

**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

I should have called it
Oliver Cable

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 lightning





WNBC radio feedline
ca 1930

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

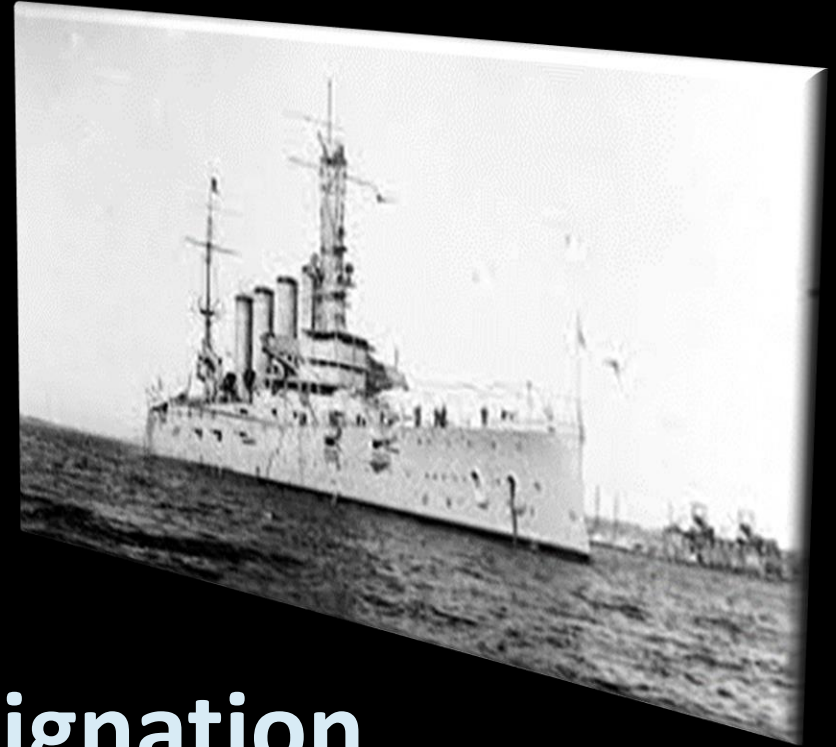
1929

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)



