted quarter-wave transmission- line stubs at the transmitter output. A typical 20-meter $\lambda/4$ wavelength shorted stub (which looks like an open circuit at 20 meters, but a short circuit at 10 meters) will provide about 25 dB of attenuation to the second harmonic. It will handle full legal amateur power too. In short, an antenna tuner that is capable of matching a wide range of impedances should not be relied on to give additional harmonic suppression.



Influence of Transmission Line

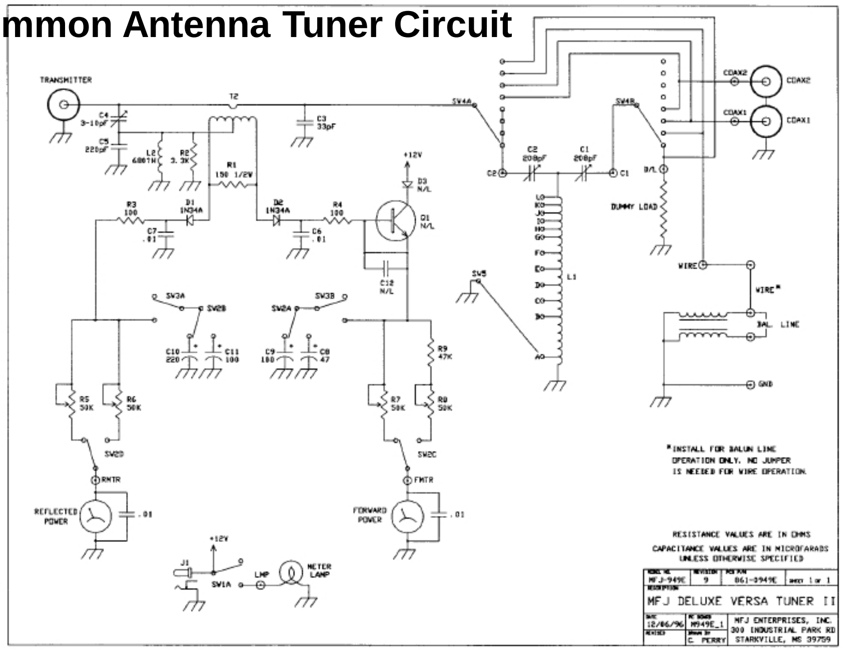
- If the impedance terminating a transmission line **differs** significantly from the characteristic impedance of the line, then the **impedance at input** will depend on the **length** of the transmission line.
- Some antenna tuners may not be able to match some impedances, so changing length of transmission line may help.
- Note that the **SWR will not change**.

Al Penney
VO1NO

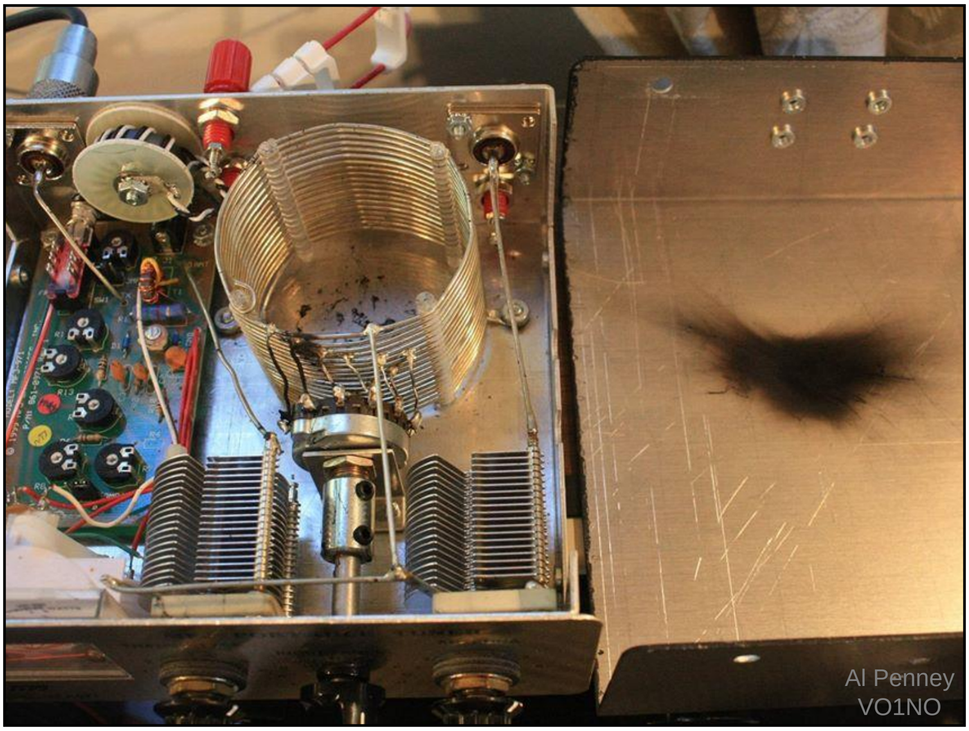
If the line impedance and load impedance don't match, the input will see an impedance value that is a function of the line length. The mathematics to calculate the value of the impedance in this situation is more than a little demanding and then some!

Designers can take advantage of this characteristic by using special lengths of transmission lines of certain impedances to match some types of antennas to 50 Ohm impedance coaxial cable. This topic is beyond what you need to know for the Basic course however!

Common Antenna Tuner Circuit



Al Penney
VO1NO

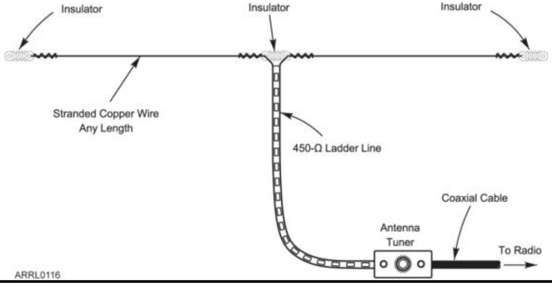


Al Penney
VO1NO

The result of trying to tune an antenna tuner with too much power initially!

Open Wire Line and SWR

- **Open wire** transmission line has **less loss** than coax and can **tolerate high SWRs** without much additional loss.
- If used with an antenna tuner, it provides a simple way to build a multiband antenna.



Questions?

Al Penney
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Review Question 1

The characteristic impedance of a transmission line is determined by the:

- frequency at which the line is operated
- load placed on the line
- physical dimensions and relative positions of the conductors
- length of the line

Review Question 1

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- frequency at which the line is operated
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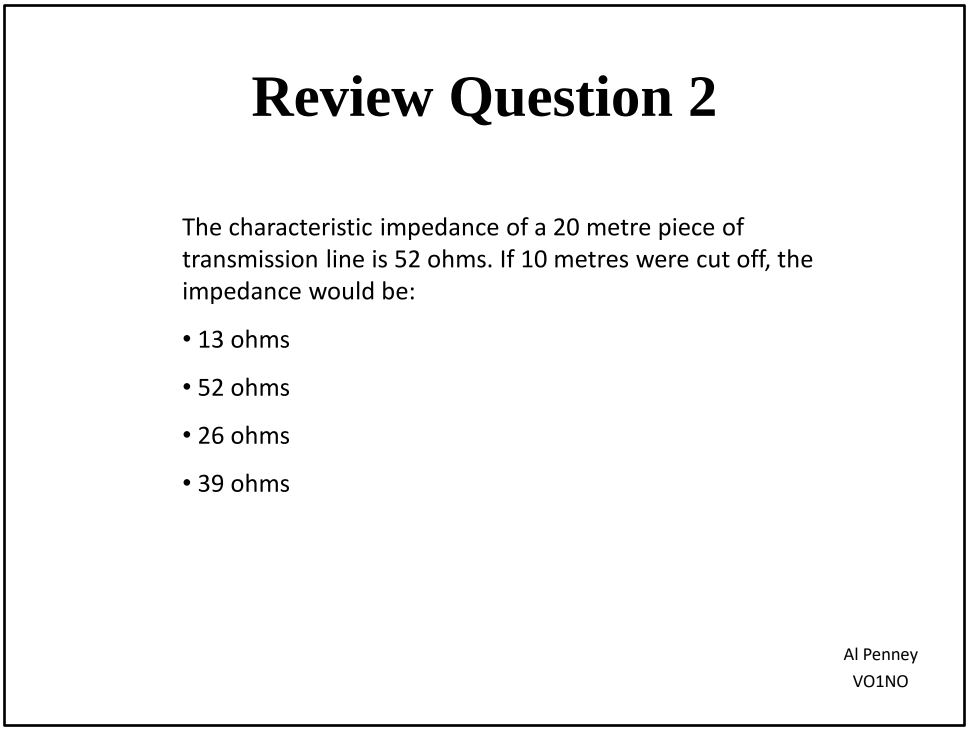
< physical dimensions and relative positions of the conductors >

