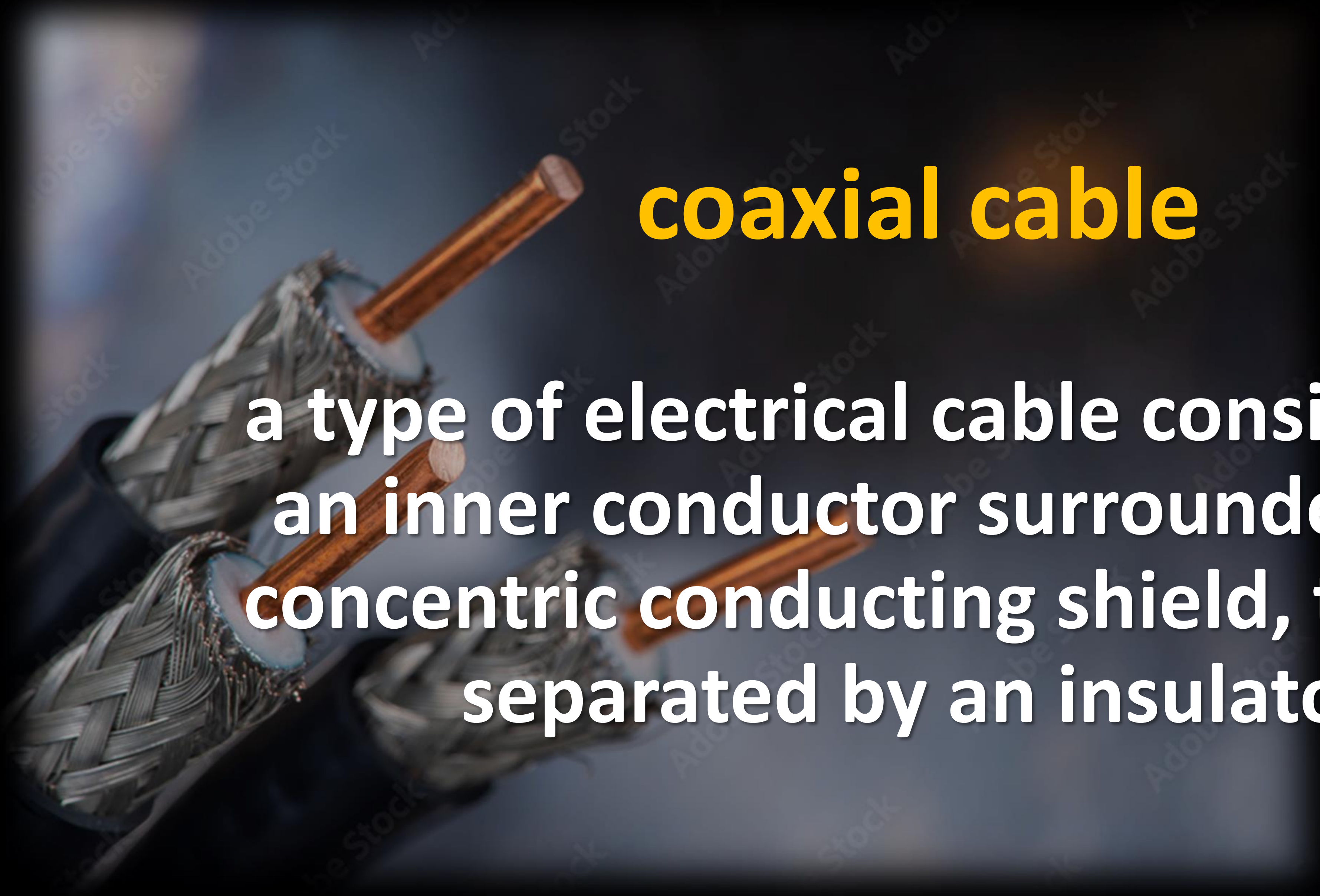
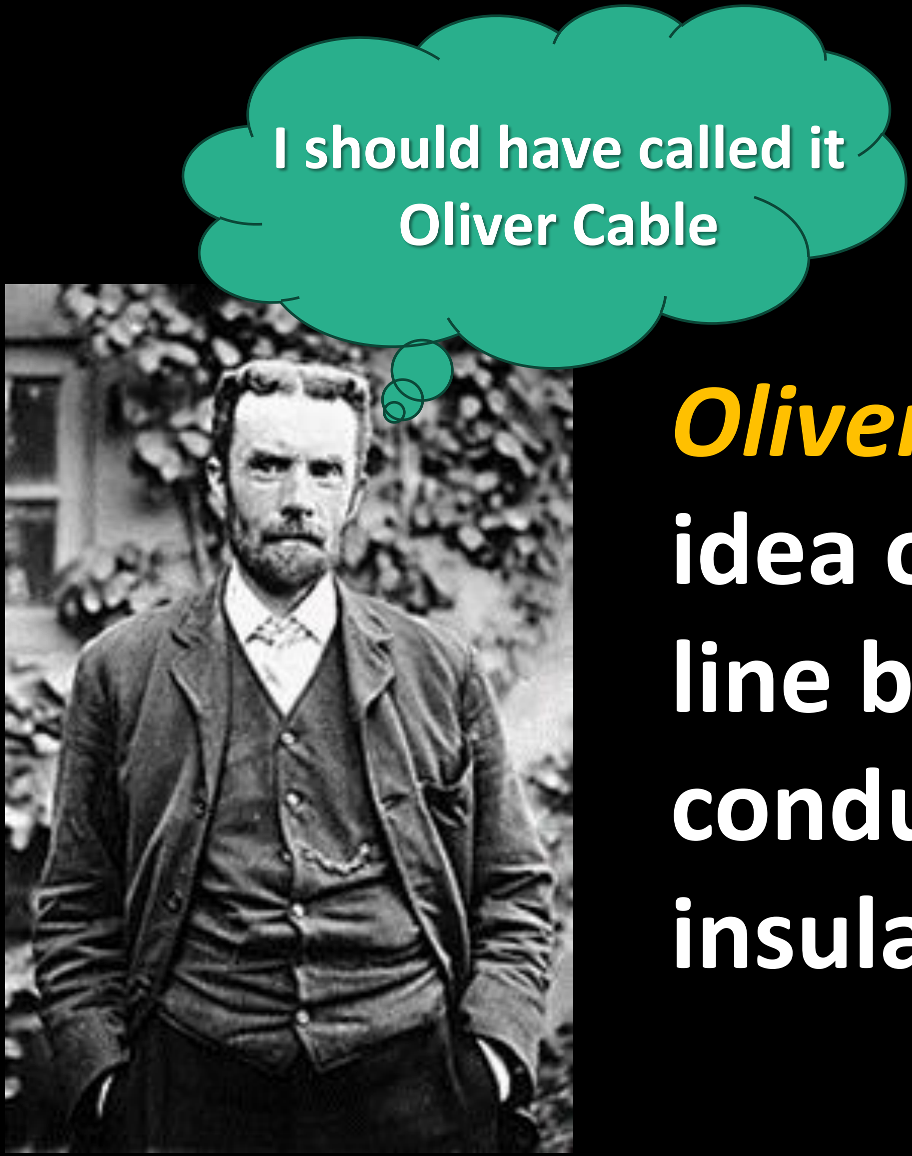
information in this presentation was taken
from many sources and is not offered
as original research


coaxial cables
for amateur radio



# coaxial cable

a type of electrical cable consisting of an inner conductor surrounded by a concentric conducting shield, the two separated by an insulator



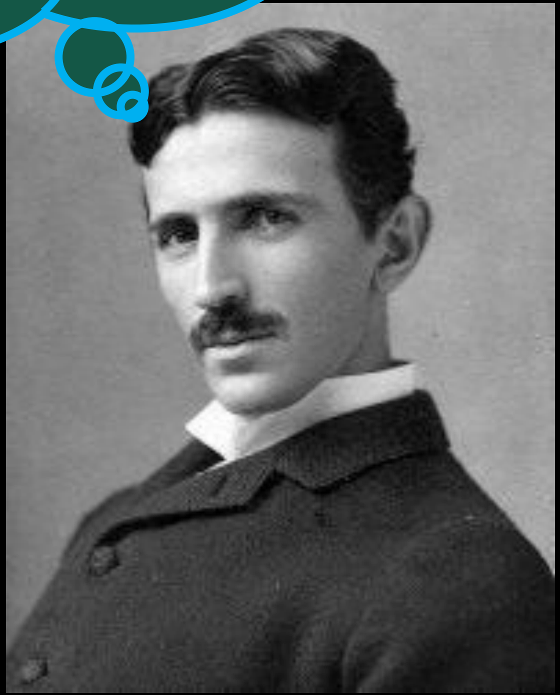

# 1880

***Oliver Heaviside*** **perfected the idea of a coaxial transmission line by wrapping an inner conductor in a steel tube with insulating material**

# 1884

U.S. Patent Office awards ***Nikola Tesla***, the first electrical conductor patent, his concept was the key to constructing the coaxial cables we use today

hmmm… I think my next invention will be a shiny ball that shoots lightening



WNBC radio feedline
ca 1930

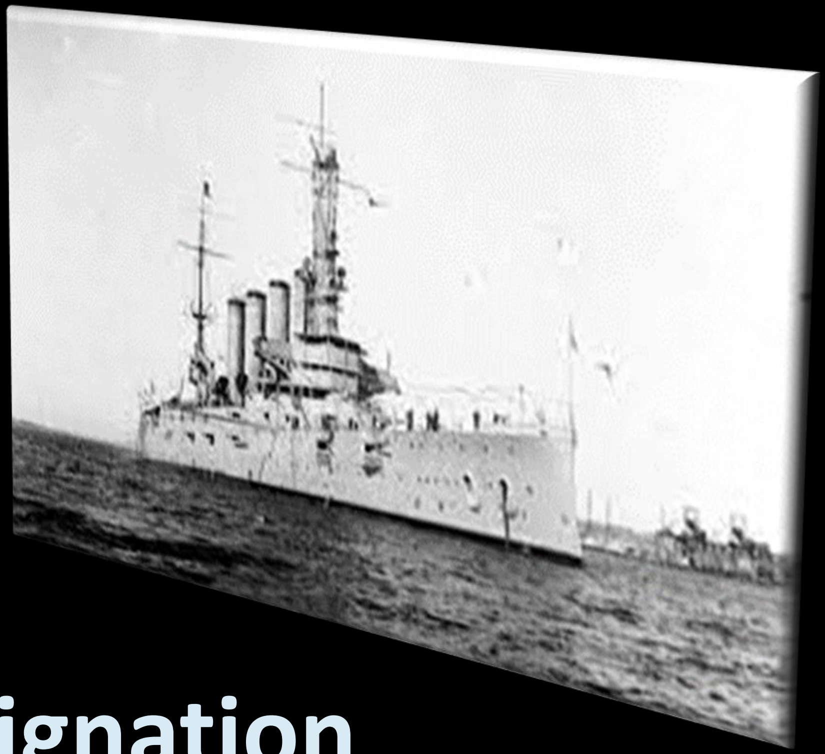
early commercial coaxial cable was a conductor suspended in a conductive metal pipe

# 1929

*Herman Affel* and
*Lloyd Espenschied* create the
modern-day
coaxial cable at the
Bell Telephone Laboratories

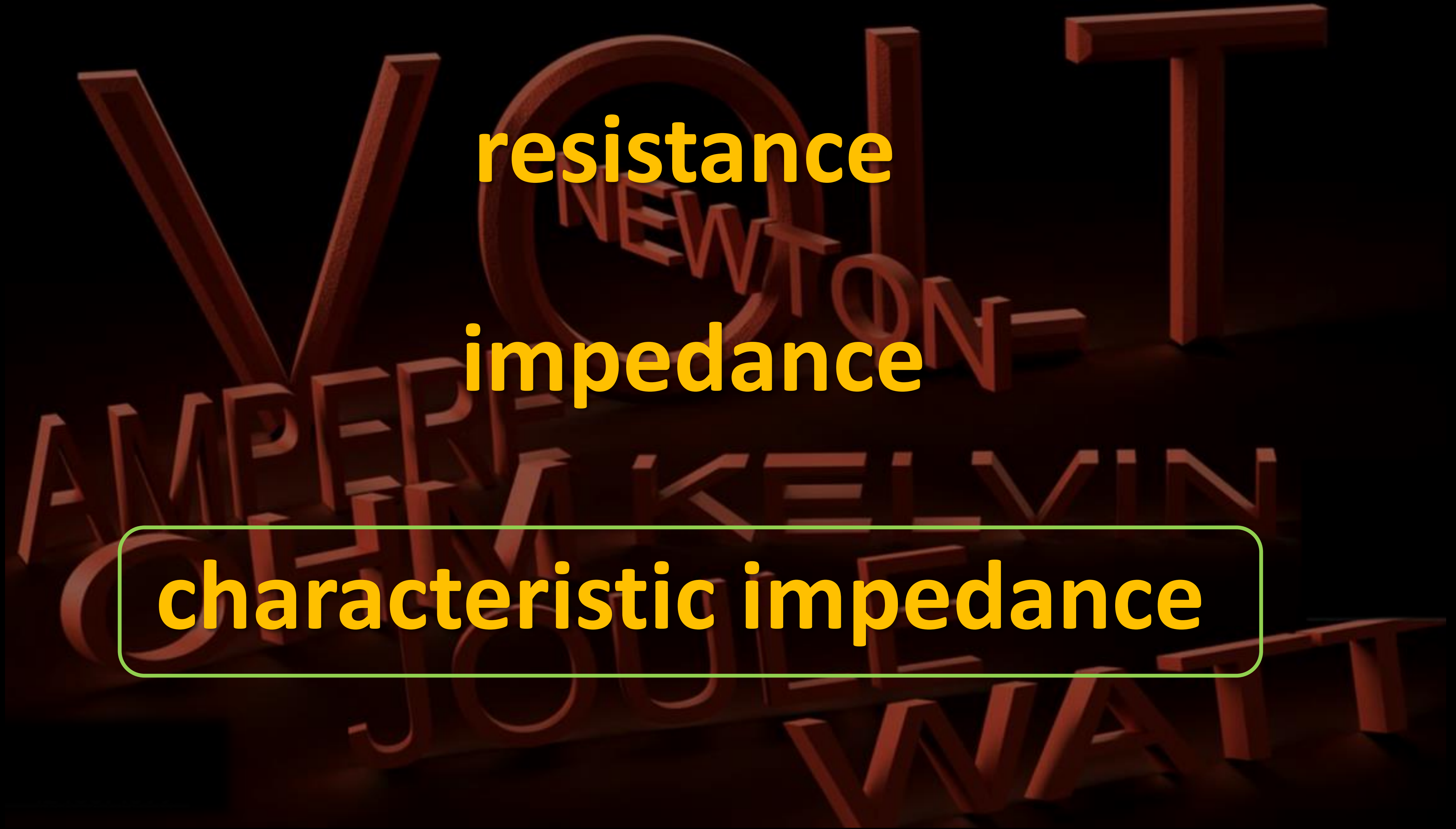
# 1939

*US Navy* adopts coaxial cable for shipboard applications leading to the "MIL SPEC" designation for RF transmission cables