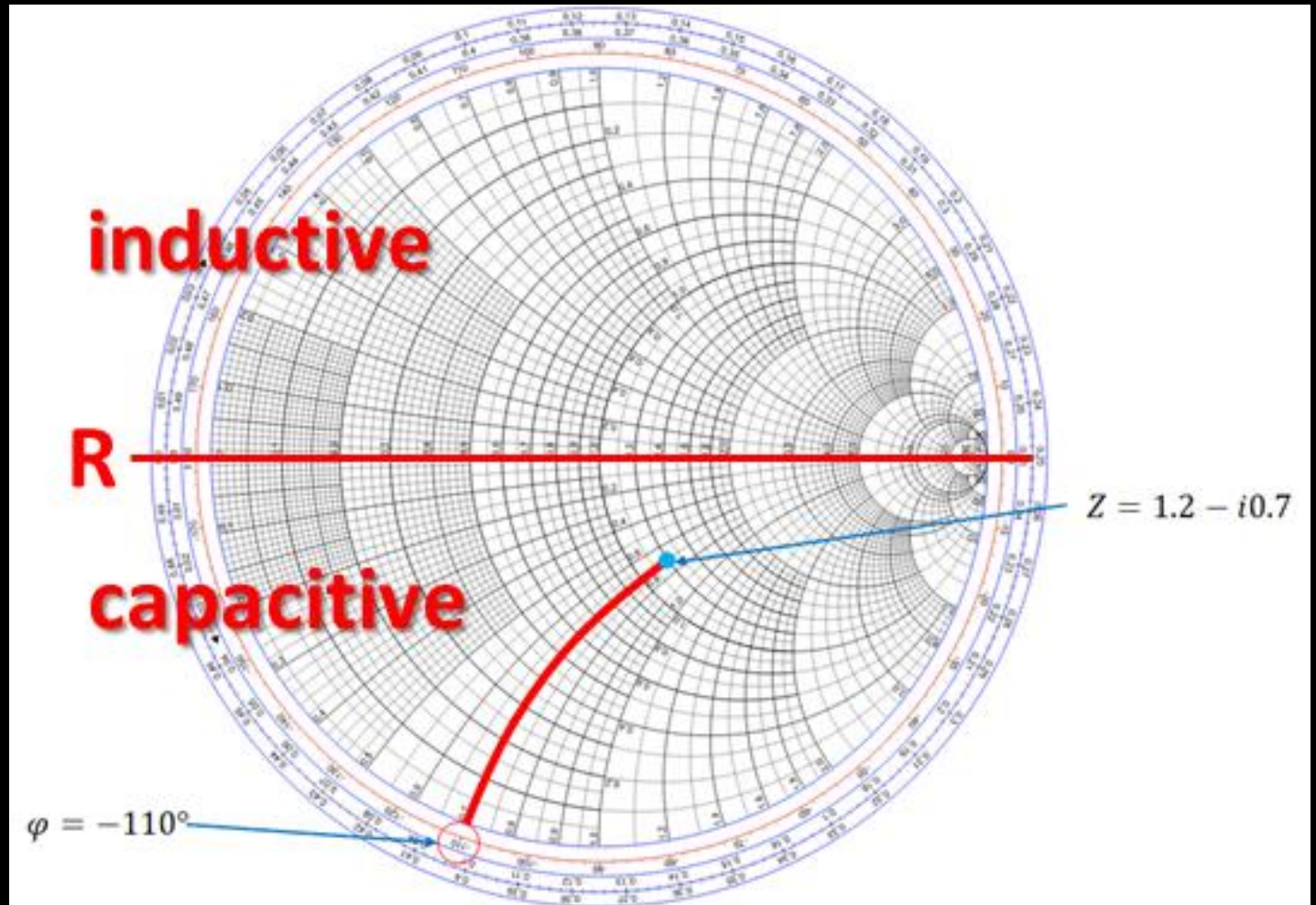
$$Z=R + jX$$

“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

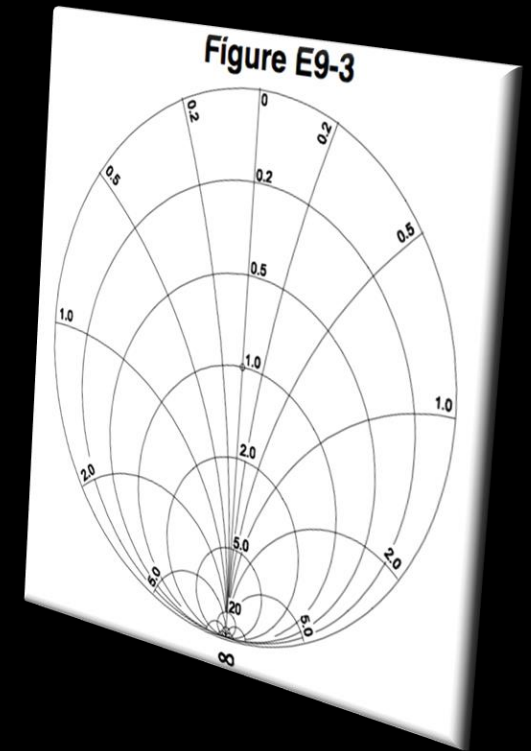
X_C



POP QUIZ!

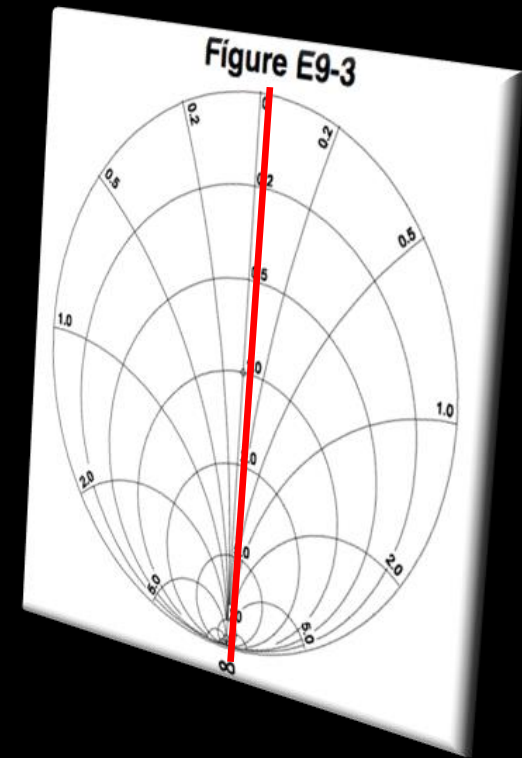
what is a Smith Chart most often used for in amateur radio?

finding **impedance** (Z & Z_0)
and **VSWR** values in
transmission lines



what does the only straight line
on Smith Chart represent?