Al Penney
VO1NO



Review Question 2

The characteristic impedance of a 20 metre piece of transmission line is 52 ohms. If 10 metres were cut off, the impedance would be:

- 13 ohms
- 52 ohms
- 26 ohms
- 39 ohms

Al Penney
VO1NO

Review Question 2

The characteristic impedance of a 20 metre piece of transmission line is 52 ohms. If 10 metres were cut off, the impedance would be:

- 13 ohms
- 52 ohms
- 26 ohms
- 39 ohms

< 52 ohms >

Al Penney
VO1NO

Review Question 3

What commonly available antenna transmission line can be buried directly in the ground for some distance without adverse effects?

- 75 ohm twin-lead
- Coaxial cable
- 300 ohm twin-lead
- 600 ohm open-wire

Al Penney
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Review Question 3

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- 75 ohm twin-lead
- Coaxial cable
- 300 ohm twin-lead
- 600 ohm open-wire

< Coaxial cable >

Al Penney
VO1NO

Review Question 4

The characteristic impedance of a transmission line is:

- equal to the pure resistance which, if connected to the end of the line, will absorb all the power arriving along it
- the impedance of a section of the line one wavelength long
- the dynamic impedance of the line at the operating frequency
- the ratio of the power supplied to the line to the power delivered to the load

Al Penney
VO1NO

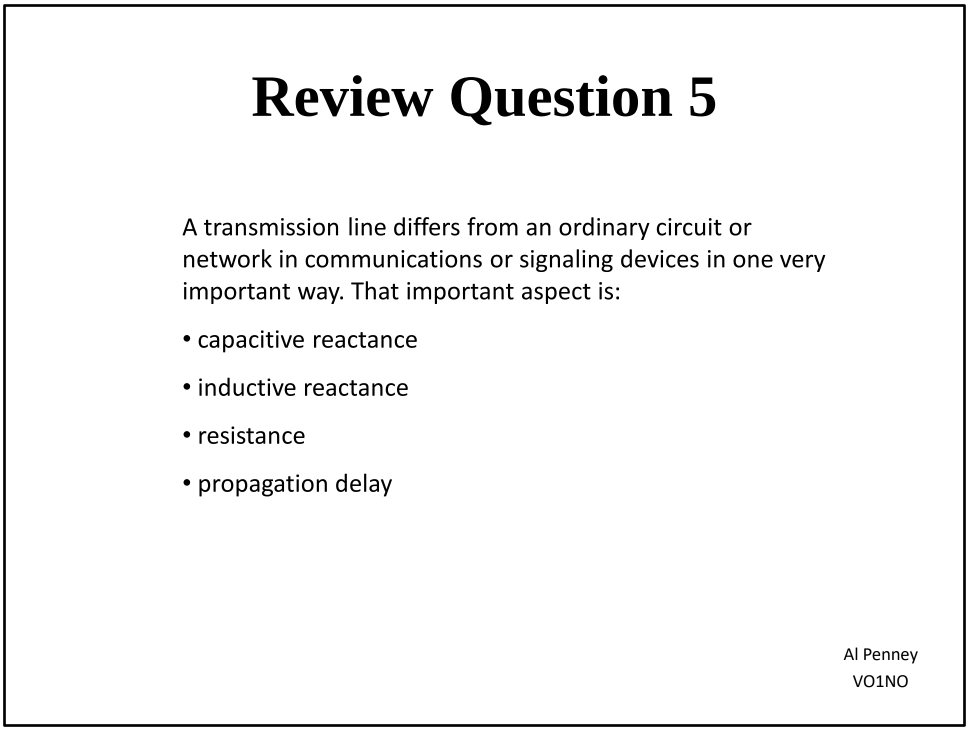
Review Question 4

The characteristic impedance of a transmission line is:

- equal to the pure resistance which, if connected to the end of the line, will absorb all the power arriving along it
- the impedance of a section of the line one wavelength long
- the dynamic impedance of the line at the operating frequency
- the ratio of the power supplied to the line to the power delivered to the load

< equal to the pure resistance which, if connected to the end of the line, will absorb all the power arriving along it >

Al Penney
VO1NO



Review Question 5

A transmission line differs from an ordinary circuit or network in communications or signaling devices in one very important way. That important aspect is:

- capacitive reactance
- inductive reactance
- resistance
- propagation delay

Al Penney
VO1NO

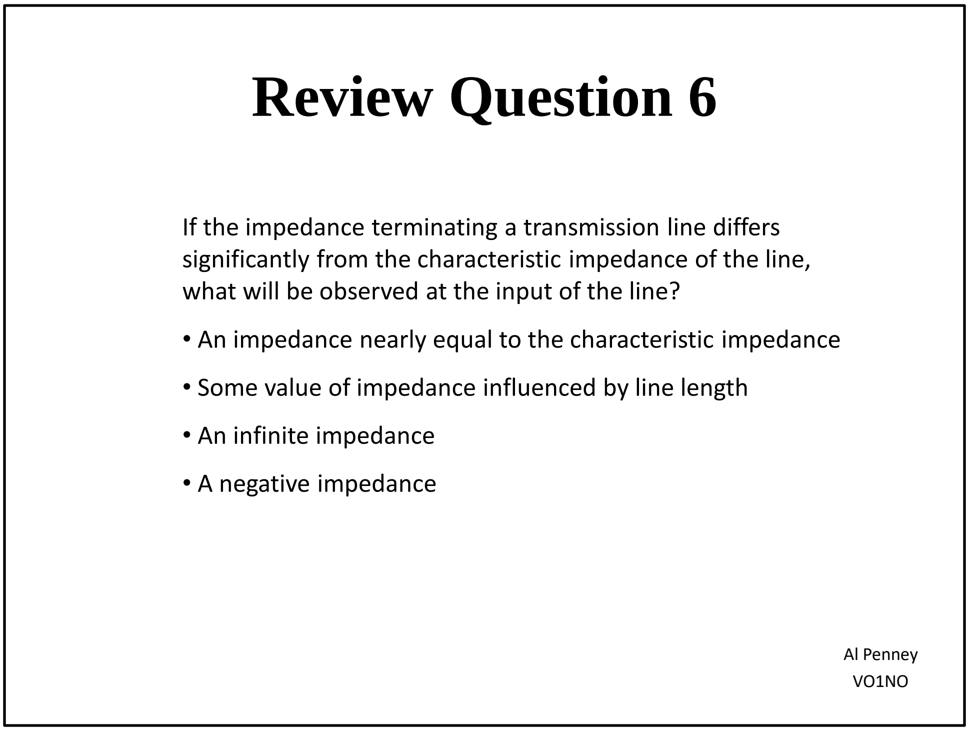
Review Question 5

A transmission line differs from an ordinary circuit or network in communications or signaling devices in one very important way. That important aspect is:

- capacitive reactance
- inductive reactance
- resistance
- propagation delay

< propagation delay >

Al Penney
VO1NO



Review Question 6

If the impedance terminating a transmission line differs significantly from the characteristic impedance of the line, what will be observed at the input of the line?

- An impedance nearly equal to the characteristic impedance
- Some value of impedance influenced by line length
- An infinite impedance
- A negative impedance

Al Penney
VO1NO

Review Question 6

If the impedance terminating a transmission line differs significantly from the characteristic impedance of the line, what will be observed at the input of the line?

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< Some value of impedance influenced by line length >

If the line impedance and load impedance don't match, the input will see an impedance value that is a function of the line length. The mathematics to calculate the value of the impedance in this situation is more than a little demanding and then some!

Al Penney
VO1NO

Review Question 7

What factors determine the characteristic impedance of a parallel-conductor antenna transmission line?