# 1939

best performance
RF coaxial cable
*characteristic impedances*
were determined at
Bell Laboratories




# resistance

# impedance

# characteristic impedance

**resistance (R)**
opposes the flow of both direct current (DC) and alternating current (AC)

**impedance (Z)**
solely opposes the flow of alternating current

# impedance

the limiting of current flow in an AC circuit

indicated by the symbol "Z"

measured in ohms (Ω)

the higher the impedance, the more resistance to the flow of current

## ($Z$) consists of resistance ($R$) and reactance ($X$)

$$Z = R + jX$$

( j- if $X$ capacitive     j+ if $X$ inductive )


**system impedance, not characteristic impedance ($Z_0$)**

$Z = R + jX$

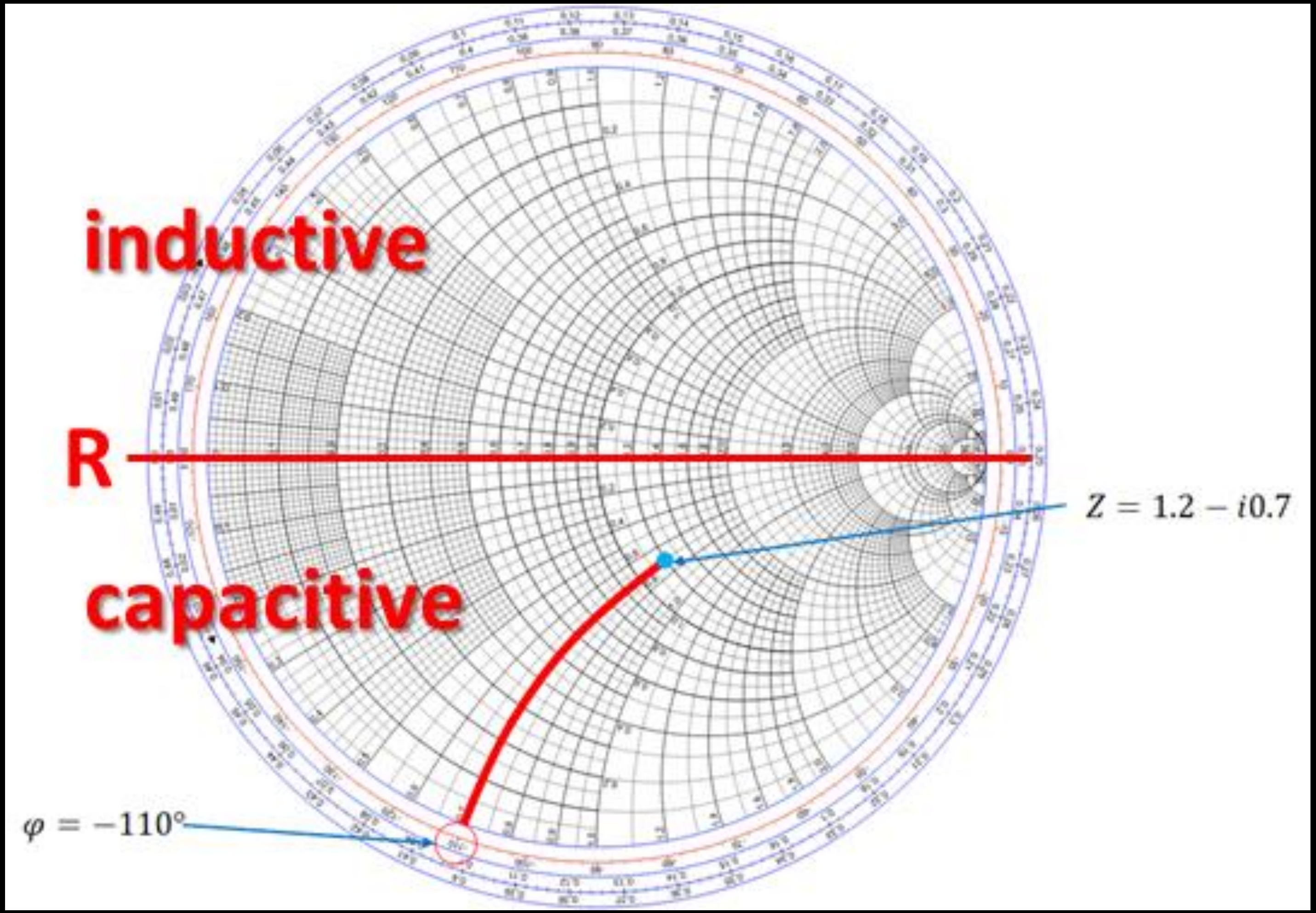
"j" is the unknown value
found by plotting the
R and X values on a Smith Chart

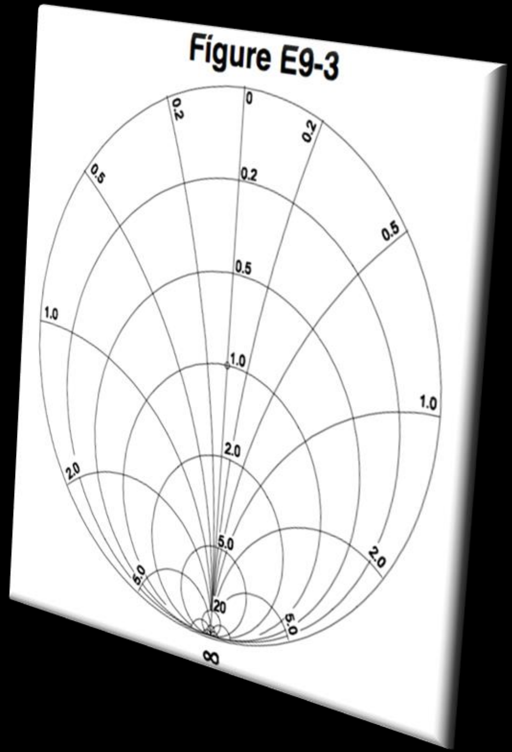
"j" is an expression of "X"

inductive "+" ($X_L$) or capacitive "-" ($X_C$)

$X_L$

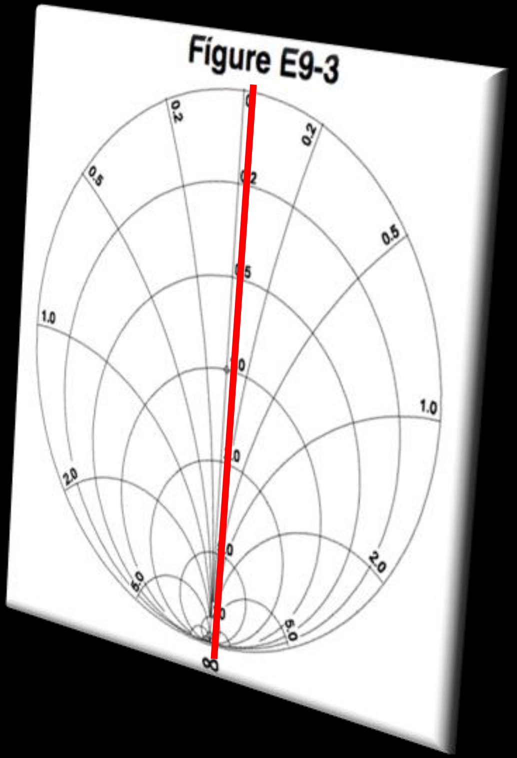
$X_C$




what is a Smith Chart most often used for in amateur radio?

finding **impedance** ($Z$ & $Z_O$) and **VSWR** values in transmission lines what does the only straight line on Smith Chart represent?

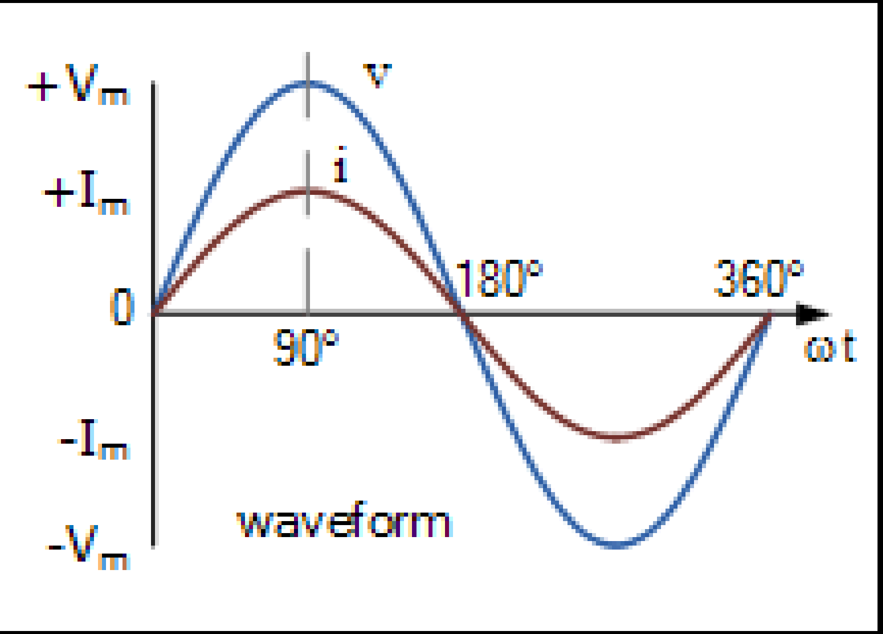



the resistance (R) axis

**impedance** is resistance to the flow of **alternating current** between the transmitter and the load (antenna)

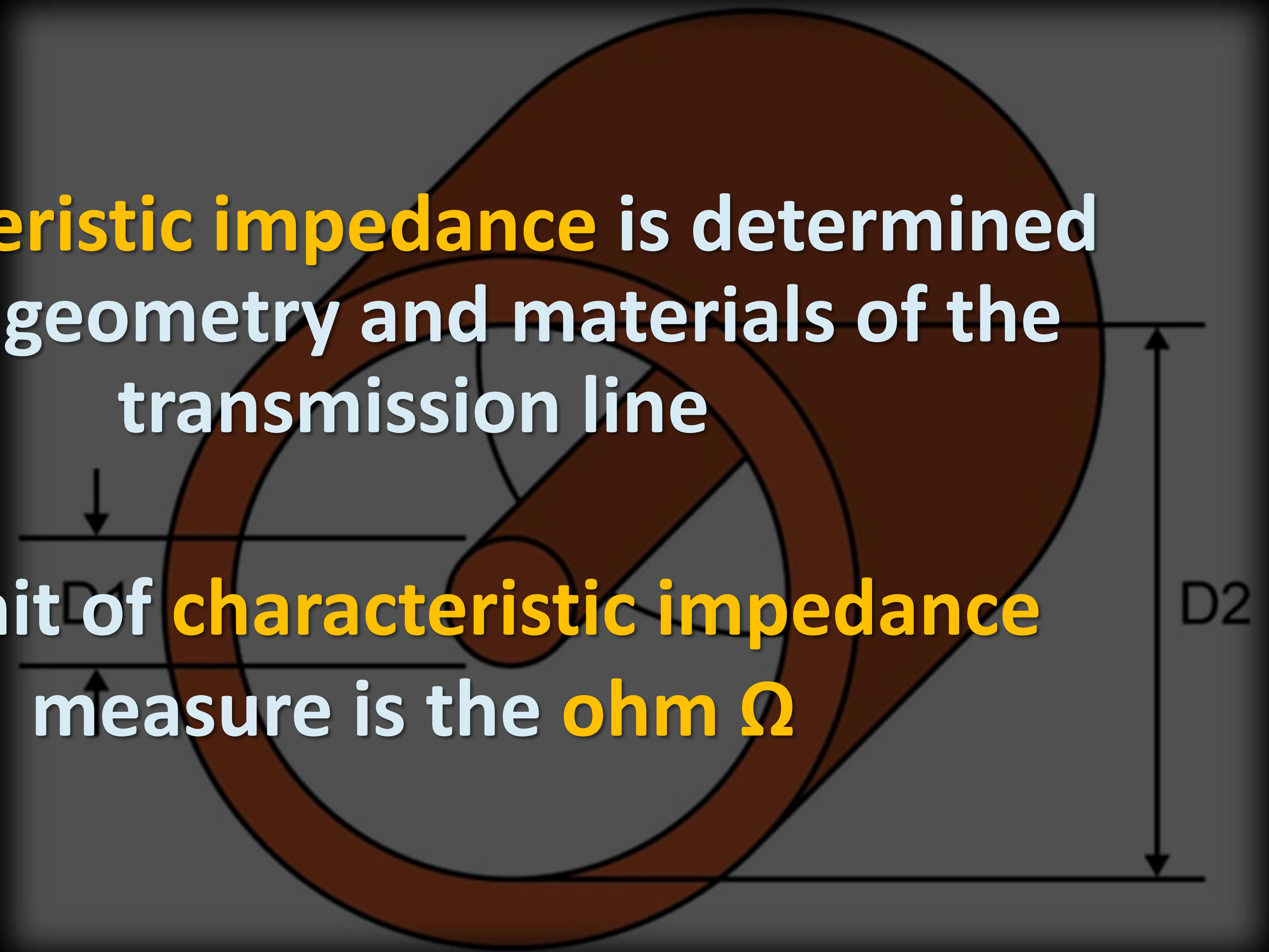
# characteristic impedance ($Z_0$)