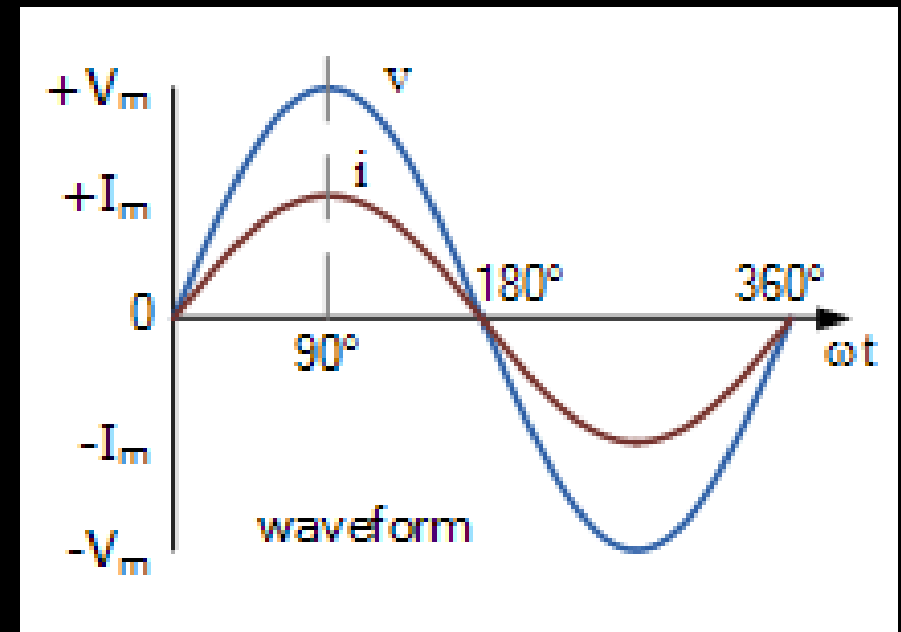
the resistance (**R**) axis



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)