- The radius of the conductors and the frequency of the signal
- The frequency of the signal and the length of the line
- The distance between the centres of the conductors and the radius of the conductors
- The distance between the centres of the conductors and the length of the line

Al Penney
VO1NO

Review Question 7

What factors determine the characteristic impedance of a parallel-conductor antenna transmission line?

- The radius of the conductors and the frequency of the signal
- The frequency of the signal and the length of the line
- The distance between the centres of the conductors and the radius of the conductors
- The distance between the centres of the conductors and the length of the line

< The distance between the centres of the conductors and the radius of the conductors >

Al Penney
VO1NO

Review Question 8

What factors determine the characteristic impedance of a coaxial antenna transmission line?

- The ratio of the diameter of the inner conductor to the diameter of the shield
- The diameter of the shield and the length of the line
- The diameter of the shield and the frequency of the signal
- The frequency of the signal and the length of the line

Al Penney
VO1NO

Review Question 8

What factors determine the characteristic impedance of a coaxial antenna transmission line?

- The ratio of the diameter of the inner conductor to the diameter of the shield
- The diameter of the shield and the length of the line
- The diameter of the shield and the frequency of the signal
- The frequency of the signal and the length of the line

< The ratio of the diameter of the inner conductor to the diameter of the shield >

Al Penney
VO1NO

Review Question 9

What kind of antenna transmission line is made of two conductors held apart by insulated rods?

- Twin lead in a plastic ribbon
- Twisted pair
- Open wire line
- Coaxial cable

Al Penney
VO1NO

Review Question 9

What kind of antenna transmission line is made of two conductors held apart by insulated rods?

- Twin lead in a plastic ribbon
- Twisted pair
- Open wire line
- Coaxial cable

< Open wire line >

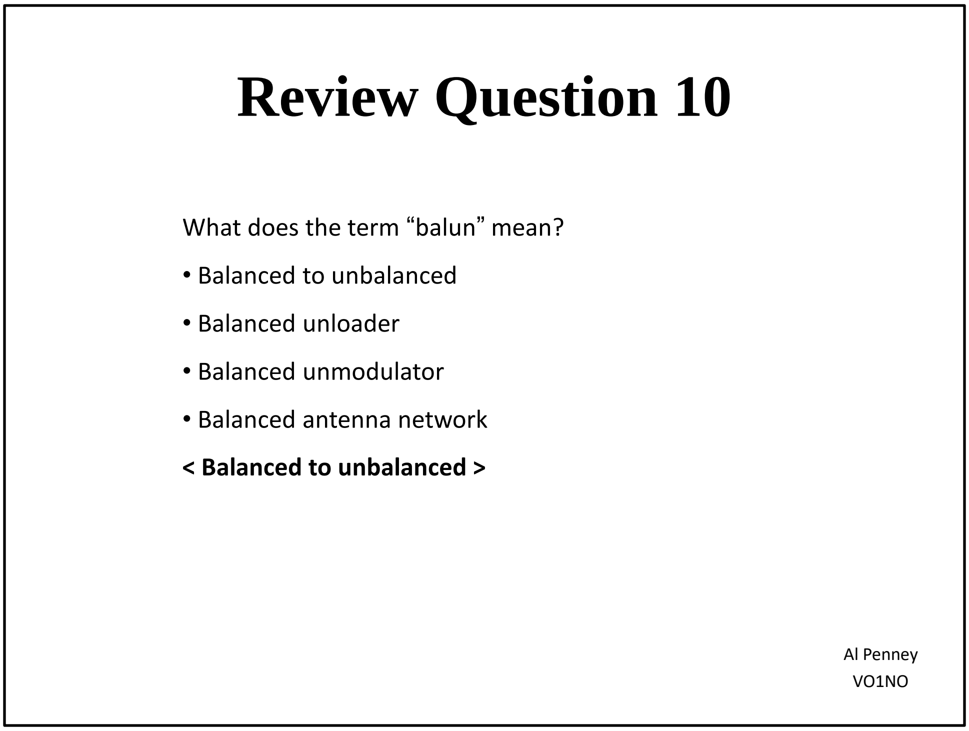
Al Penney
VO1NO

Review Question 10

What does the term “balun” mean?

- Balanced to unbalanced
- Balanced unloader
- Balanced unmodulator
- Balanced antenna network

Al Penney
VO1NO



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What does the term “balun” mean?

- Balanced to unbalanced
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- Balanced unmodulator
- Balanced antenna network

< Balanced to unbalanced >

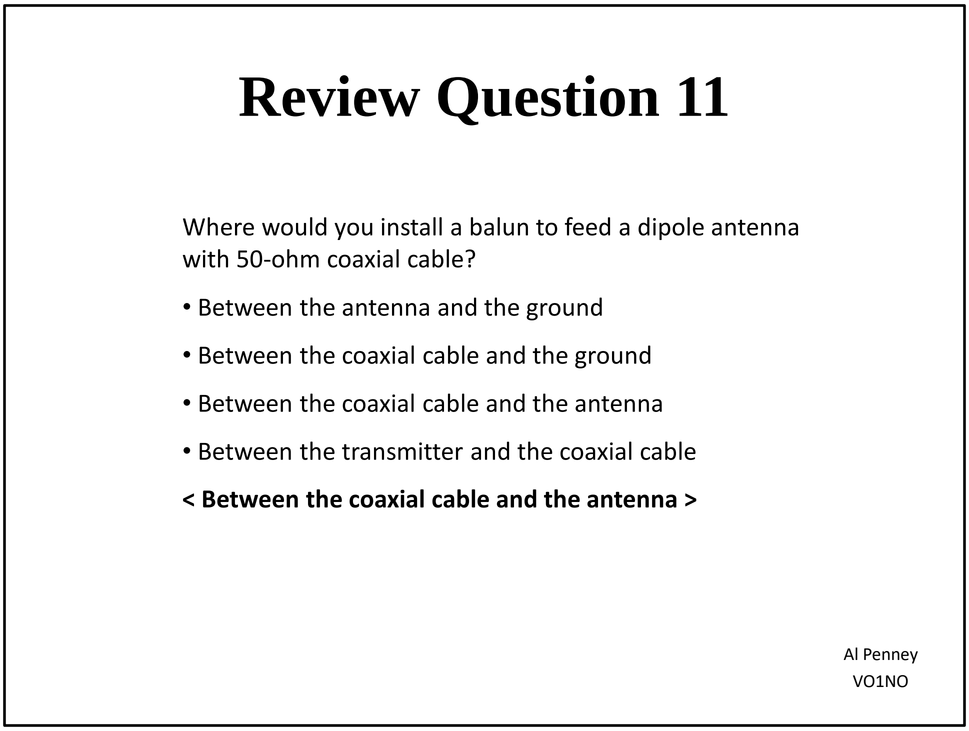
Al Penney
VO1NO

Review Question 11

Where would you install a balun to feed a dipole antenna with 50-ohm coaxial cable?

- Between the antenna and the ground
- Between the coaxial cable and the ground
- Between the coaxial cable and the antenna
- Between the transmitter and the coaxial cable