the ratio of the amplitudes of ***voltage*** and ***current*** waves propagating along a transmission line



characteristic impedance ($Z_0$)
is not the same as
a circuit impedance (Z)

both are expressed in ohms,
but characteristic impedance
is calculated differently




characteristic impedance is determined by the geometry and materials of the transmission line

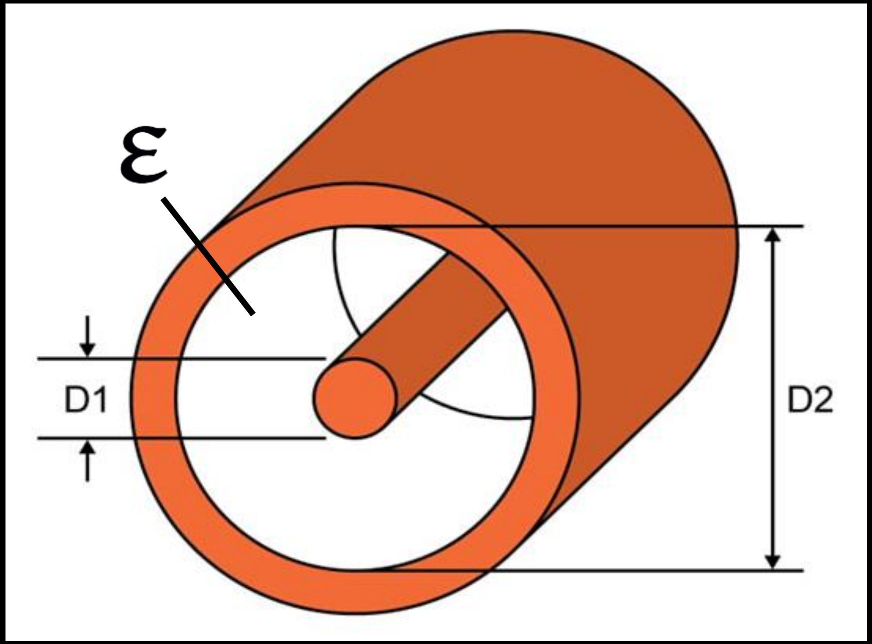
the unit of characteristic impedance measure is the ohm Ω

# characteristic impedance factors

**D1** conductor diameter

**D2** dielectric diameter

**Ɛ** dielectric constant (permittivity)



**30Ω characteristic impedance ($Z_0$) is best for efficiently *handling higher power***

**77Ω characteristic impedance ($Z_0$) is best for *minimizing attenuation* (loss)**

the arithmetic mean between 30Ω and 77Ω is 53.5Ω

the geometric mean is 48Ω

the selection of 50Ω is a compromise between power-handling capability and attenuation*

**the 50Ω characteristic impedance ($Z_0$) standard for amateur radio coax is convenient, as the isotropic impedance of a ½ wave center-fed dipole in “free space” is…73 ohms***

**lossless conductor in free space*

amateur radio equipment
manufactures design
their transceivers
to be 50Ω (Z) rated, giving
them a mid-point between
30Ω (Z) and 77Ω (Z)

*note…*

non-energized coaxial cable
doesn't have
a **resistive** (**R**) component
if correctly built and
is undamaged

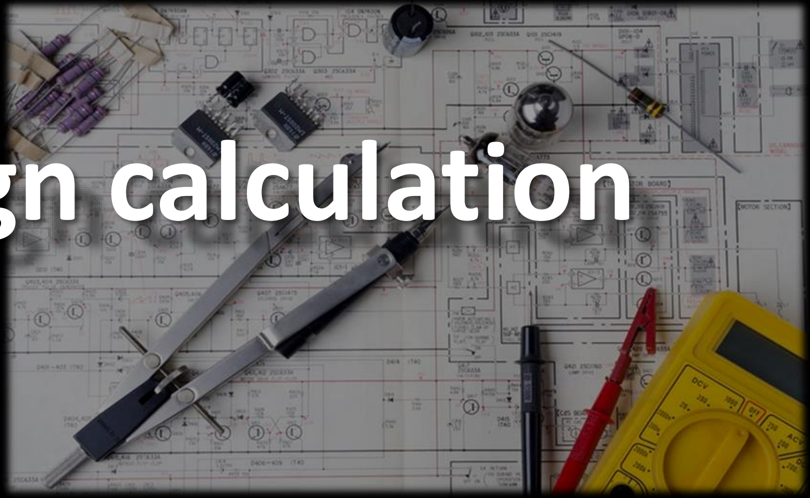
can (R) be present in a coaxial cable carrying an RF signal ?

yes, up to the point where the signal reaches the design frequency for the cable, the point where (R) becomes ($Z_0$)

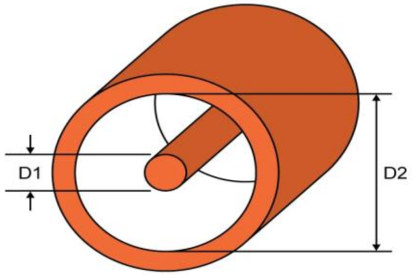
typically, we don’t measure characteristic impedance ($Z_0$)

we calculate total system impedance ($Z$)

$Z_0$ is an engineering/design calculation



# determining characteristic impedance




$$Zo = \frac{138\log_{10}\left(\frac{D_d}{D_c}\right)}{\sqrt{\epsilon_R}}\ ;\ f_{cutoff} = \frac{11.8}{\sqrt{\varepsilon_R}\,\pi\left(\frac{D_d+D_c}{2}\right)}$$

$$C_{ft} = \frac{7.354\varepsilon_R}{\log_{10}\left(\frac{D_d}{D_c}\right)}\ ;\ I_{ft} = 140.4\log_{10}\left(\frac{D_d}{D_c}\right)$$

***or…***

Inputs

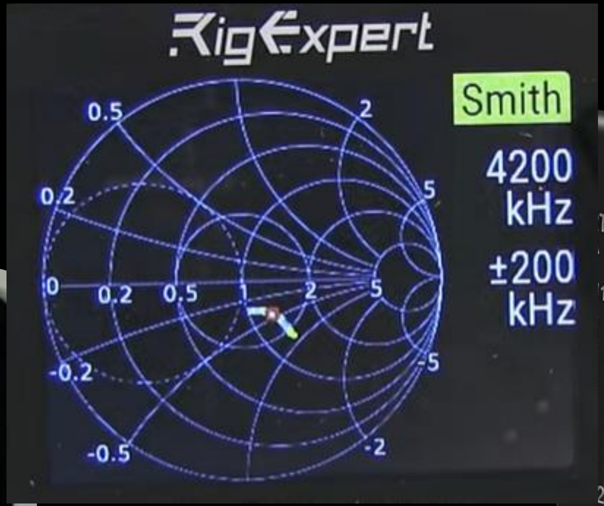
| | | |
|---|---|---|
| **Inner Conductor Diameter** | Inner Conductor Diameter | mil |
| **Inner Surface Shield Diameter** | Inner Surface Shield Diameter | mil |
| **Substrate Dielectric** | 0 | |
| | Calculate | |

***or…***

commercial
impedance analyzer


*or you can...*

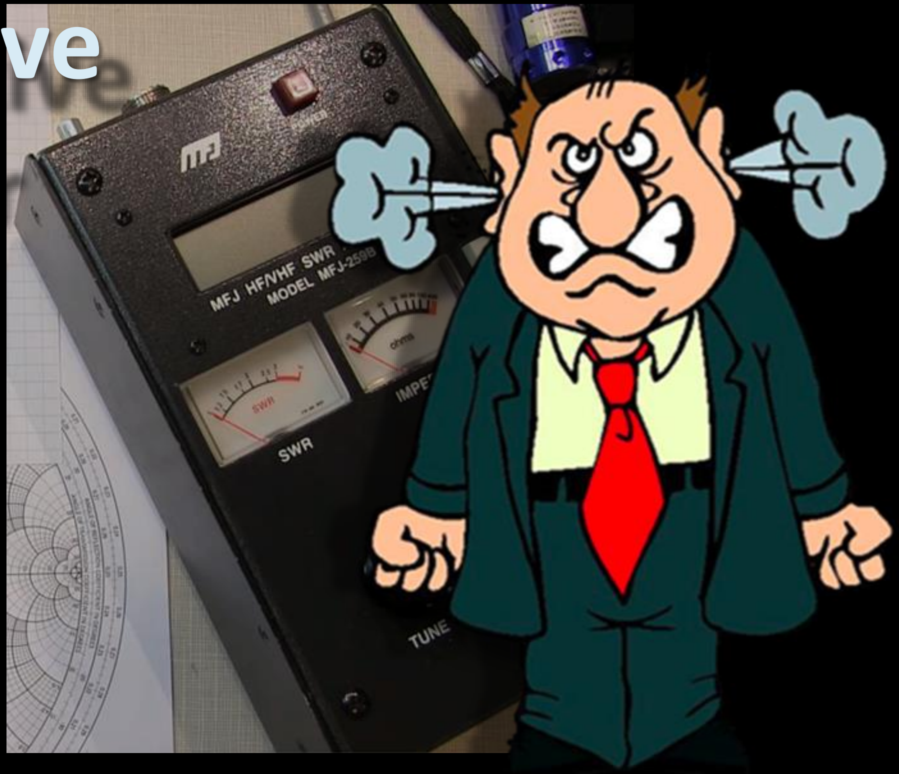
# ...use an antenna analyzer

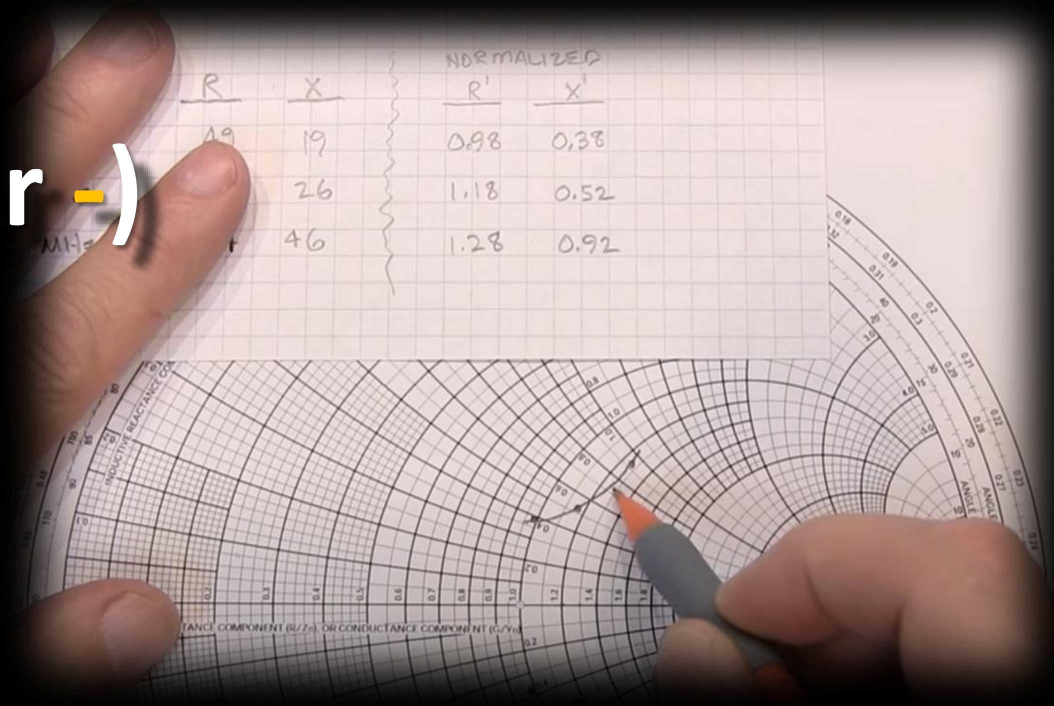


however...