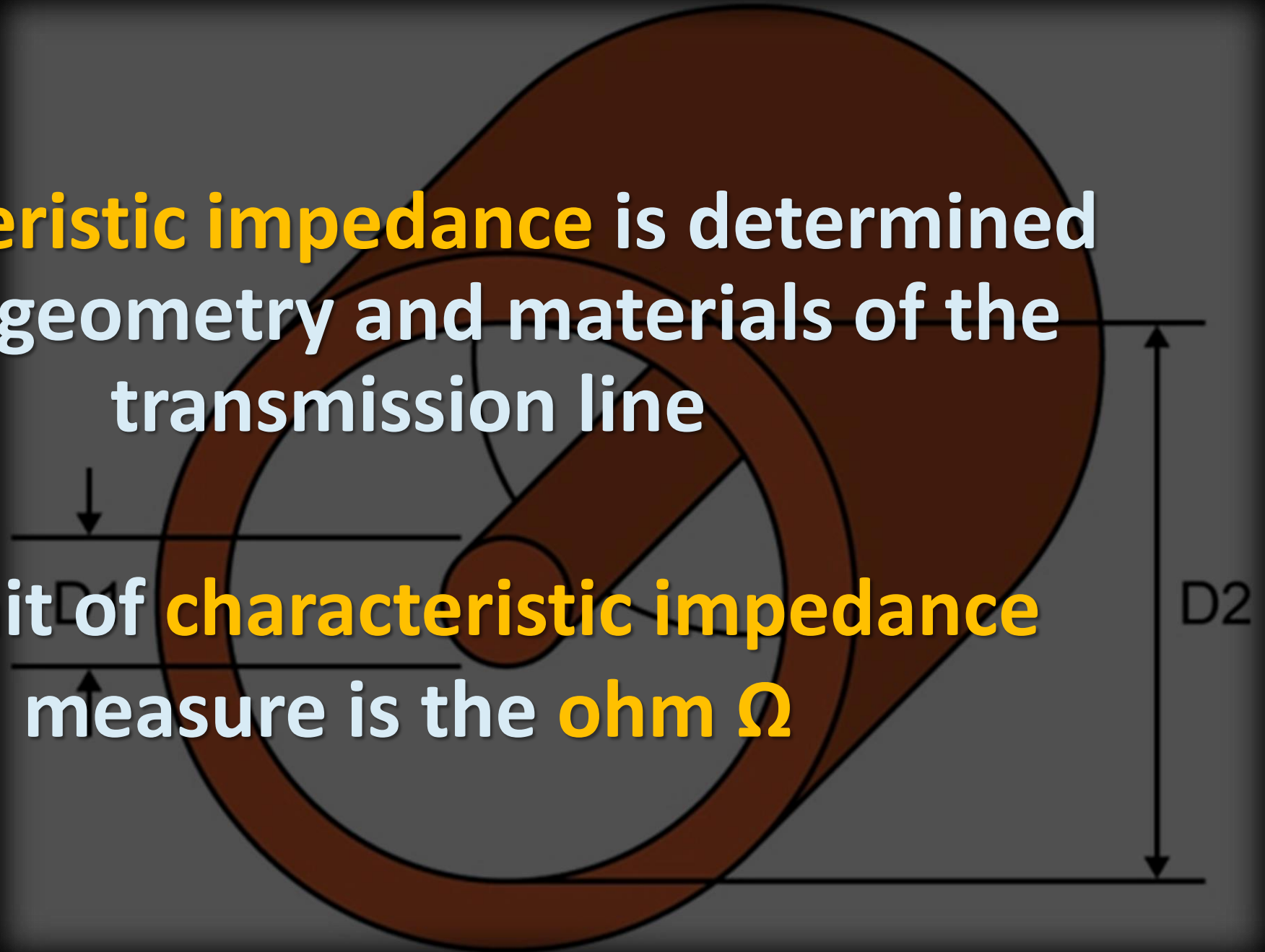
is not the same as
a circuit impedance (**Z**)