Al Penney
VO1NO



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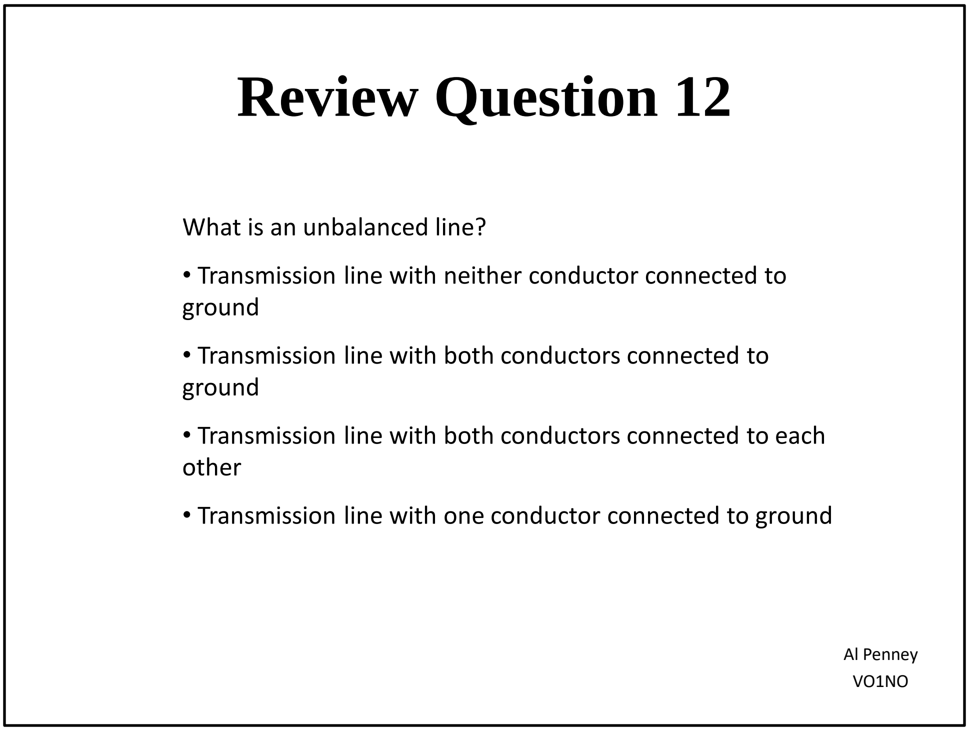
- Between the coaxial cable and the antenna
- Between the transmitter and the coaxial cable

< Between the coaxial cable and the antenna >

Al Penney
VO1NO



Review Question 12

What is an unbalanced line?

- Transmission line with neither conductor connected to ground
- Transmission line with both conductors connected to ground
- Transmission line with both conductors connected to each other
- Transmission line with one conductor connected to ground

Al Penney
VO1NO

Review Question 12

What is an unbalanced line?

- Transmission line with neither conductor connected to ground
- Transmission line with both conductors connected to ground
- Transmission line with both conductors connected to each other
- Transmission line with one conductor connected to ground

< Transmission line with one conductor connected to ground >

Al Penney
VO1NO

Review Question 13

A 75 ohm transmission line could be matched to the 300 ohm feed point of an antenna:

- with an extra 250 ohm resistor
- by using a 4 to 1 trigatron
- by inserting a diode in one leg of the antenna
- by using a 4 to 1 impedance transformer

Al Penney
VO1NO

Review Question 13

A 75 ohm transmission line could be matched to the 300 ohm feed point of an antenna:

- with an extra 250 ohm resistor
- by using a 4 to 1 trigatron
- by inserting a diode in one leg of the antenna
- by using a 4 to 1 impedance transformer

< by using a 4 to 1 impedance transformer >

Al Penney
VO1NO

Review Question 14

What kind of antenna transmission line can be constructed using two conductors which are maintained a uniform distance apart using insulated spreaders?

- Coaxial cable
- 75 ohm twin-lead
- 300 ohm twin-lead
- 600 ohm open wire line

Review Question 14

What kind of antenna transmission line can be constructed using two conductors which are maintained a uniform distance apart using insulated spreaders?

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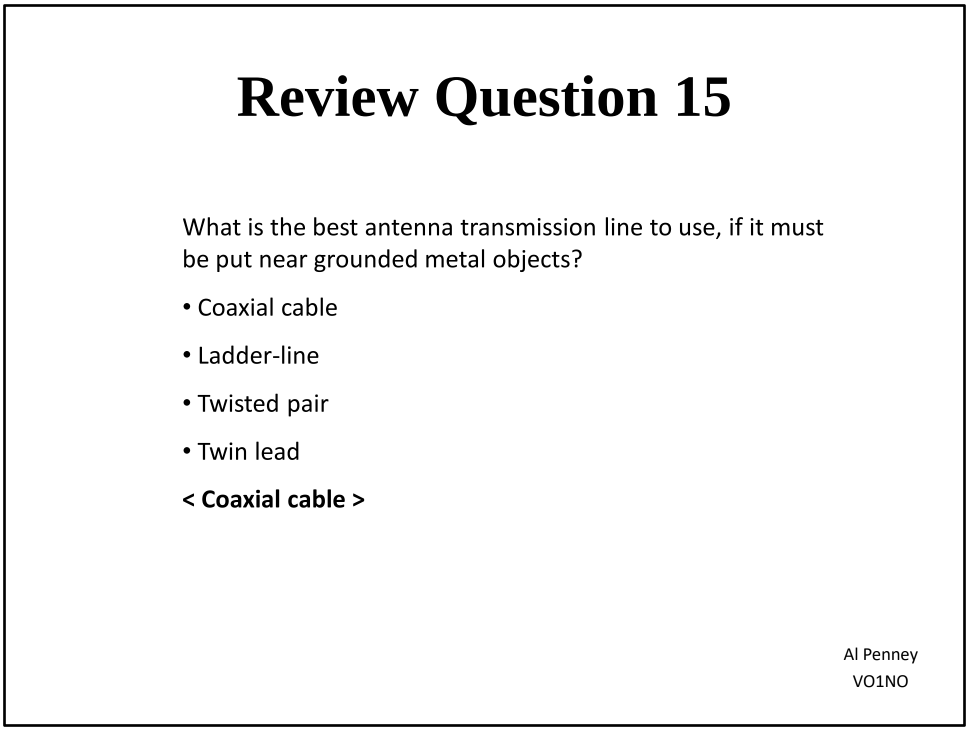
Al Penney
VO1NO

Review Question 15

What is the best antenna transmission line to use, if it must be put near grounded metal objects?

- Coaxial cable
- Ladder-line
- Twisted pair
- Twin lead

Al Penney
VO1NO



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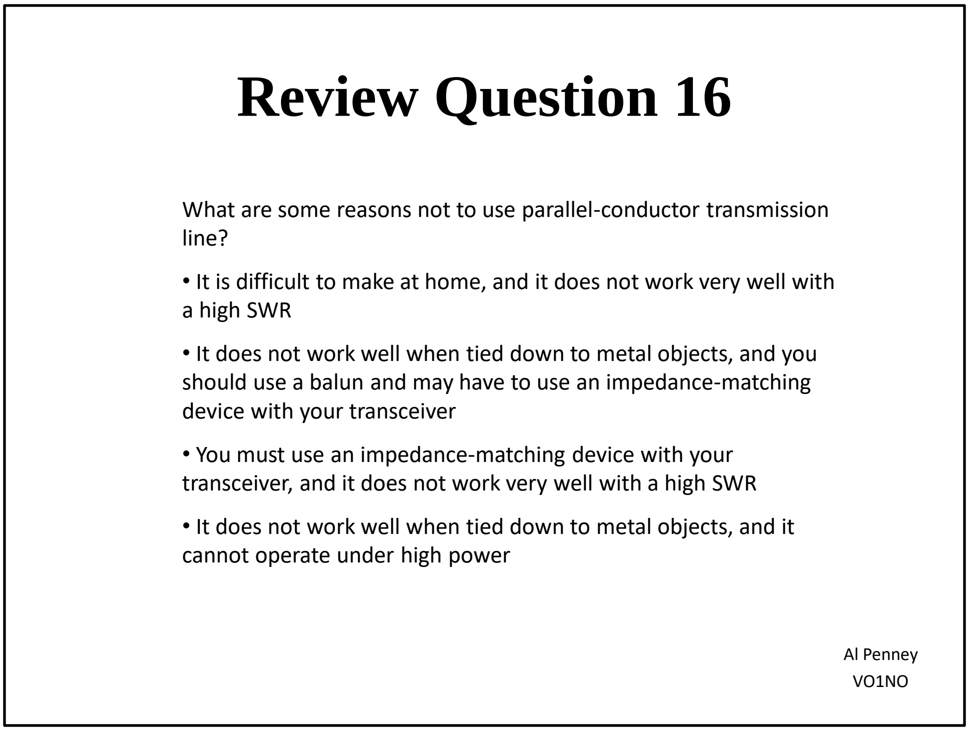
< Coaxial cable >