some analyzers lack the processing ability required to calculate $X_L$ (+) for inductive reactance and $X_C$ (-) for capacitive reactance

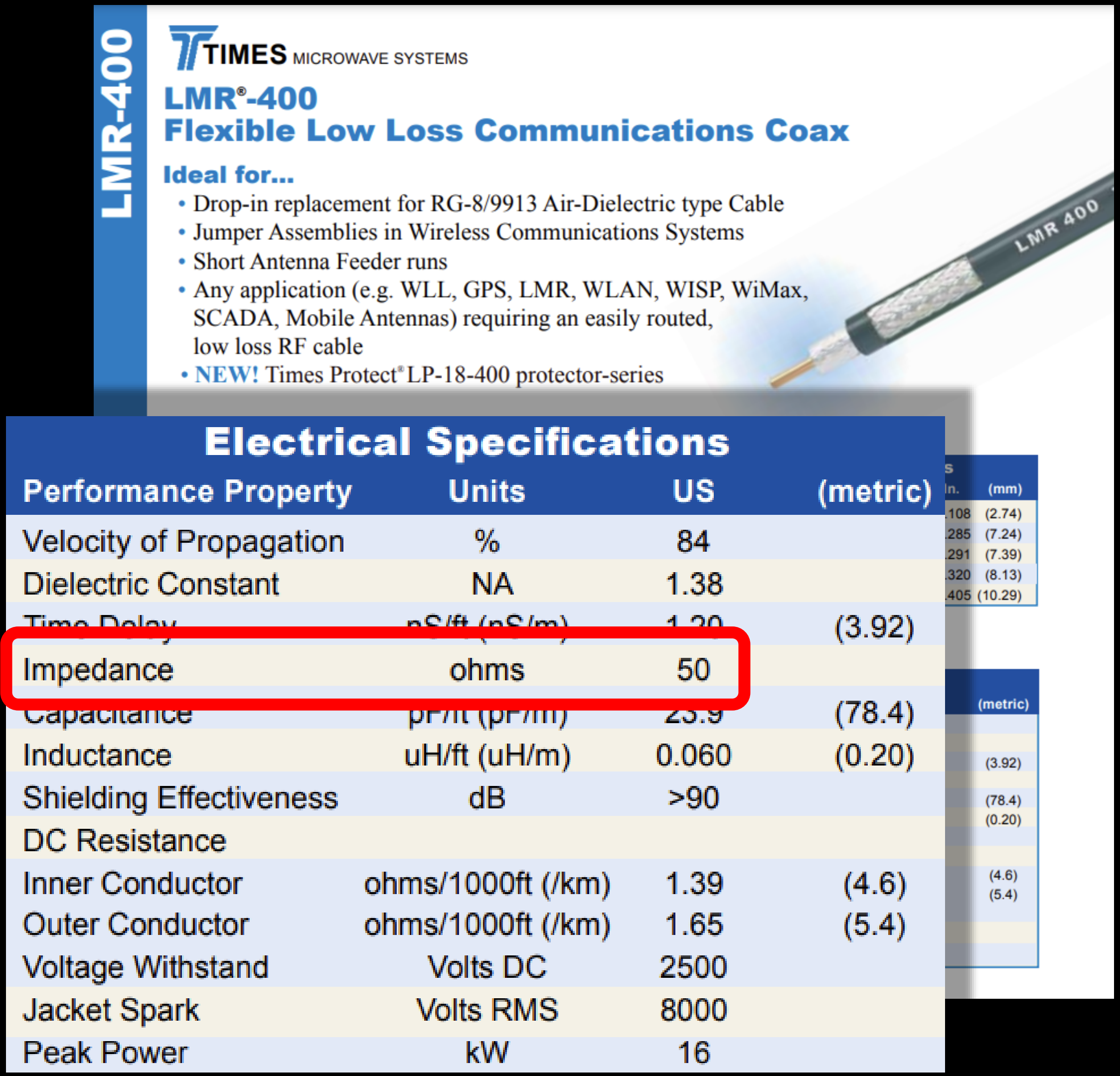


a calculation is necessary to determine "j" and the value of X (+ or -)




www.youtube.com/watch?v=_Dlw_XheKl0

# another way is to locate the manufacture’s label and search their website

LMR-400

TIMES MICROWAVE SYSTEMS

**LMR®-400**
**Flexible Low Loss Communications Coax**

**Ideal for...**

- Drop-in replacement for RG-8/9913 Air-Dielectric type Cable
- Jumper Assemblies in Wireless Communications Systems
- Short Antenna Feeder runs
- Any application (e.g. WLL, GPS, LMR, WLAN, WISP, WiMax, SCADA, Mobile Antennas) requiring an easily routed, low loss RF cable
- NEW! Times Protect® LP-18-400 protector-series

**Electrical Specifications**

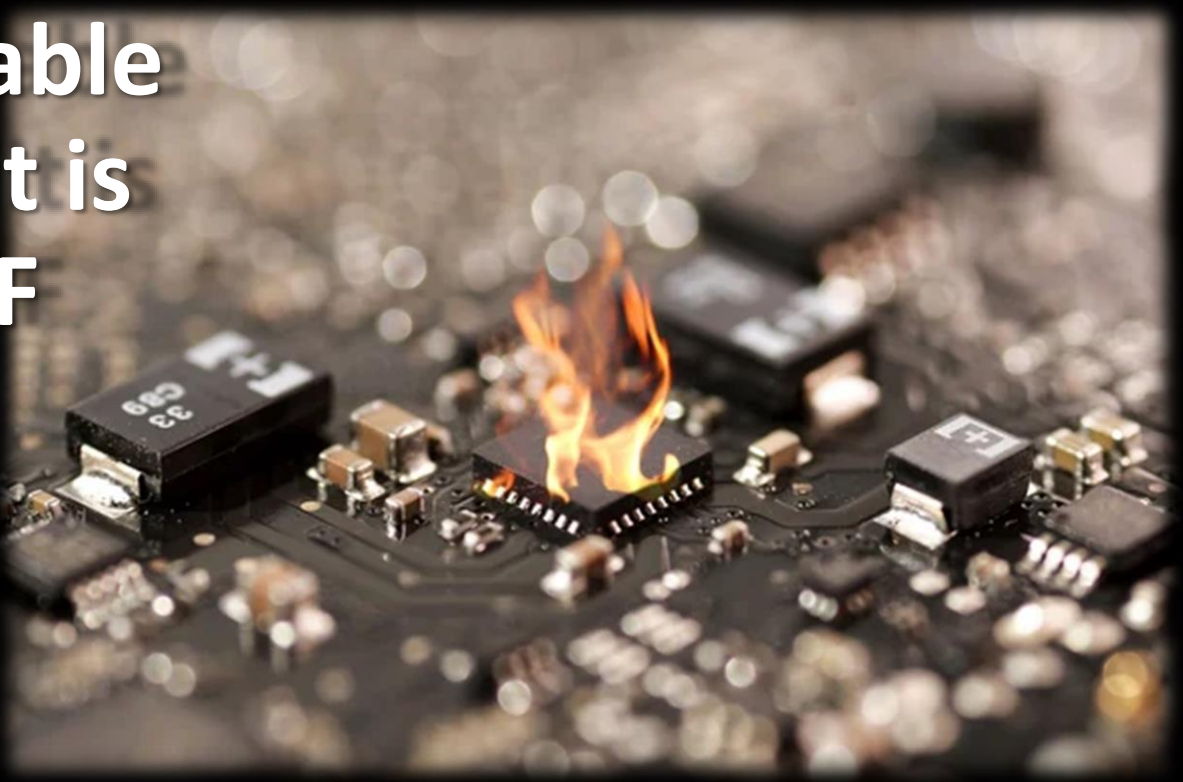
| Performance Property | Units | US | (metric) |
|---|---|---|---|
| Velocity of Propagation | % | 84 | |
| Dielectric Constant | NA | 1.38 | |
| Time Delay | nS/ft (nS/m) | 1.20 | (3.92) |
| Impedance | ohms | 50 | |
| Capacitance | pF/ft (pF/m) | 23.9 | (78.4) |
| Inductance | uH/ft (uH/m) | 0.060 | (0.20) |
| Shielding Effectiveness | dB | >90 | |
| DC Resistance | | | |
| Inner Conductor | ohms/1000ft (/km) | 1.39 | (4.6) |
| Outer Conductor | ohms/1000ft (/km) | 1.65 | (5.4) |
| Voltage Withstand | Volts DC | 2500 | |
| Jacket Spark | Volts RMS | 8000 | |
| Peak Power | kW | 16 | |

if you cannot find a manufacturer's label, you don't do calculus, and you don't have an analyzer, you are…


of

don’t assume an unmarked cable is rated at 50Ω based on its appearance alone

coaxial cable other than 50Ω paired with a 50Ω transciever may result in a mismatch and high or erratic VSWR never attempt to read the characteristic impedance value of your coaxial cable or your system when it is energized with an RF signal using an antenna analyzer

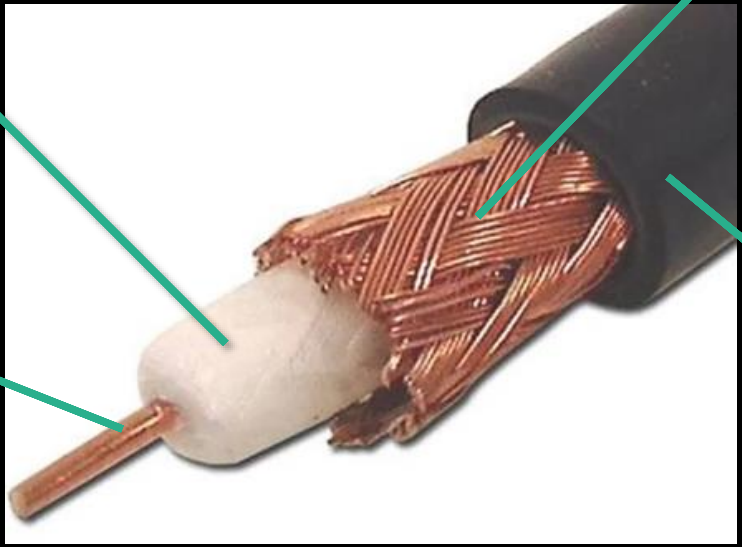


there are 200 or more design variations of modern coaxial cable

# typical modern RF coaxial cable

polyethylene (PE) insulator (dielectric)

braided copper shield (also a conductor)



solid copper center conductor

outer (protective) jacket (PVC)

# MIL SPEC standards led to the adoption of the common designation system for coaxial cable types

**RG 213 UF**

**Radio Guide**
MIL SPEC classification

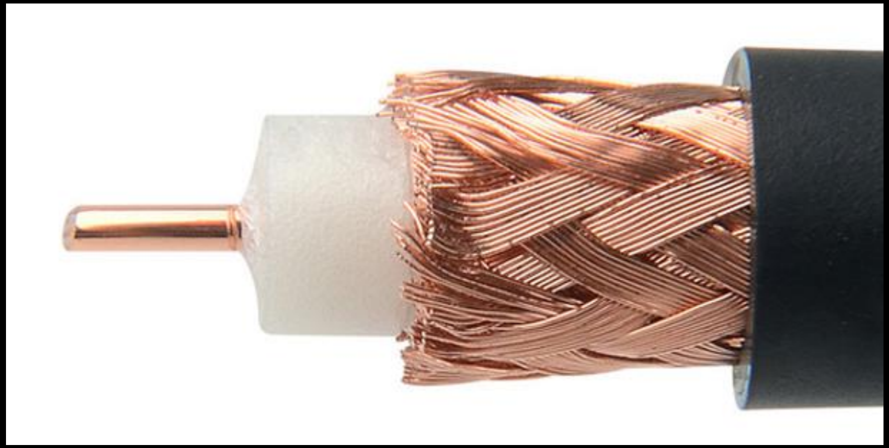
**build specifications**
outside diameter, size and type of conductor, etc.