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**

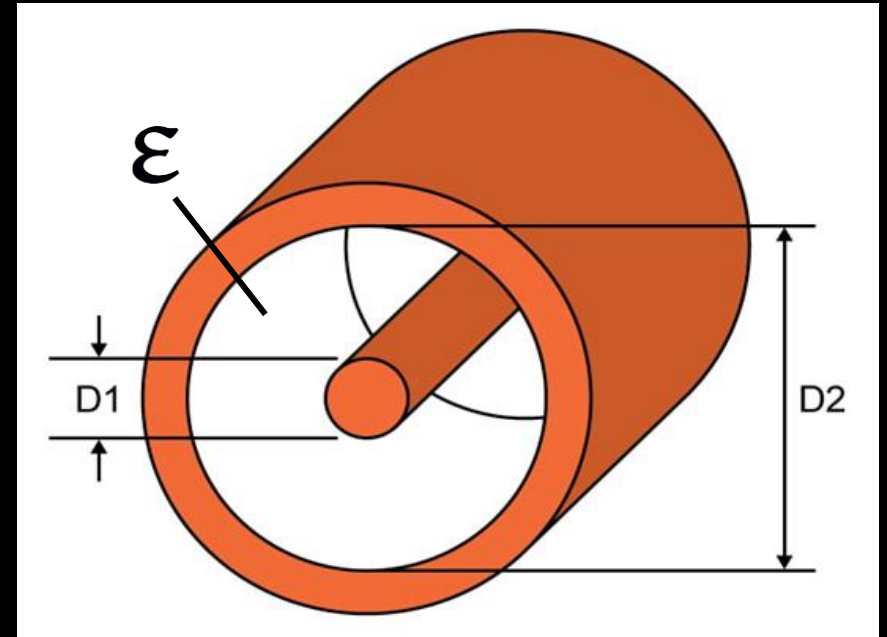


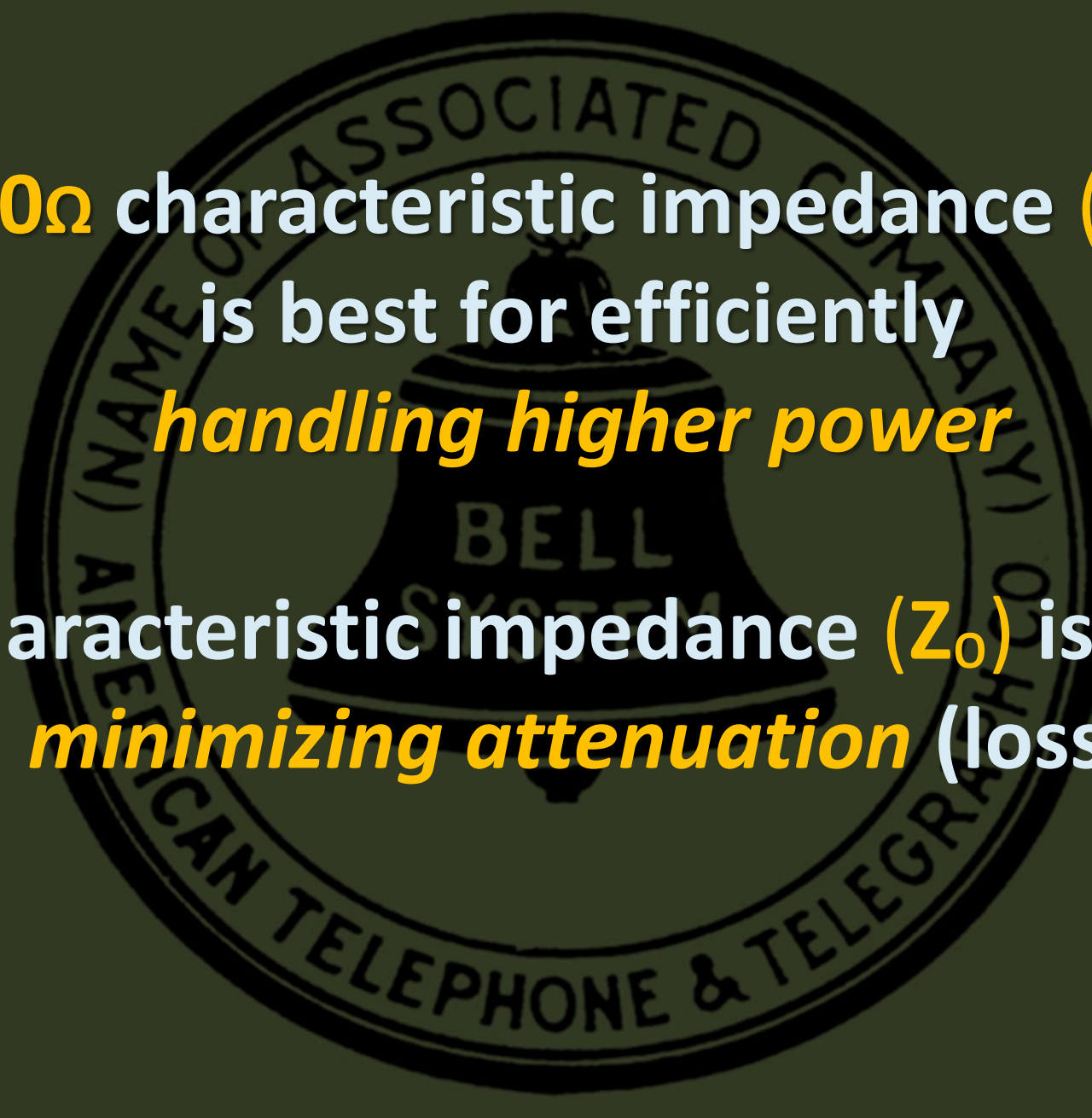
characteristic impedance factors

D1 conductor diameter

D2 dielectric diameter

ϵ dielectric constant
(permittivity)



The background features a large, semi-transparent watermark of the Bell System logo. It consists of a circular seal with a bell in the center. The text "BELL SYSTEM" is written across the bell. The outer ring of the seal contains the text "AMERICAN TELEPHONE & TELEGRAPH CO." and "ASSOCIATED COMPANY".