Al Penney
VO1NO

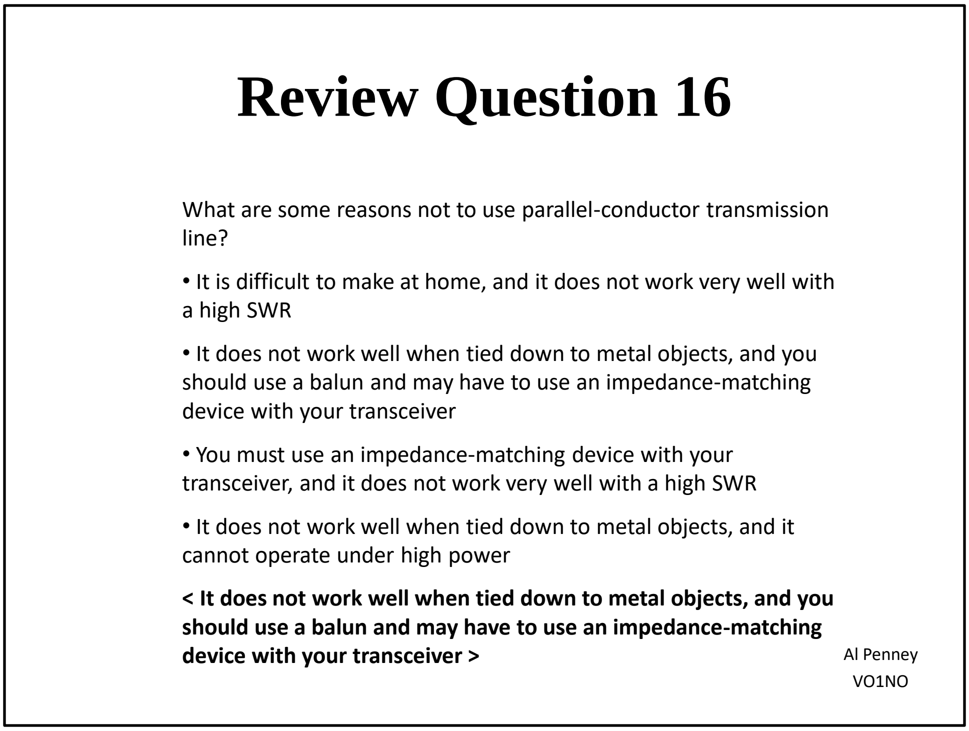


Review Question 16

What are some reasons not to use parallel-conductor transmission line?

- It is difficult to make at home, and it does not work very well with a high SWR
- It does not work well when tied down to metal objects, and you should use a balun and may have to use an impedance-matching device with your transceiver
- You must use an impedance-matching device with your transceiver, and it does not work very well with a high SWR
- It does not work well when tied down to metal objects, and it cannot operate under high power

Al Penney
VO1NO



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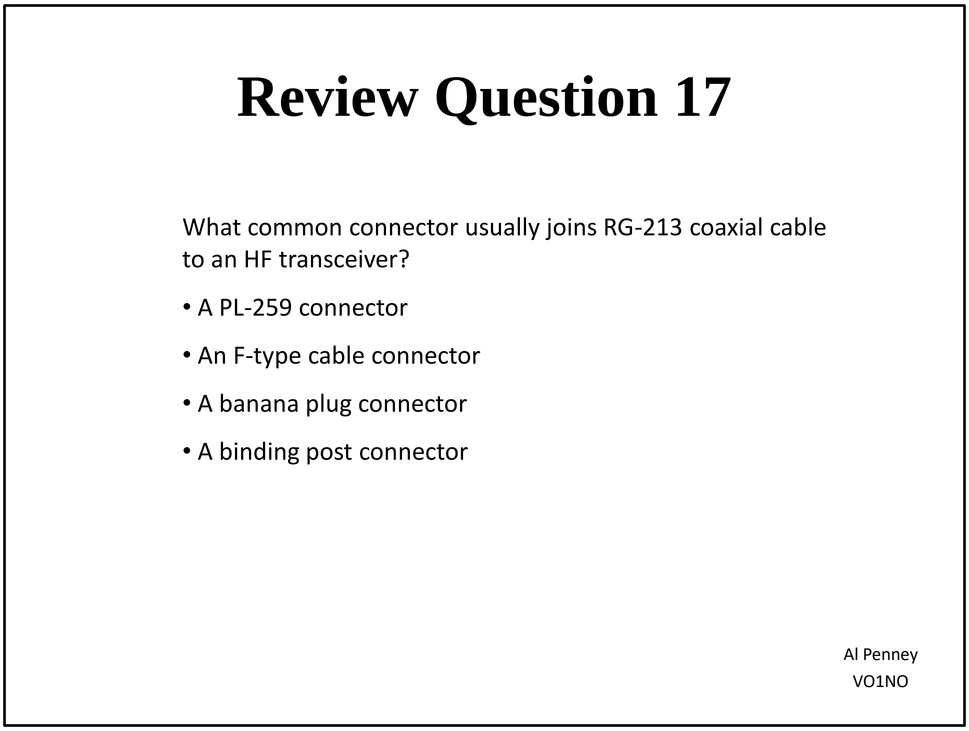
Al Penney
VO1NO



Review Question 17

What common connector usually joins RG-213 coaxial cable to an HF transceiver?

- A PL-259 connector
- An F-type cable connector
- A banana plug connector
- A binding post connector

Al Penney
VO1NO

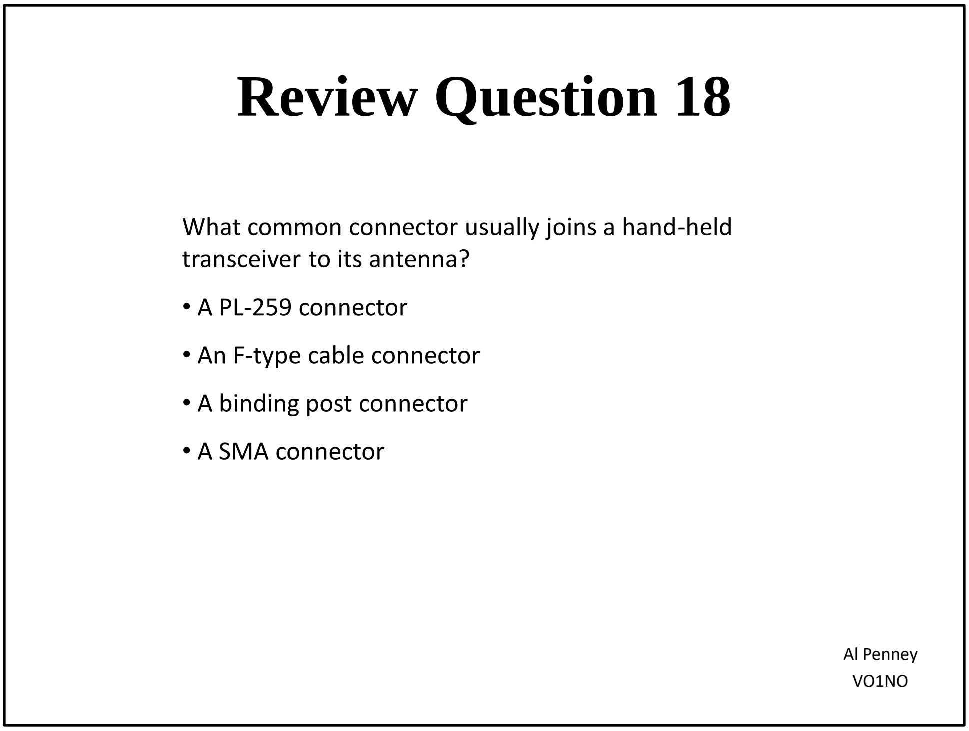
Review Question 17

What common connector usually joins RG-213 coaxial cable to an HF transceiver?

- A PL-259 connector
- An F-type cable connector
- A banana plug connector
- A binding post connector

< A PL-259 connector >

Al Penney
VO1NO



Review Question 18

What common connector usually joins a hand-held transceiver to its antenna?

- A PL-259 connector
- An F-type cable connector
- A binding post connector
- A SMA connector

Al Penney
VO1NO

Review Question 18

What common connector usually joins a hand-held transceiver to its antenna?

- A PL-259 connector
- An F-type cable connector
- A binding post connector
- A SMA connector

< A SMA connector >

Al Penney
VO1NO

Review Question 19

Which of these common connectors has the lowest loss at UHF?

- An F-type cable connector
- A BNC connector
- A PL-259 connector
- A type-N connector

Al Penney
VO1NO

Review Question 19

Which of these common connectors has the lowest loss at UHF?