**miscellaneous**
application, type of jacket, etc.

# center conductor

## solid copper

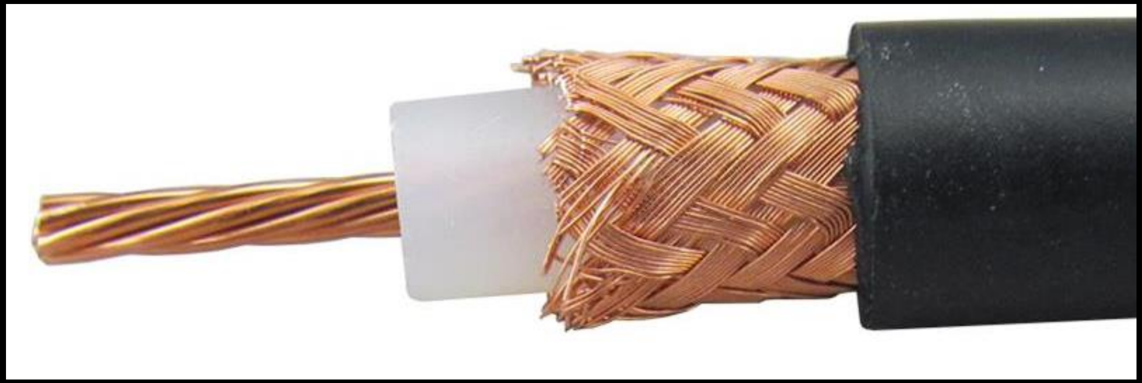
- ✓ excellent conductor
- ✗ lacks flexibility
- ✗ expensive
- ✗ heaviest



# center conductor

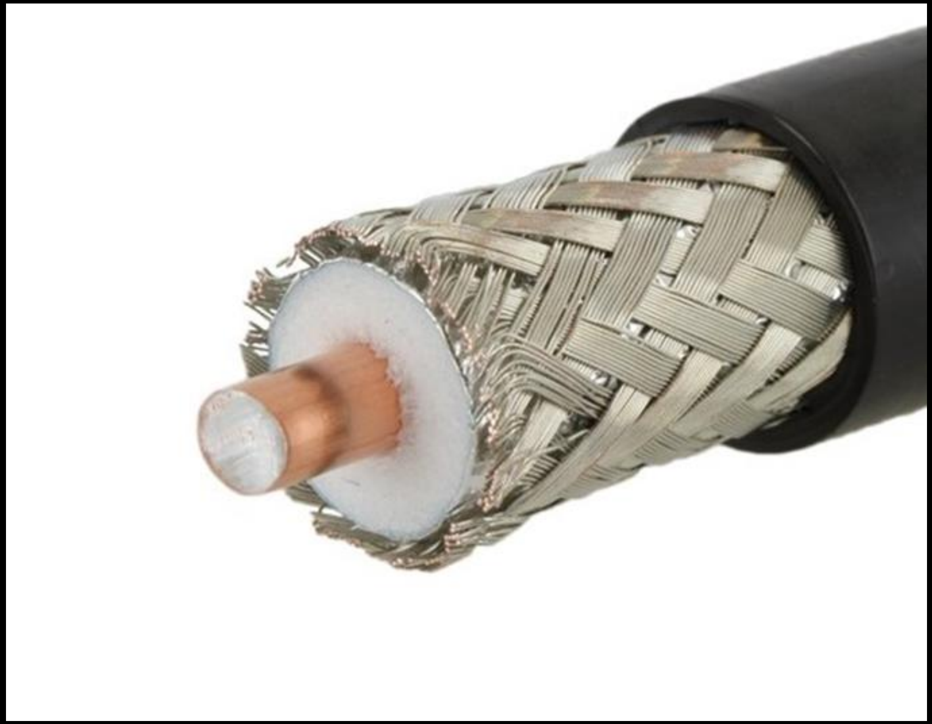
## stranded copper

- ✓ good conductor
- ✓ flexible
- ✗ heavy



# center conductor
## copper clad aluminum

- good conductor
- moderate flexibility
- moderately priced
- light weight




**how many conductive paths are there in a typical coaxial cable?**

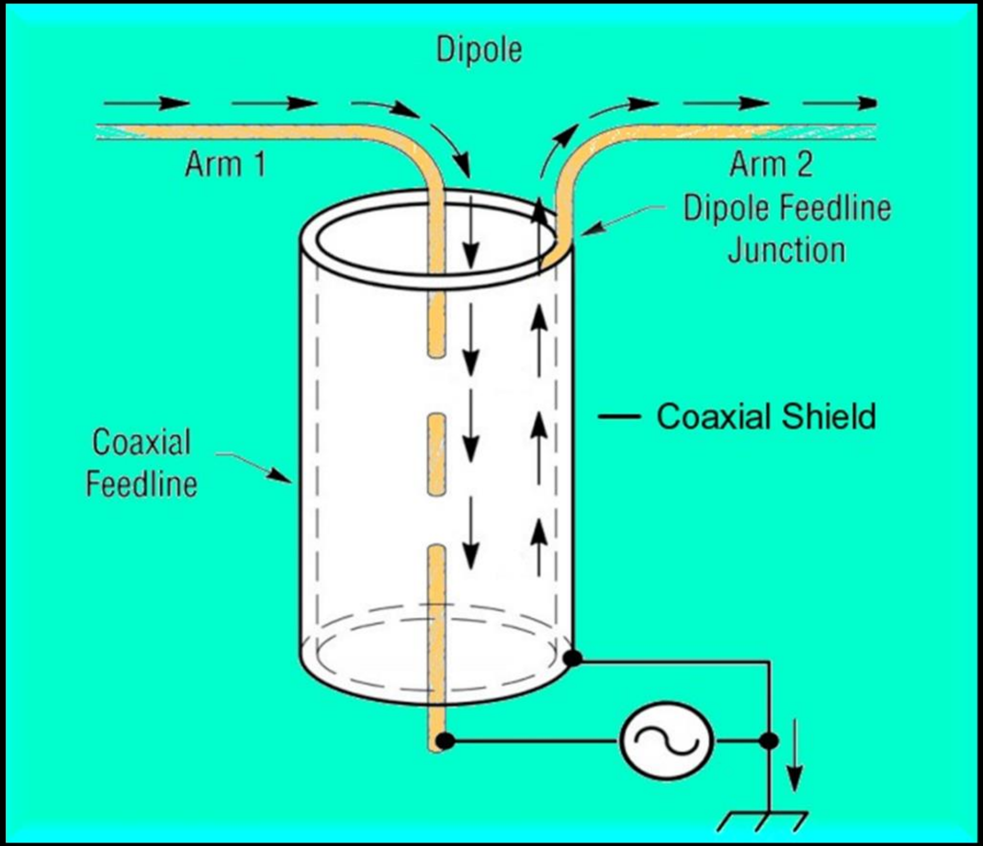
# coaxial shield

shielding is the current return path on the coaxial cable

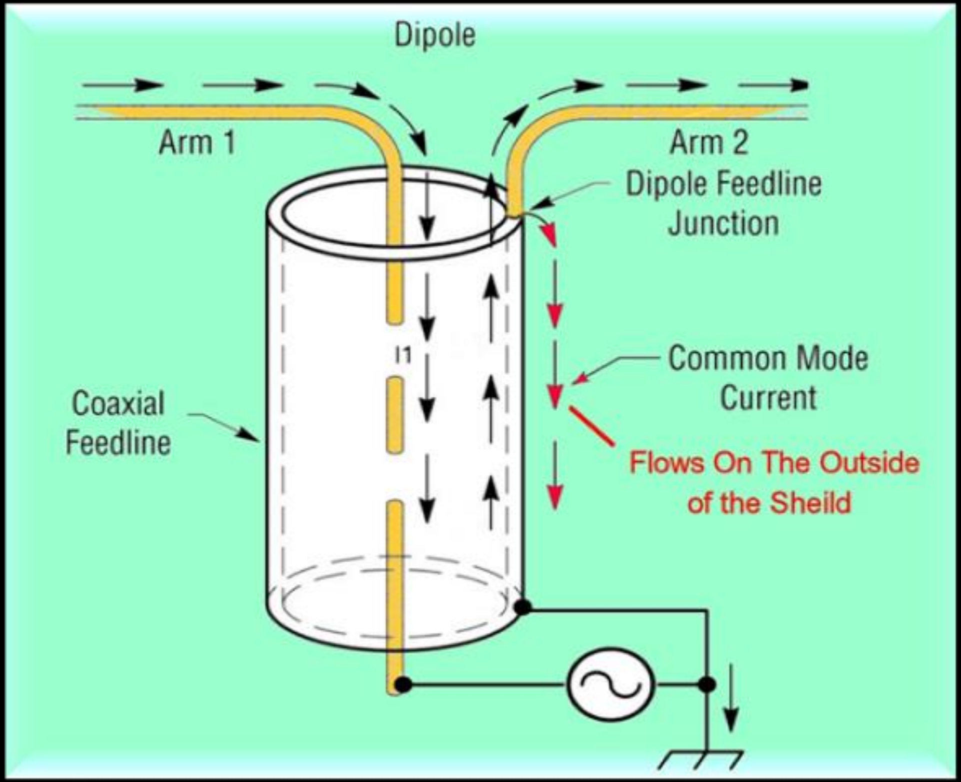
protects the transmission line from external EFI influence

reduces EFI emissions

# coaxial cable current flow

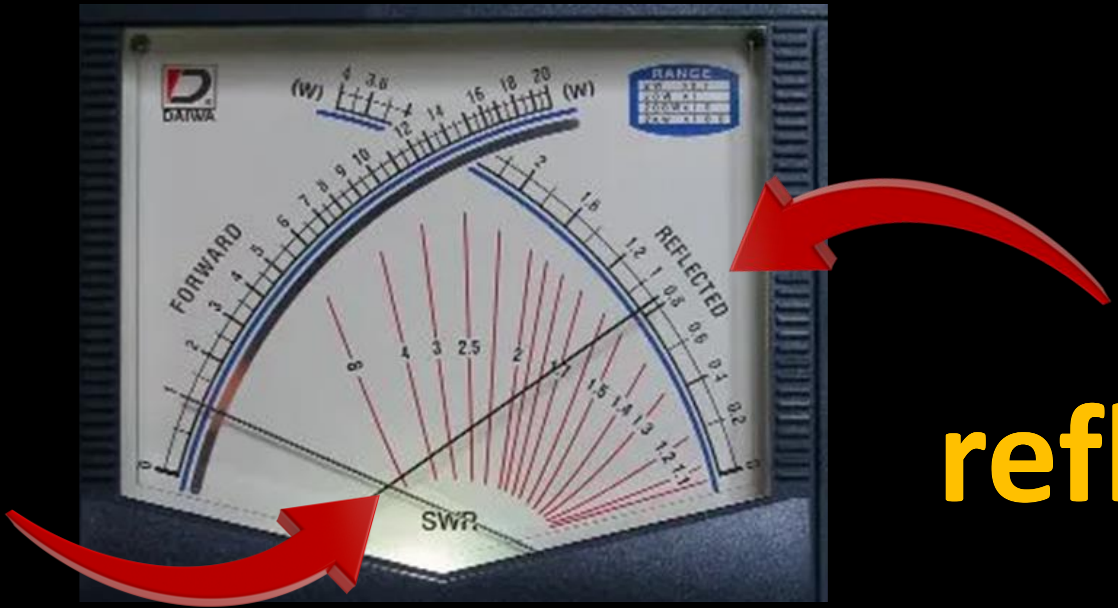



differential current flows on the center conductor and on the inside of the shield



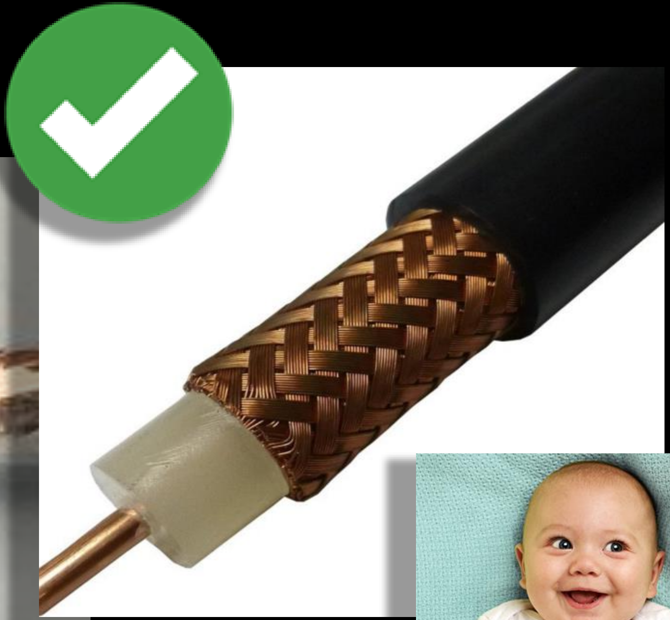

**common mode current flows on the outside of the shield**

# coaxial shield also carries our nemesis…




**reflected power**

# 90 - 95%+ shield coverage
# is the standard



# bare copper shield

- ✓ excellent current conductor
- ✓ excellent ground conductor
- ✗ susceptible to oxidation & corrosion

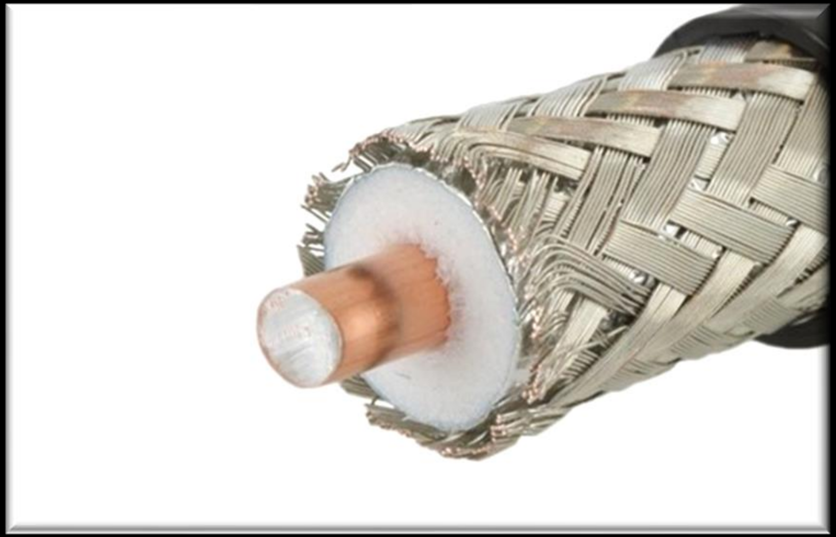
# tinned copper shield

- ✅ same functionality as bare copper
- ✅ protection against oxidation & corrosion