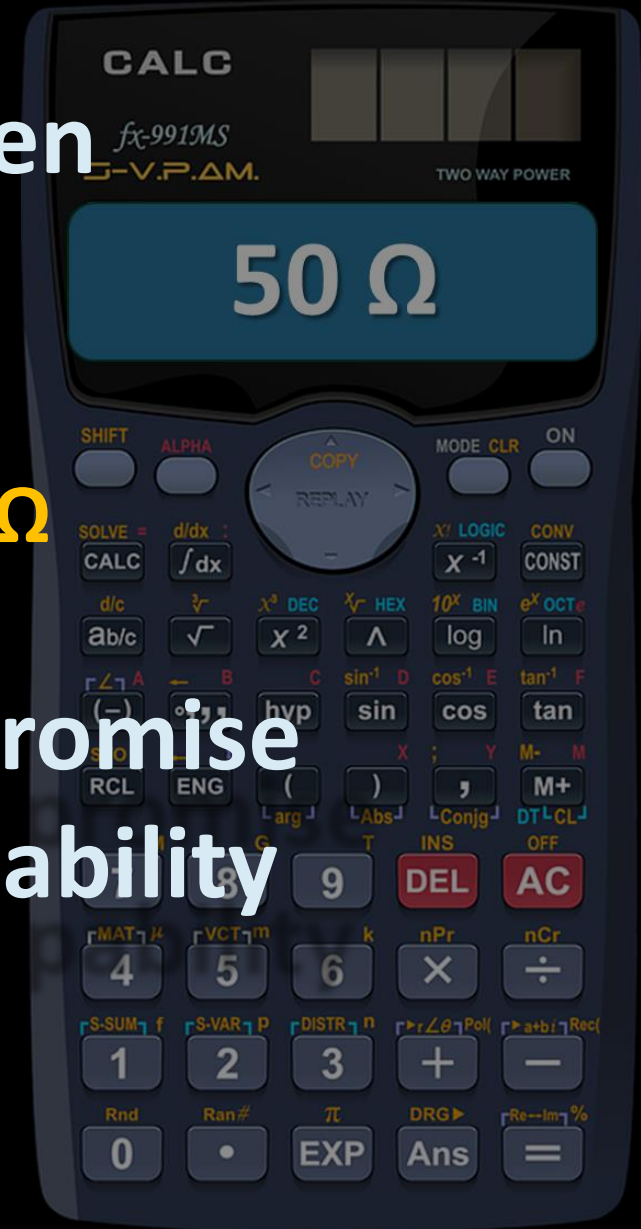
30 Ω characteristic impedance (Z_0)
is best for efficiently
handling higher power


77 Ω 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 background features a black electronic component with several wires extending from it. A large coil of brown wire is positioned in the foreground. To the right, there is a large, 3D blue question mark and a small white 3D figure standing next to it, appearing to be in a state of confusion or questioning.

the **50 Ω** characteristic impedance (Z_0) standard for amateur radio coax is convenient, as the isotropic impedance of a $\frac{1}{2}$ wave center-fed dipole in “free space” is... **73 ohms***

**lossless conductor in free space*



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

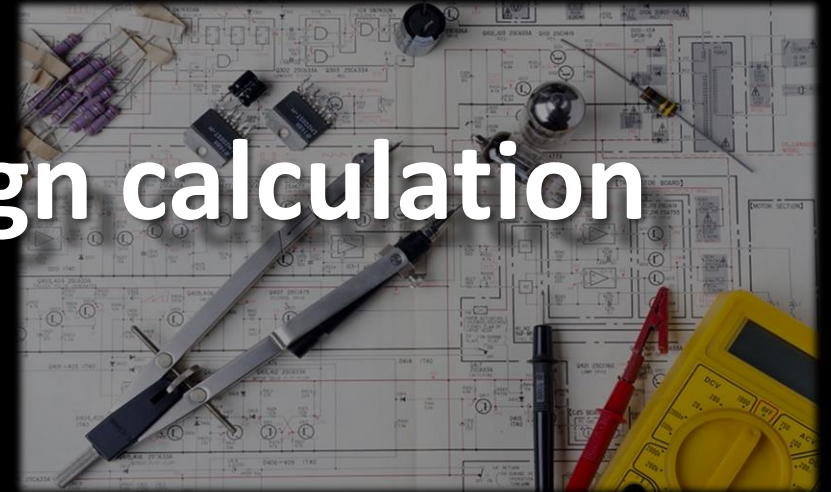
yes, up to the point where the
signal reaches the design
frequency for the cable, the point
where (**R**) becomes (**Z₀**)