- An F-type cable connector
- A BNC connector
- A PL-259 connector
- A type-N connector

< A type-N connector >

Al Penney
VO1NO

Review Question 20

If you install a 6-metre Yagi on a tower 60 metres (200 ft) from your transmitter, which of the following transmission lines provides the least loss?

- RG-58
- RG-213
- RG-174
- RG-59

Al Penney
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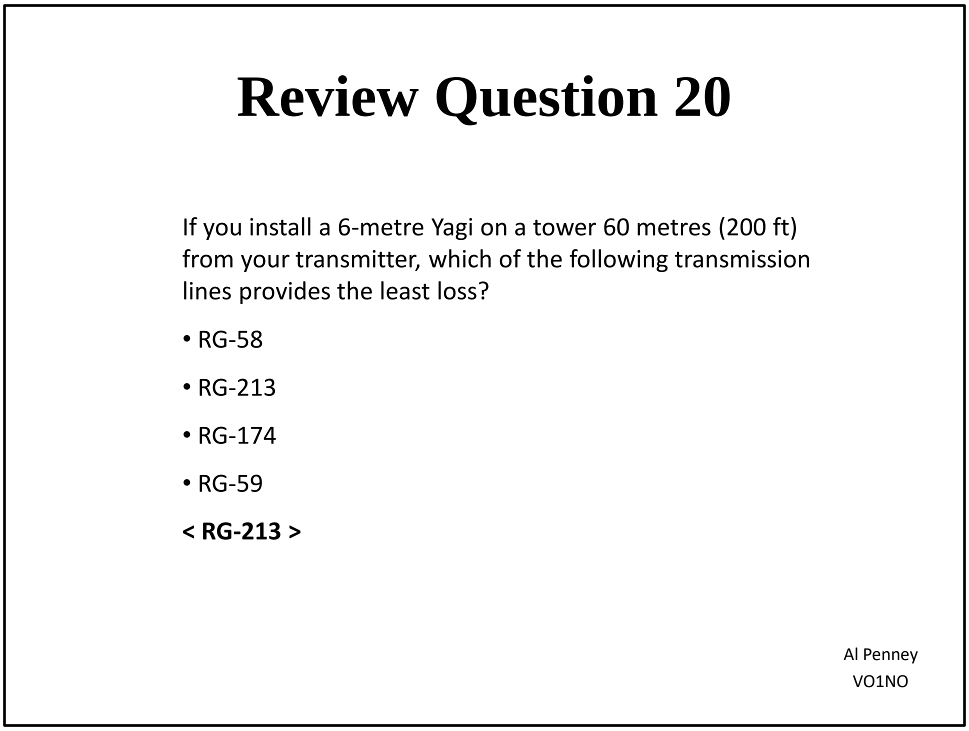

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- RG-174
- RG-59

< RG-213 >

Al Penney
VO1NO

Review Question 21

What commonly available antenna transmission line can be buried directly in the ground for some distance without adverse effects?

- 75 ohm twin-lead
- 600 ohm open wire line
- 300 ohm twin-lead
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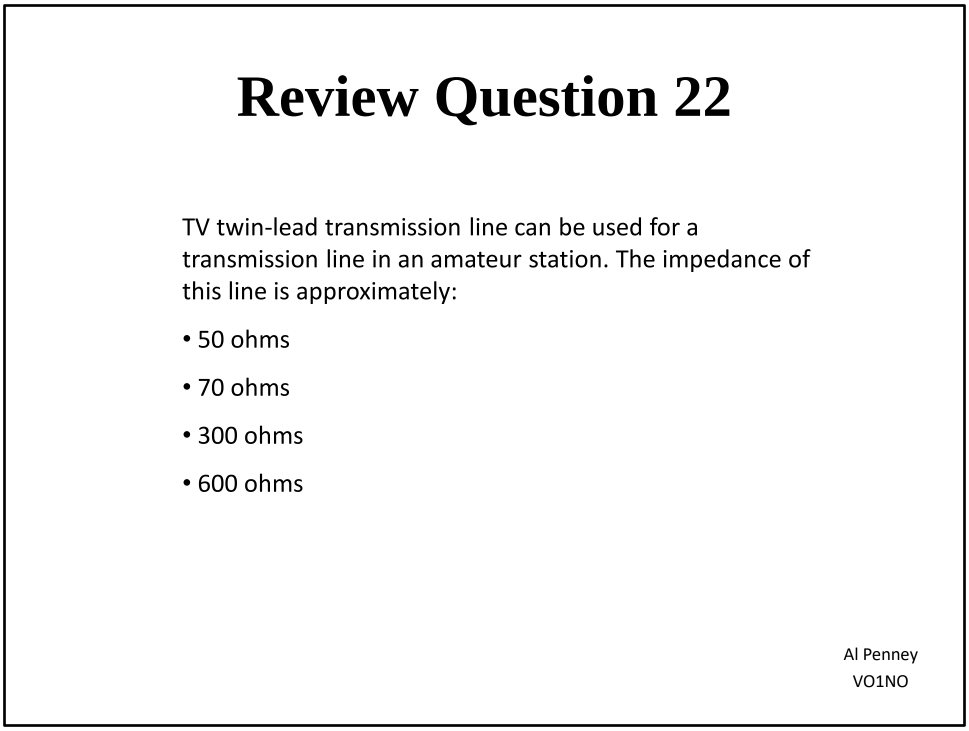
< Coaxial cable >

Al Penney
VO1NO



Review Question 22

TV twin-lead transmission line can be used for a transmission line in an amateur station. The impedance of this line is approximately:

- 50 ohms
- 70 ohms
- 300 ohms
- 600 ohms

Al Penney
VO1NO

Review Question 22

TV twin-lead transmission line can be used for a transmission line in an amateur station. The impedance of this line is approximately:

- 50 ohms
- 70 ohms
- 300 ohms
- 600 ohms

< 300 ohms >

Al Penney
VO1NO

Review Question 23

Why should you use only good quality coaxial cable and connectors for an UHF antenna system?

- To keep the standing wave ratio of your antenna system high
- To keep RF loss low
- To keep television interference high
- To keep the power going to your antenna system from getting too high

Al Penney
VO1NO

Review Question 23

Why should you use only good quality coaxial cable and connectors for an UHF antenna system?

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- To keep RF loss low
- To keep television interference high
- To keep the power going to your antenna system from getting too high

< To keep RF loss low >

Al Penney
VO1NO

Review Question 24

What are some reasons to use parallel-conductor transmission line?

- It has low impedance and works with a high SWR
- It will operate with a high SWR, and it works well when tied down to metal objects
- It has a low impedance, and has less loss than coaxial cable
- It will operate with a high SWR, and has less loss than coaxial cable

Al Penney
VO1NO

Review Question 24

What are some reasons to use parallel-conductor transmission line?

- It has low impedance and works with a high SWR
- It will operate with a high SWR, and it works well when tied down to metal objects
- It has a low impedance, and has less loss than coaxial cable
- It will operate with a high SWR, and has less loss than coaxial cable

< It will operate with a high SWR, and has less loss than coaxial cable >

Al Penney
VO1NO

Review Question 25

As the frequency of a signal is changed, what happens to signal loss in a transmission line?

- Signal loss is the least when the signal’s wavelength is the same as the transmission line’s length
- Signal loss is the same for any frequency
- Signal loss increases with increasing frequency
- Signal loss increases with decreasing frequency

Al Penney
VO1NO

Review Question 25

As the frequency of a signal is changed, what happens to signal loss in a transmission line?

- Signal loss is the least when the signal's wavelength is the same as the transmission line's length
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- Signal loss increases with decreasing frequency

< Signal loss increases with increasing frequency >

Al Penney
VO1NO

Review Question 26

The lowest loss transmission line on HF is:

- 75 ohm twin-lead
- coaxial cable
- 300 ohm twin-lead
- open wire line

Al Penney
VO1NO

Review Question 26

The lowest loss transmission line on HF is:

- 75 ohm twin-lead
- coaxial cable
- 300 ohm twin-lead
- open wire line

< open wire line >

Al Penney
VO1NO

Review Question 27

If the length of coaxial transmission line is increased from 20 metres (66 ft) to 40 metres (132 ft), how would this affect the line loss?