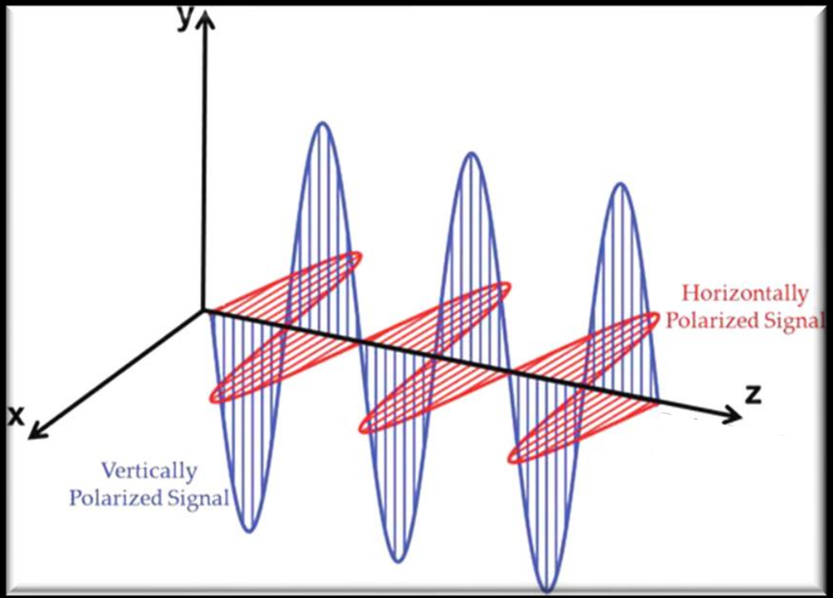
# dielectric insulator

dielectric insulates
the center conductor

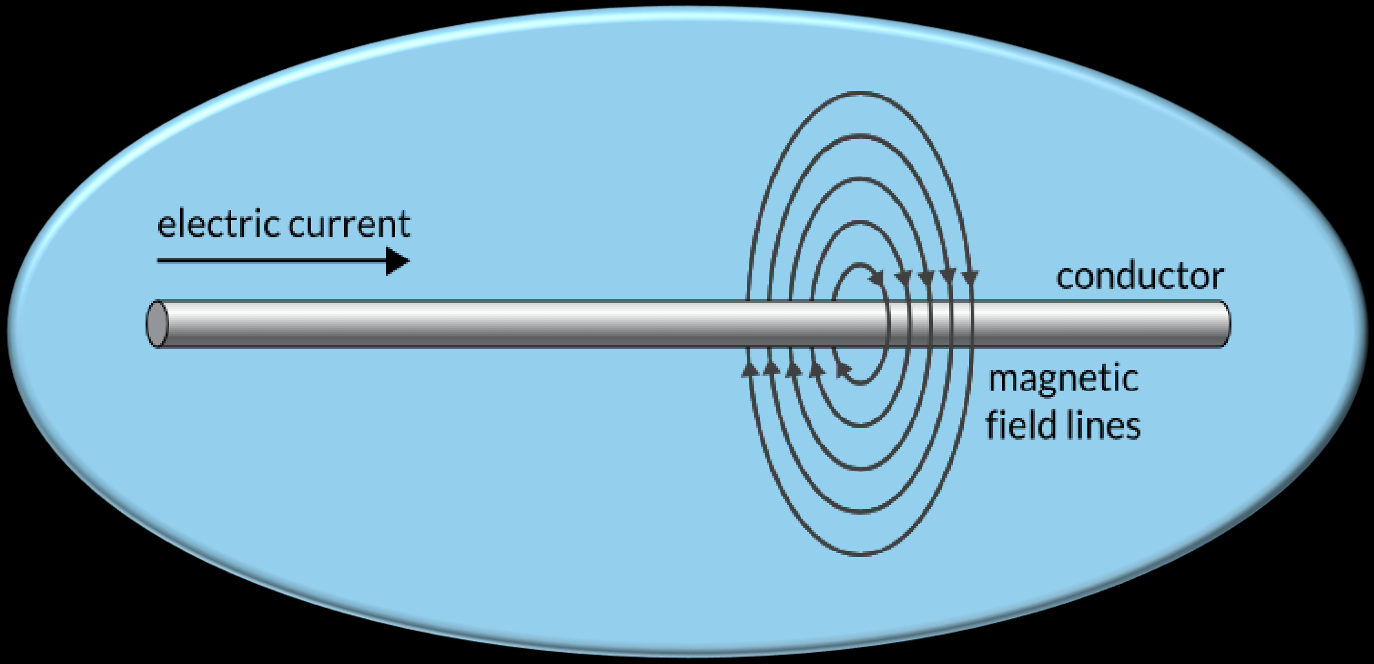
dielectric centers the center
conductor within the cable
(shield) to prevent loss



*dielectric* reacts to the signal traveling on the center conductor, becoming polarized creating a magnetic field



# the magnetic field insulates the center conductor and the outer shield



the type of dielectric used is a factor in calculating the impedance of a cable

the diameter of the center conductor, the "constant" of the dielectric, and the distance to the outer layer (shield) also defines the **characteristic impedance ($Z_0$)**

# dielectric constant (ε)

## (permittivity)

the ability of a

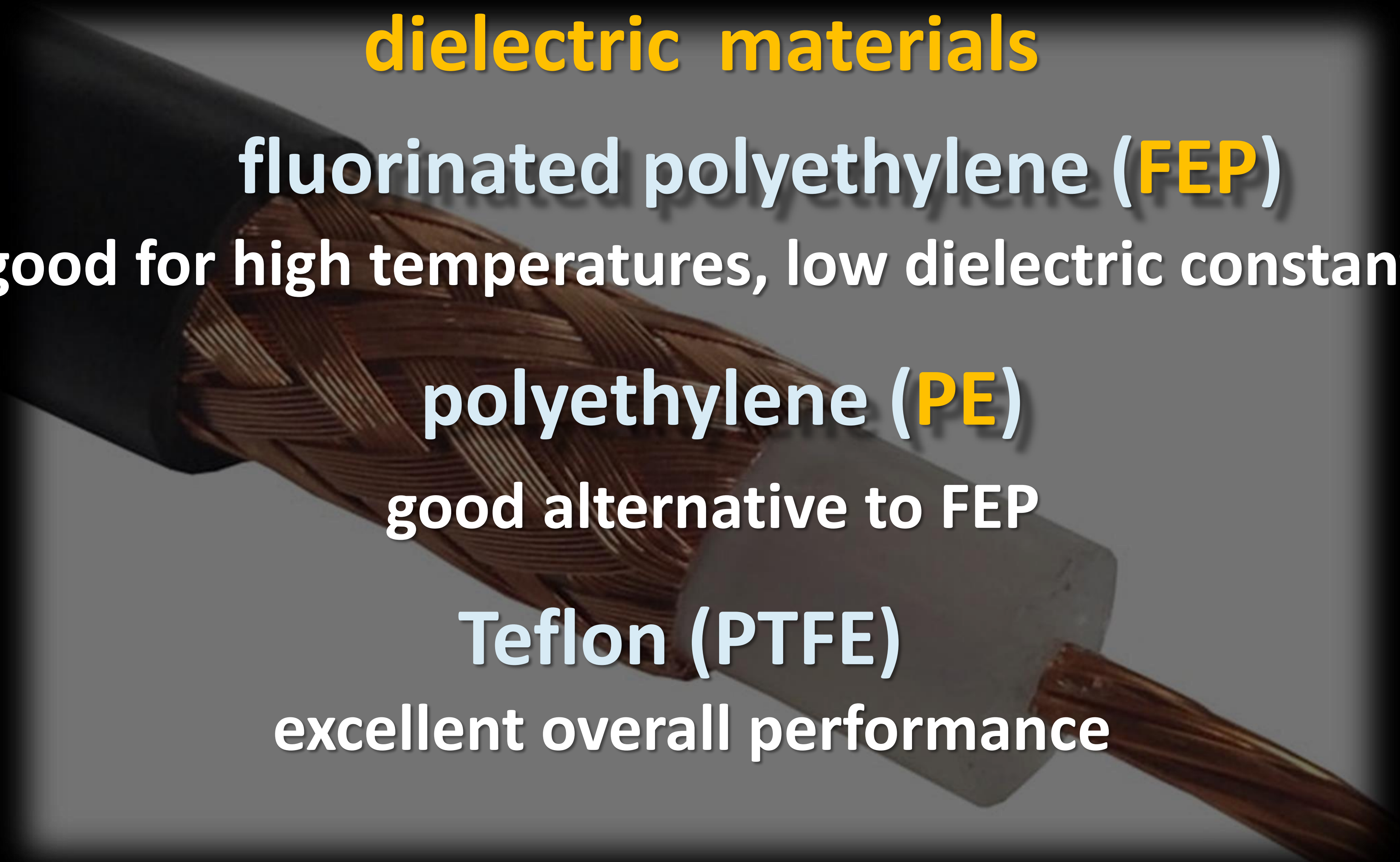
an elect

the lower the con

insulati

**Electrical Specifications**

| Performance Property | Units | US | (metric) |
|---|---|---|---|
| Velocity of Propagation | % | 84 | |
| Dielectric Constant | NA | 1.38 | |
| Time Delay | nS/ft (nS/m) | 1.20 | (3.92) |
| Impedance | ohms | 50 | |
| Capacitance | pF/ft (pF/m) | 23.9 | (78.4) |
| Inductance | uH/ft (uH/m) | 0.060 | (0.20) |
| Shielding Effectiveness | dB | >90 | |
| DC Resistance | | | |
| Inner Conductor | ohms/1000ft (/km) | 1.39 | (4.6) |
| Outer Conductor | ohms/1000ft (/km) | 1.65 | (5.4) |
| Voltage Withstand | Volts DC | 2500 | |
| Jacket Spark | Volts RMS | 8000 | |
| Peak Power | kW | 16 | |



# dielectric materials

## fluorinated polyethylene (FEP)

good for high temperatures, low dielectric constant

## polyethylene (PE)

good alternative to FEP

## Teflon (PTFE)

excellent overall performance

# solid dielectric

durable, mechanical and electrical protection for the conductor

flexible, excellent crush and impact resistance

# foam dielectric

extruded polymer with bubbles
of air or nitrogen throughout

lower attenuation and capacitance than solid

high-performance coaxial cables

foamed insulation is not as physically
robust as solid insulation

# common causes of dielectric failure

moisture incursion

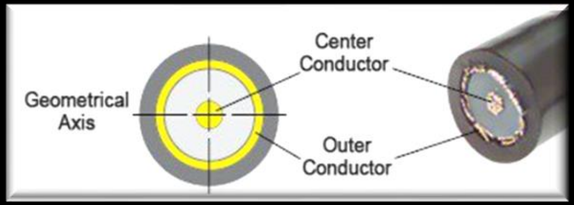
crushed or punctured

heat damage

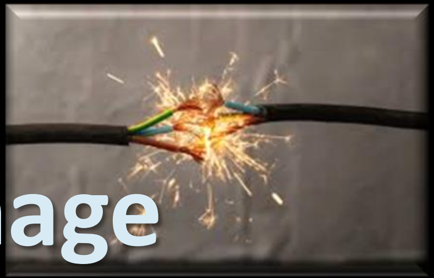
excessive current damage

# jacket materials

maintains the
correct geometry




protection from moisture



protects against damage


NEC and building code requirements

*polyurethane* (**PUR**)

**resists abrasion, chemicals, UV rays, radiation and fungus, flexible**

*polyethylene* (**PE**)

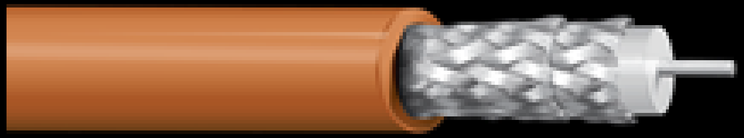
**abrasion resistant, typically rigid**

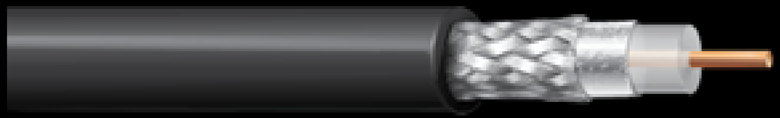
*poly vinyl chloride* (**PVC**)