- It would be reduced by 10%
- It would be increased by 10%
- It would be reduced to 50%
- It would be increased by 100%

Review Question 27

If the length of coaxial transmission line is increased from 20 metres (66 ft) to 40 metres (132 ft), how would this affect the line loss?

- It would be reduced by 10%
- It would be increased by 10%
- It would be reduced to 50%
- It would be increased by 100%

< It would be increased by 100% >

Al Penney
VO1NO

Review Question 28

If the frequency is increased, how would this affect the loss on a transmission line?

- It would decrease
- It would increase
- It is independent of frequency
- It depends on the line length

Al Penney
VO1NO

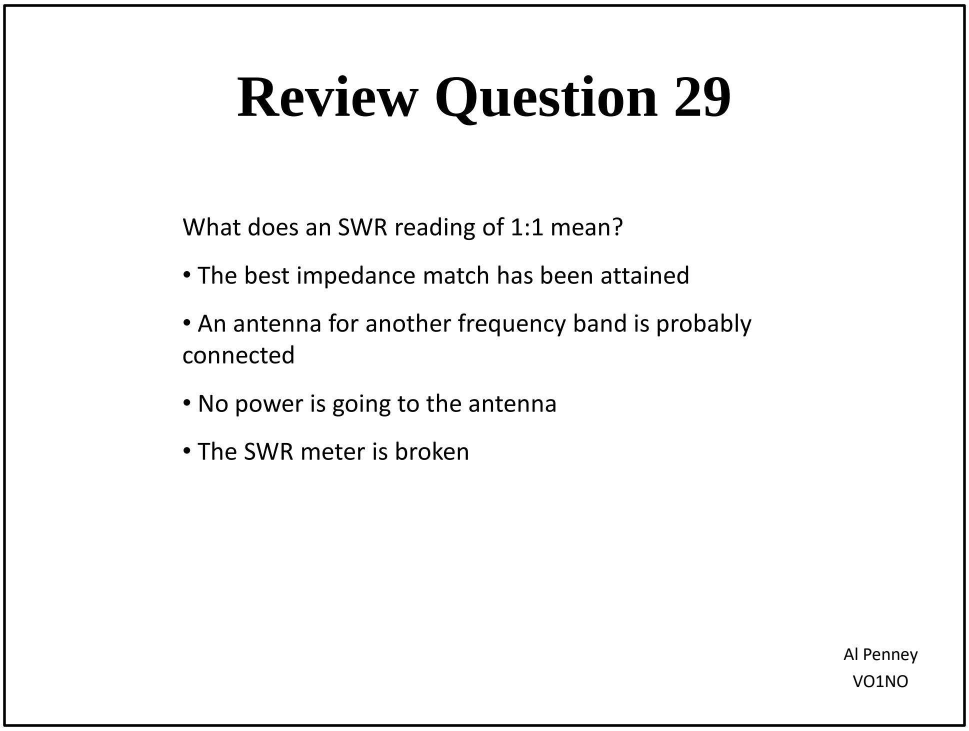
Review Question 28

If the frequency is increased, how would this affect the loss on a transmission line?

- It would decrease
- It would increase
- It is independent of frequency
- It depends on the line length

< It would increase >

Al Penney
VO1NO

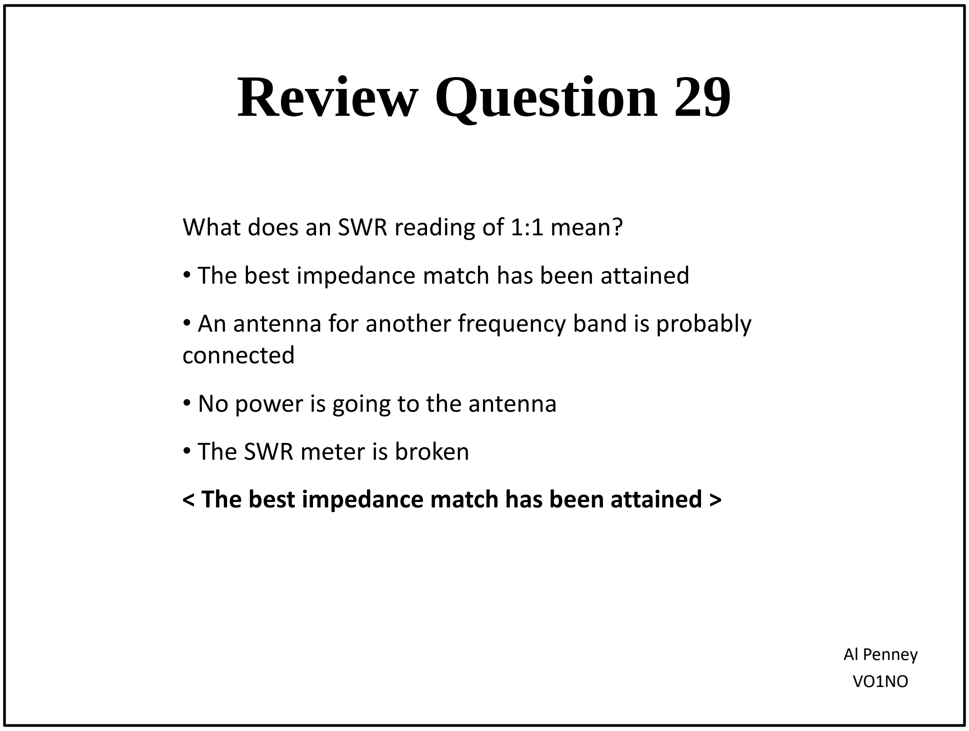


Review Question 29

What does an SWR reading of 1:1 mean?

- The best impedance match has been attained
- An antenna for another frequency band is probably connected
- No power is going to the antenna
- The SWR meter is broken

Al Penney
VO1NO



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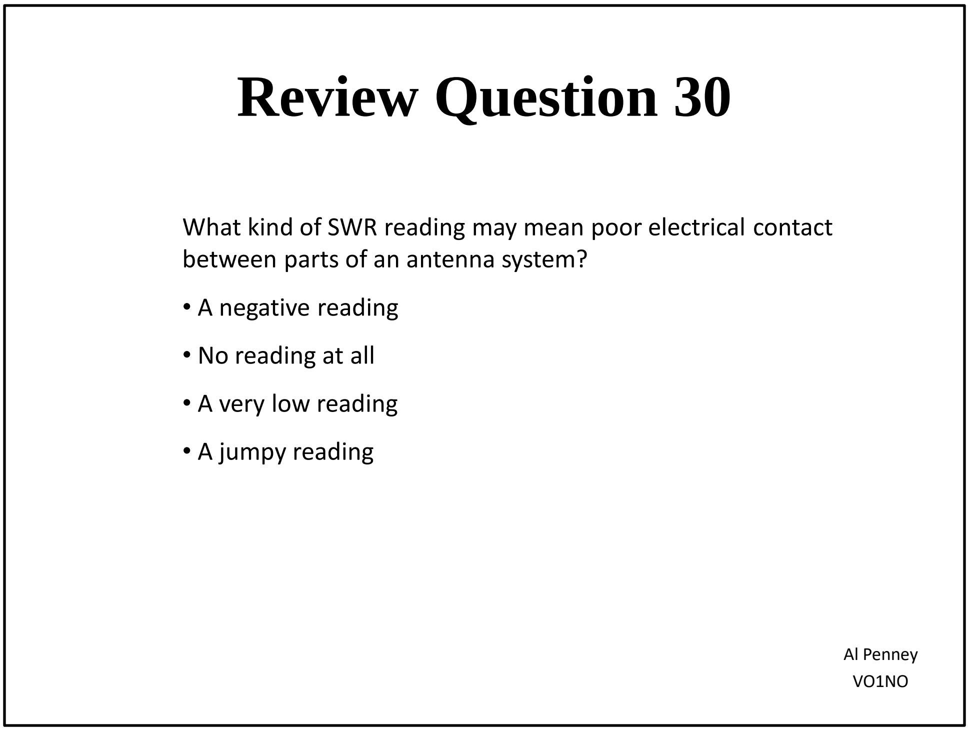
Al Penney
VO1NO



Review Question 30

What kind of SWR reading may mean poor electrical contact between parts of an antenna system?