**flexible, rugged, flame/oil-resistant, matte or glossy finish**

# visual clues

# jacket color / finish may indicate a specific application





gloss surface

resists abrasion, moisture, UV, weathering high & low temps, rigid, direct burial, limited bend radius

dull surface

flexible, small bend radius, less moisture and abrasion resistant

# velocity factor

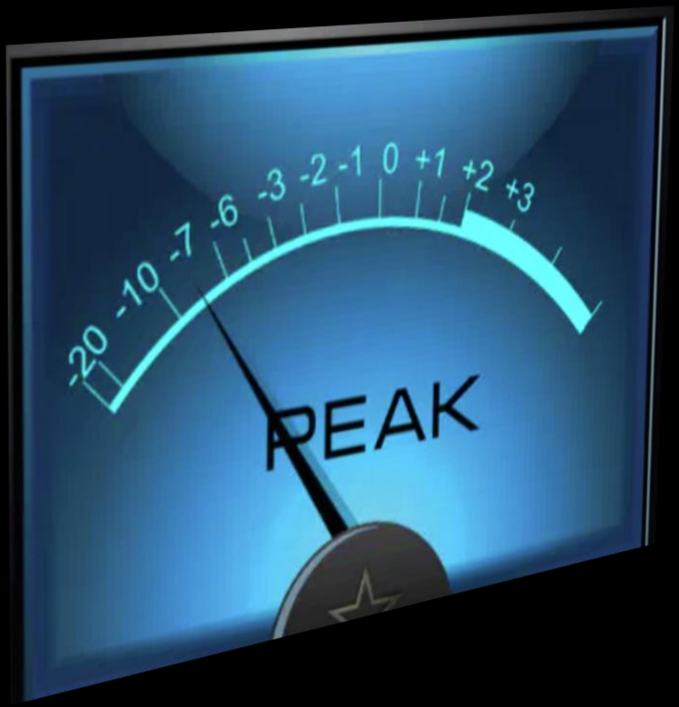
the velocity of propagation (Vp) - the speed at which the RF signal travels within the cable

| Electrical Specifications | | | |
|---|---|---|---|
| Performance Property | Units | US | (metric) |
| Velocity of Propagation | % | 84 | |
| Dielectric Constant | NA | 1.38 | |
| Time Delay | nS/ft (nS/m) | 1.20 | (3.92) |
| Impedance | ohms | 50 | |
| Capacitance | pF/ft (pF/m) | 23.9 | (78.4) |
| Inductance | uH/ft (uH/m) | 0.060 | (0.20) |
| Shielding Effectiveness | dB | >90 | |
| DC Resistance | | | |
| Inner Conductor | ohms/1000ft (/km) | 1.39 | (4.6) |
| Outer Conductor | ohms/1000ft (/km) | 1.65 | (5.4) |
| Voltage Withstand | Volts DC | 2500 | |
| Jacket Spark | Volts RMS | 8000 | |
| Peak Power | kW | 16 | |

# attenuation is loss

"loss" is a decrease in the power or
quality of a signal  usually
measured in decibels (dB)

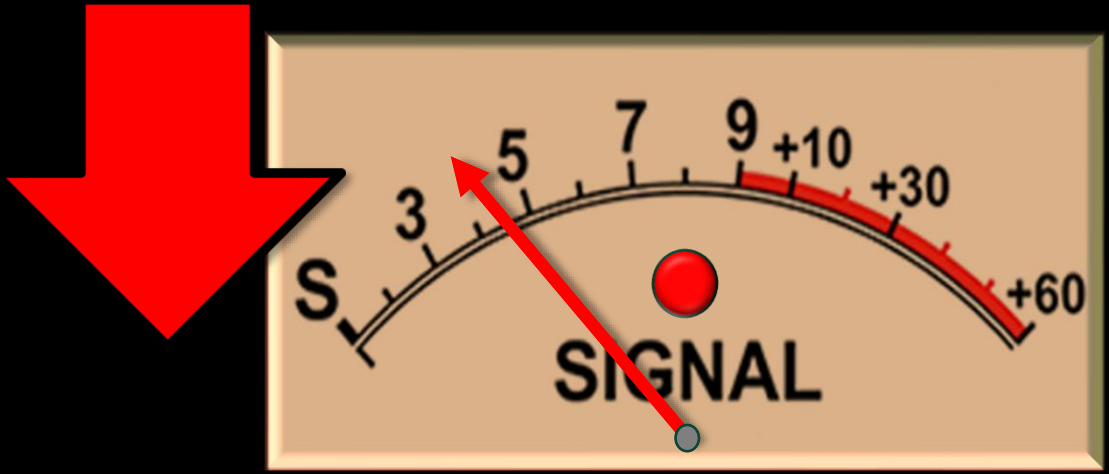
# insertion loss




RF signals that pass through coaxial cable, connectors, and other components experience **insertion loss** (attenuation)

1dB of attenuation represents about 20% loss of signal power

where as 3dB of loss represents a loss of about 50%



# 3 dB rule

3 dB loss means about half the power *

a system with 40 watts of input power and
a 6 dB insertion loss will only have 10 watts
of output power

## each “S Unit” represents a change in strength of about 4 to 6 dB *

# coaxial cable losses in db

(per 100 ft)

| | VHF | UHF |
|---|---|---|
| RG-58 | 6.2 | 10.6 |
| RG-8X | 4.7 | 8.0 |
| RG-213 | 2.7 | 5.2 |
| 9913 | 1.5 | 2.8 |
| LMR-400 | 1.5 | 2.7 |

# VHF attenuation comparison

| Attenuation (dB per 100 feet) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **LMR1200** | **LMR900** | **LMR600** | **1/2" FSJ4-50B** | **RFP400 LMR400** | **Belden 9913F7** | **9914** | **RG214 RG213** | **RFP240 LMR240** | **Belden RG8X** | **LMR200** | **LMR195** | **RG58/U** |
| **Frequency/ Size** | **1.200"** | **0.870"** | **0.590"** | 0.520" | **0.405"** | 0.405" | 0.400" | 0.405" | **0.240"** | 0.242" | 0.195" | 0.195" | 0.195" |
| 30 MHz | **0.209** | **0.288** | **0.421** | 0.561 | **0.7** | 0.8 | 0.8 | 1.2 | **1.3** | 2.0 | 1.8 | 1.8 | 2.5 |
| 50 MHz | **0.272** | **0.374** | **0.547** | 0.730 | **0.9** | 1.1 | 1.1 | 1.6 | **1.7** | 2.5 | 2.3 | 2.3 | 3.1 |
| 150 MHz | | | | | **1.5** | 1.7 | 1.7 | 2.8 | **3.0** | 4.7 | 3.9 | 4.0 | 6.2 |
| 220 MHz | **0.589** | **0.803** | **1.18** | 1.58 | **1.8** | 2.1 | 2.1 | 3.5 | **3.7** | 6.0 | 4.8 | 4.8 | 7.4 |
| 450 MHz | **0.864** | **1.17** | **1.72** | 2.32 | **2.7** | 3.1 | 3.1 | 5.2 | **5.3** | 8.6 | 6.9 | 7.0 | 10.6 |
| 900 MHz | **1.27** | **1.70** | **2.50** | 3.41 | **3.9** | 4.4 | 4.5 | 8.0 | **7.6** | 12.8 | 9.9 | 9.9 | 16.5 |
| 1,500 MHz | **1.69** | **2.24** | **3.31** | 4.57 | **5.1** | 6.0 | | | **9.9** | | 12.7 | 12.9 | |

# what is insertion loss?

"insertion loss" is the attenuation (loss) of signal strength resulting from the insertion of a component in the transmission line

**insertion loss is measured in decibels (dB)**

# insertion loss - attenuation

a quality made and properly installed connector, PL259 or "N" type, will have a very minor insertion loss

| TOTAL LOSS PER CONNECTOR (dB) | | |
|---|---|---|
| FREQ (MHz) | N type | PL 259 |
| 1.8 | 0 | 0 |
| 30 | 0 | 0 |
| 100 | 0 | 0 |
| 150 | 0 | 0.01 |
| 200 | 0 | 0.015 |
| 450 | 0 | 0.09 |
| 600 | 0 | 0.13 |
| 900 | 0 | 0.33 |
| 1000 | 0.025 | 0.4 |
| 1300 | 0.5 | 0.43 |
| 1600 | 0.025 | 0.25 |

**poorly designed, manufactured or installed connectors are the main culprit in signal degradation**

MIL SPEC “RG” type 50Ω cable is widely used today, however cable capable of higher performance is popular among hams and communications systems designers

TIMES MICROWAVE SYSTEMS
An Amphenol Company

in the 1970s, the
*Times Microwave Company*
developed the “LMR” type cable
widely used today by hams, and
the telecommunications industry

# LMR

# *Land Mobile Radio*

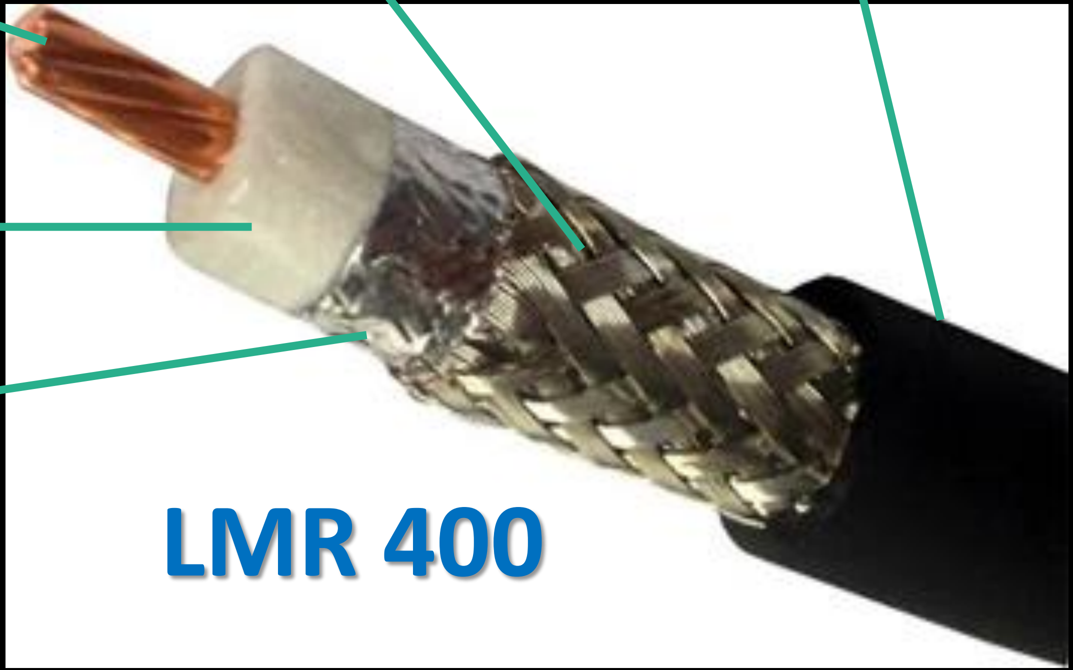
tinned copper shield - resists corrosion

moisture/UV resistant outer jacket

stranded center conductor greater flexibility

high constant dielectric

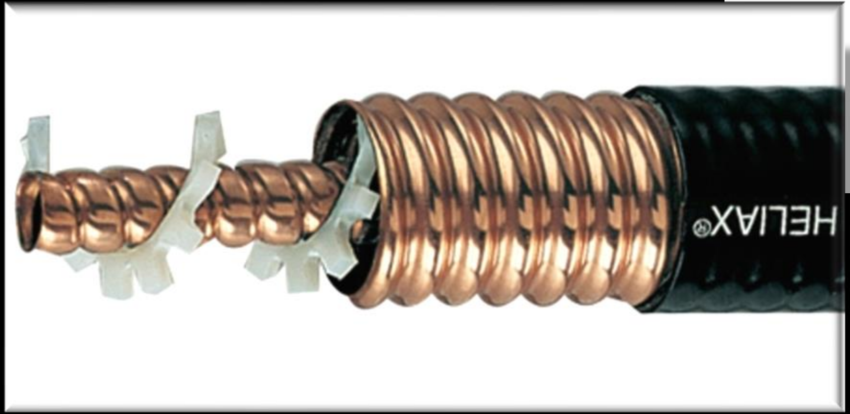
foil shield - greater protection from RF/EMI



# LMR type coaxial cables

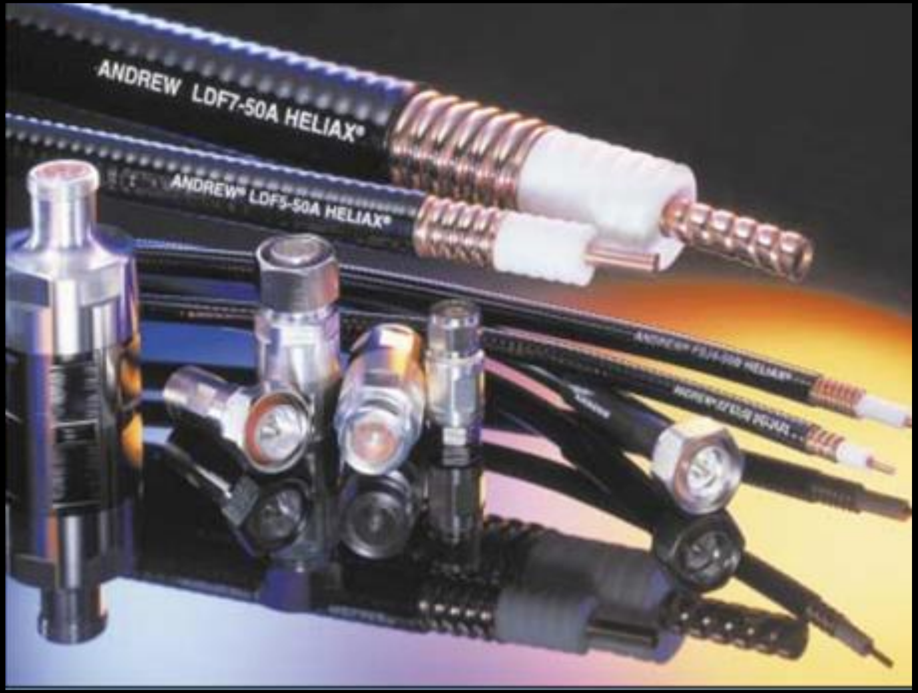
as the RF communications spectrum moved to higher frequencies, the need for high performance cable capable of handling frequencies into the gigahertz range was needed

**the solution was “hardline” also known Heliax or F4 type cable created by the *Andrew Corporation***

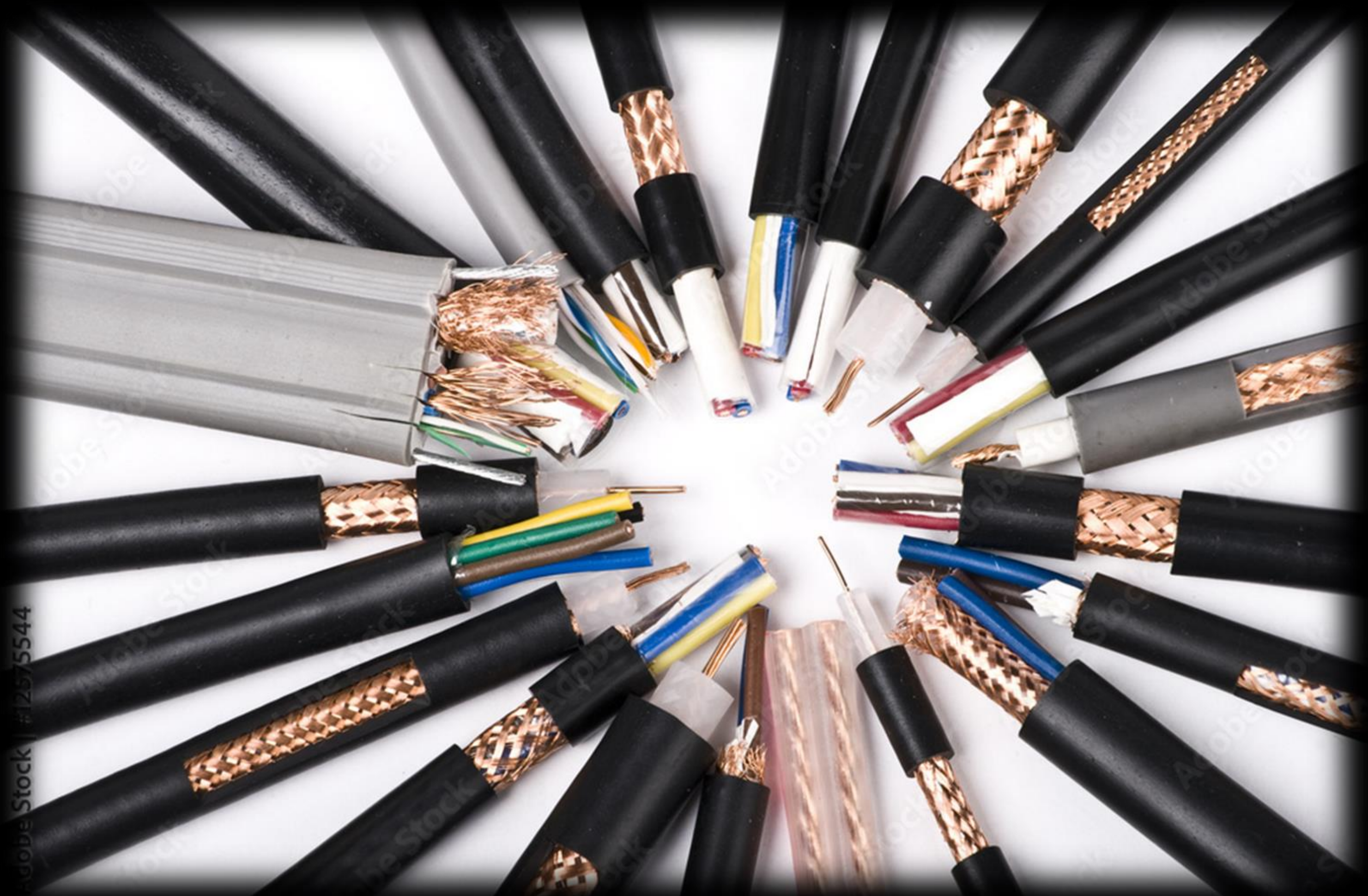


low-loss and high-power capability along with high strength make **hardline** well suited for commercial applications

high cost of cable and connectors, lack of flexibility and greater weight make hardline impractical for most in-home amateur radio stations



# choosing the right coaxial cable



# which cable do I need?

- frequency range will you be operating in?
- antenna design will you be using?
- how much power are you running?
- environment the cable will be in?
- how long is your cable run?
- are you working with tight spaces?
- what is your budget?

# coaxial cable selection

indoor installation

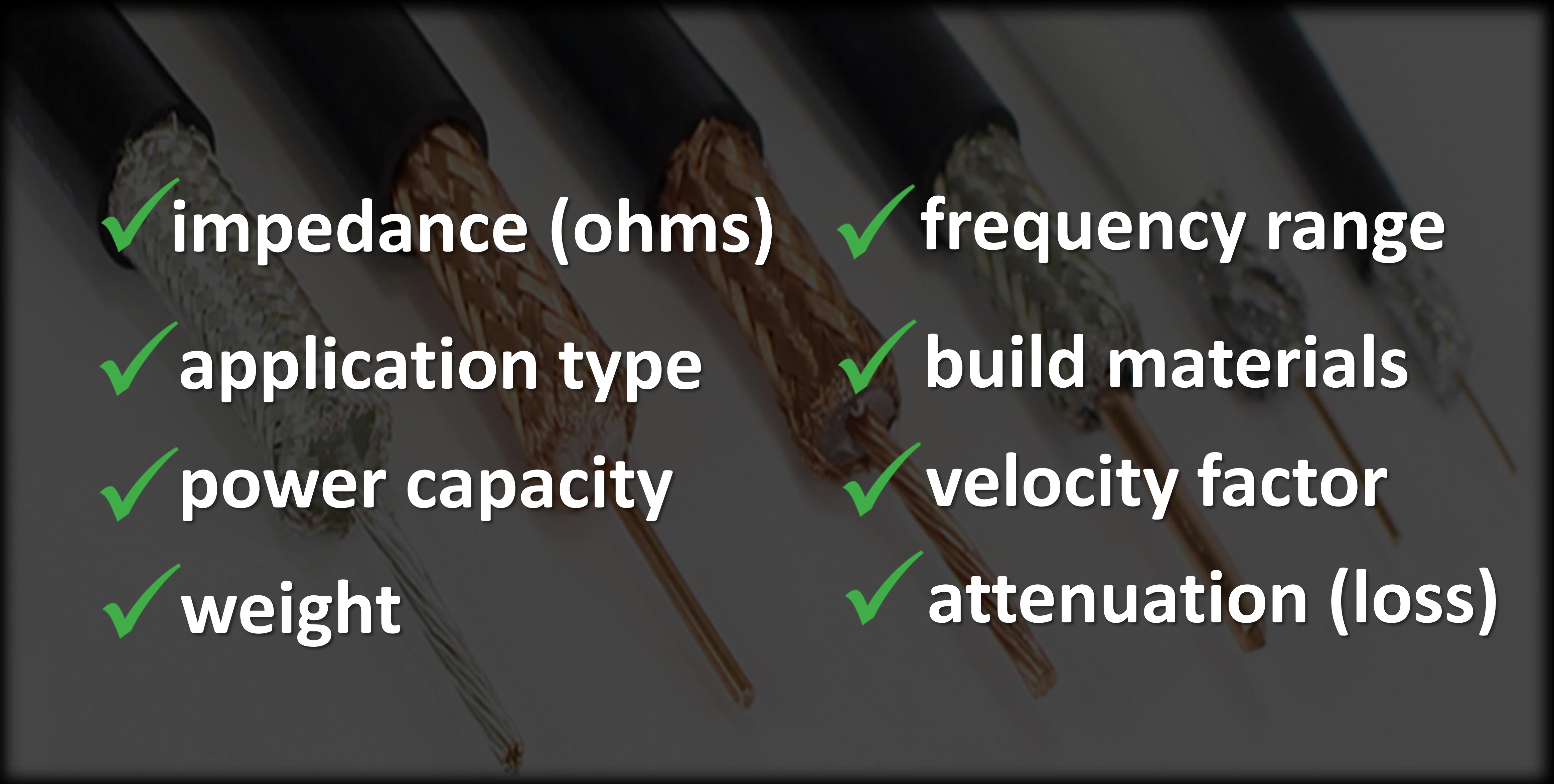
outdoor installation

bend radius

direct burial

hazard mitigation

building codes

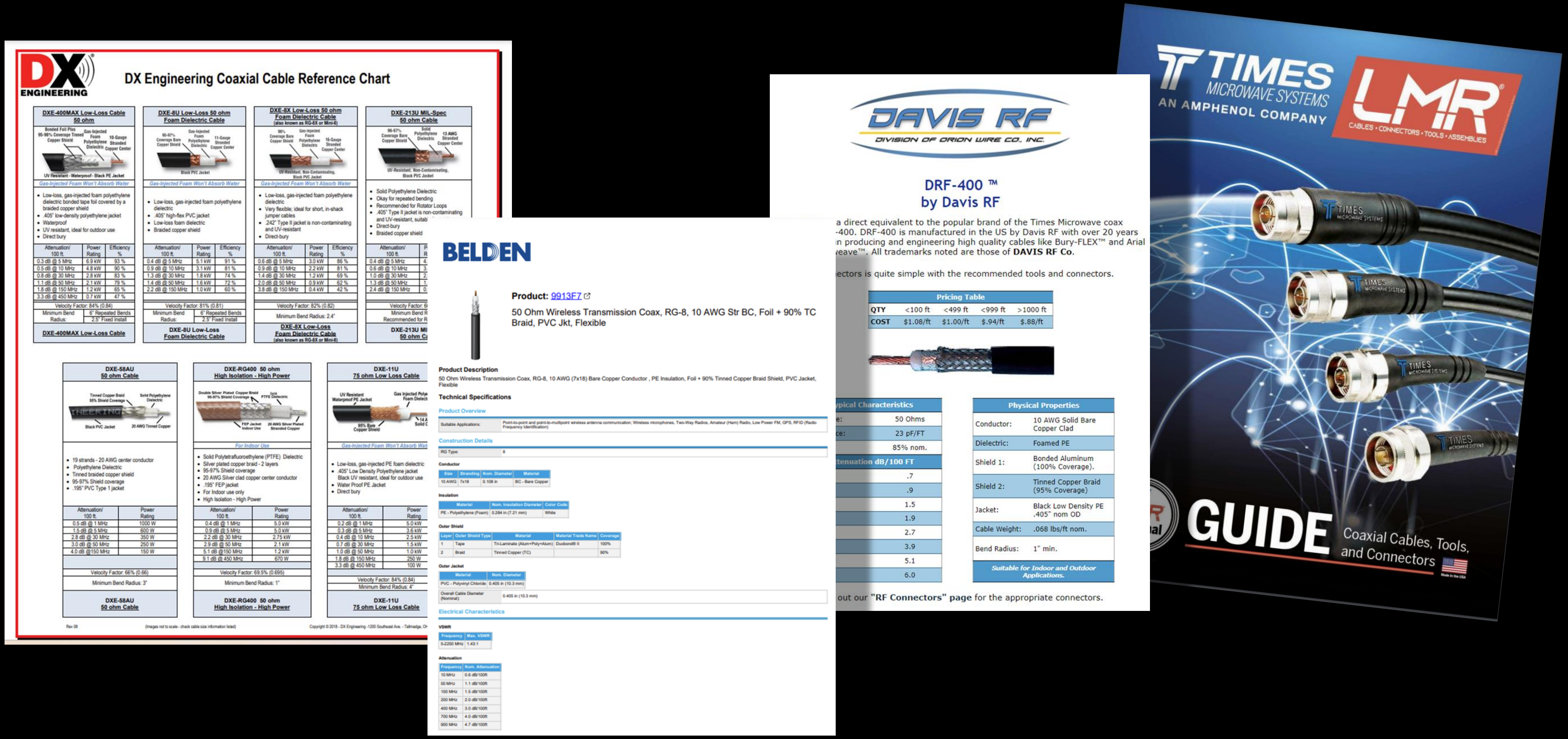

✓impedance (ohms)
✓ frequency range
✓ application type
✓ build materials
✓ power capacity
✓ velocity factor
✓ weight
✓ attenuation (loss)

# can I use my TV signal 75 Ω coax on my system?

designed for cable and TV antenna receive only

not rated for high transmitter voltages and currents

# manufacturers data sheets



next session…

…connectors