- A negative reading
- No reading at all
- A very low reading
- A jumpy reading

Al Penney
VO1NO

Review Question 30

What kind of SWR reading may mean poor electrical contact between parts of an antenna system?

- A negative reading
- No reading at all
- A very low reading
- A jumpy reading

< A jumpy reading >

Al Penney
VO1NO

Review Question 31

What does a very high SWR reading mean?

- The transmitter is putting out more power than normal, showing that it is about to go bad
- There is a large amount of solar radiation, which means very poor radio conditions
- The signals coming from the antenna are unusually strong, which means very good radio conditions
- The antenna is the wrong length for the operating frequency, or the transmission line may be an open or short circuited

Al Penney
VO1NO

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< The antenna is the wrong length for the operating frequency, or the transmission line may be an open or short circuited >

Al Penney
VO1NO

Review Question 32

What does standing-wave ratio mean?

- The ratio of maximum to minimum voltages on a transmission line
- The ratio of maximum to minimum inductances on a transmission line
- The ratio of maximum to minimum resistances on a transmission line
- The ratio of maximum to minimum impedances on a transmission line

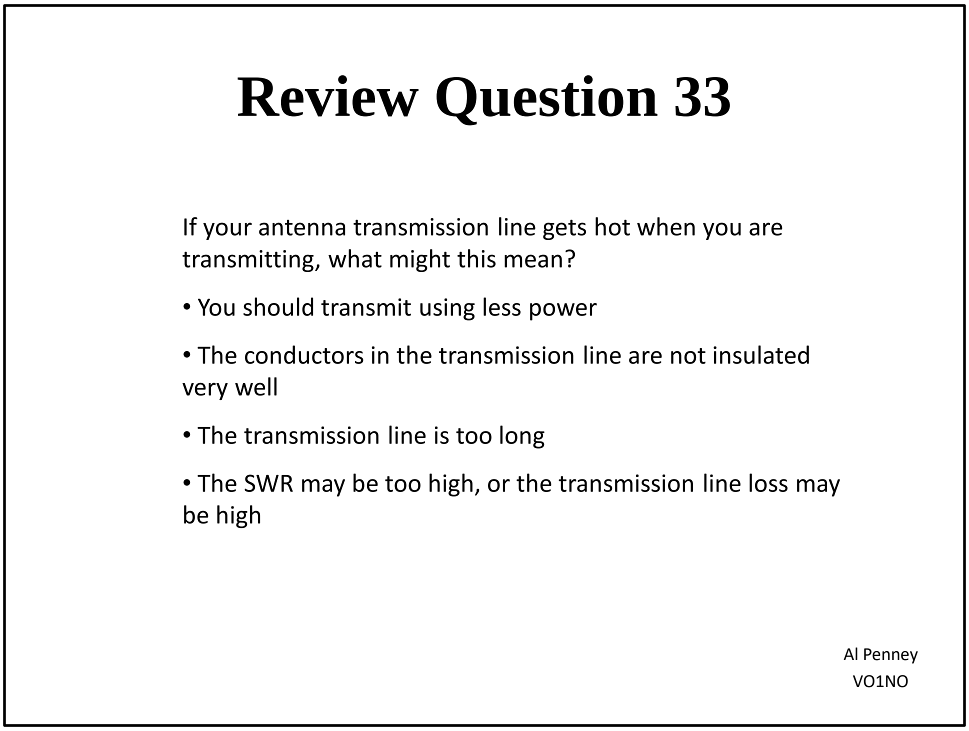
Al Penney
VO1NO

Review Question 32

What does standing-wave ratio mean?

- The ratio of maximum to minimum voltages on a transmission line
- The ratio of maximum to minimum inductances on a transmission line
- The ratio of maximum to minimum resistances on a transmission line
- The ratio of maximum to minimum impedances on a transmission line

< The ratio of maximum to minimum voltages on a transmission line >



Review Question 33

If your antenna transmission line gets hot when you are transmitting, what might this mean?

- You should transmit using less power
- The conductors in the transmission line are not insulated very well
- The transmission line is too long
- The SWR may be too high, or the transmission line loss may be high

Al Penney
VO1NO

Review Question 33

If your antenna transmission line gets hot when you are transmitting, what might this mean?

- You should transmit using less power
- The conductors in the transmission line are not insulated very well
- The transmission line is too long
- The SWR may be too high, or the transmission line loss may be high

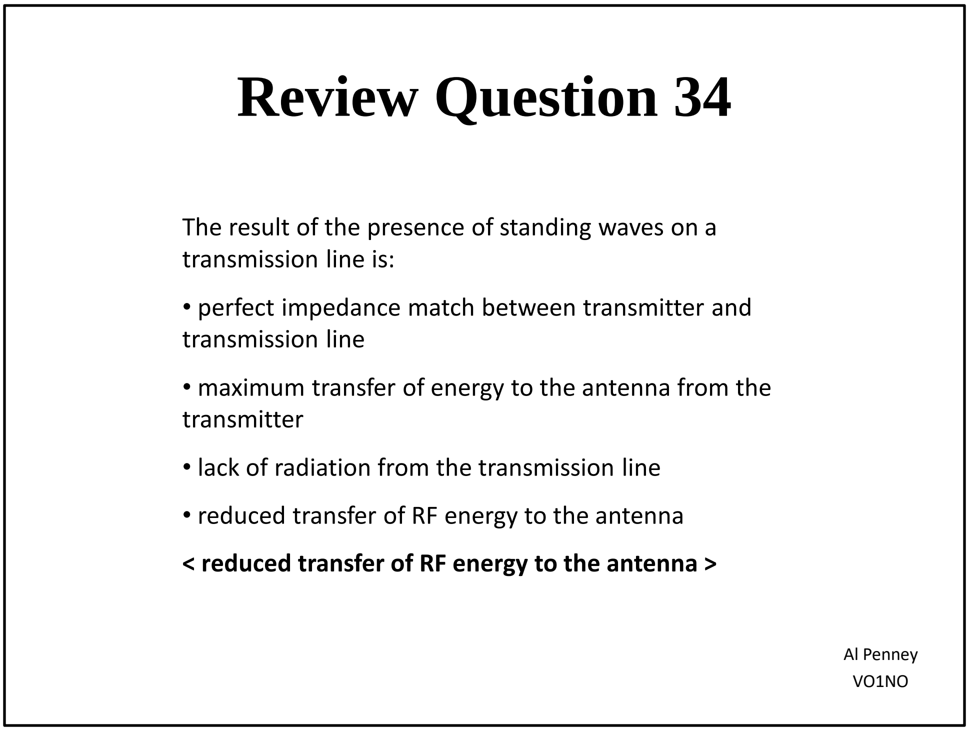
< The SWR may be too high, or the transmission line loss may be high >

Review Question 34

The result of the presence of standing waves on a transmission line is:

- perfect impedance match between transmitter and transmission line
- maximum transfer of energy to the antenna from the transmitter
- lack of radiation from the transmission line
- reduced transfer of RF energy to the antenna

Al Penney
VO1NO



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Review Question 35

If an antenna is correctly matched to a transmitter, the length of transmission line:

- must be an odd number of quarter-wave
- must be an even number of half-waves
- will have no effect on the matching
- must be a full wavelength long

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VO1NO

Review Question 35

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< will have no effect on the matching >

Al Penney
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For Next Class:

- Review Chapter 7 of Basic Study Guide;
- Read Chapter 8 of Basic Study Guide; and
- Read RBR-4 again:
  - https://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/rbr-4-issue2-2014.pdf/$file/rbr-4-issue2-2014.pdf

Questions?

Al Penney
VO1NO

A "cage line" transmission line to feed radio power to the antenna mast (background) of the Solt transmitter (Hungarian: Solti rádióadó) for Kossuth Rádió near Solt, Hungary which broadcasts on 540 kHz in the medium wave (MW) band. With an output power of 2000 kW (2 MW) it is the most powerful medium wave radio transmitter in Europe and also the most powerful in the world (along with three Saudi transmitters). The line consists of an inner circular bundle of parallel wires carrying the power, surrounded by an outer circle of grounded wires that function as a "shield". The line functions similarly to a large coaxial cable. Cage lines are used to carry low frequency, high power RF currents.