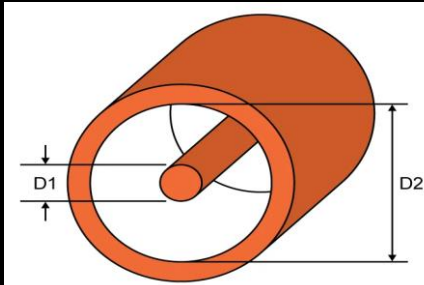
typically, we don't measure
characteristic impedance (Z_0)

we calculate total system impedance (Z)

Z_0 is an engineering/design calculation



determining characteristic impedance



$$Z_0 = \frac{138 \log_{10} \left(\frac{D_d}{D_c} \right)}{\sqrt{\epsilon_R}} ; f_{cutoff} = \frac{11.8}{\sqrt{\epsilon_R} \pi \left(\frac{D_d + D_c}{2} \right)}$$
$$C_{ft} = \frac{7.354 \epsilon_R}{\log_{10} \left(\frac{D_d}{D_c} \right)} ; I_{ft} = 140.4 \log_{10} \left(\frac{D_d}{D_c} \right)$$

or...

Inputs

Inner Conductor Diameter

Inner Surface Shield Diameter

Substrate Dielectric

Calculate

or...



commercial
impedance analyzer

or you can...



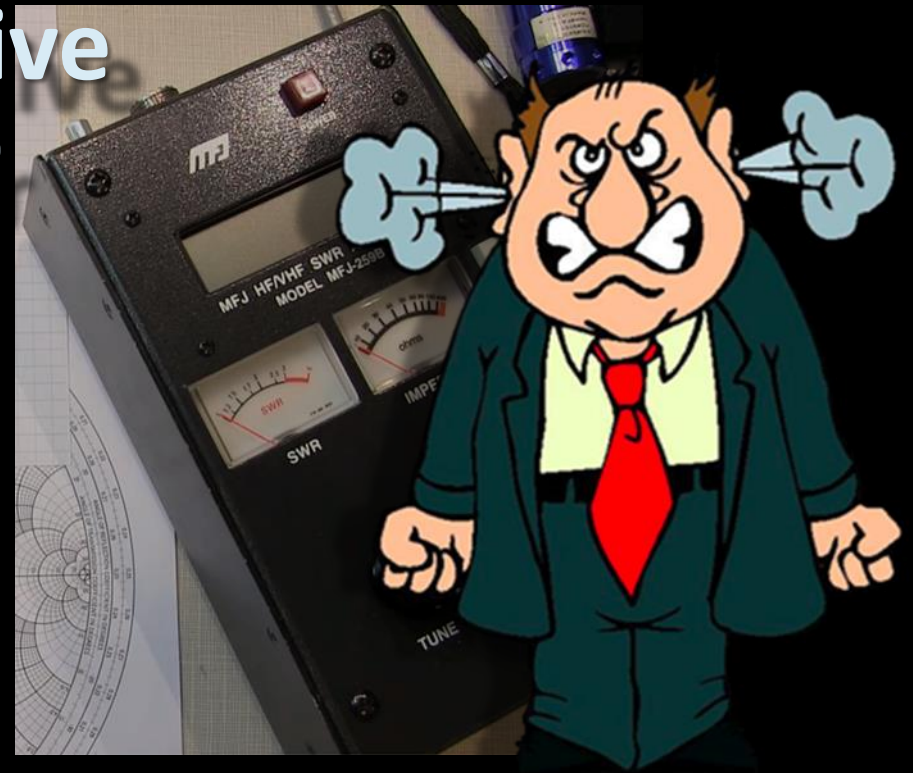
...use an antenna analyzer



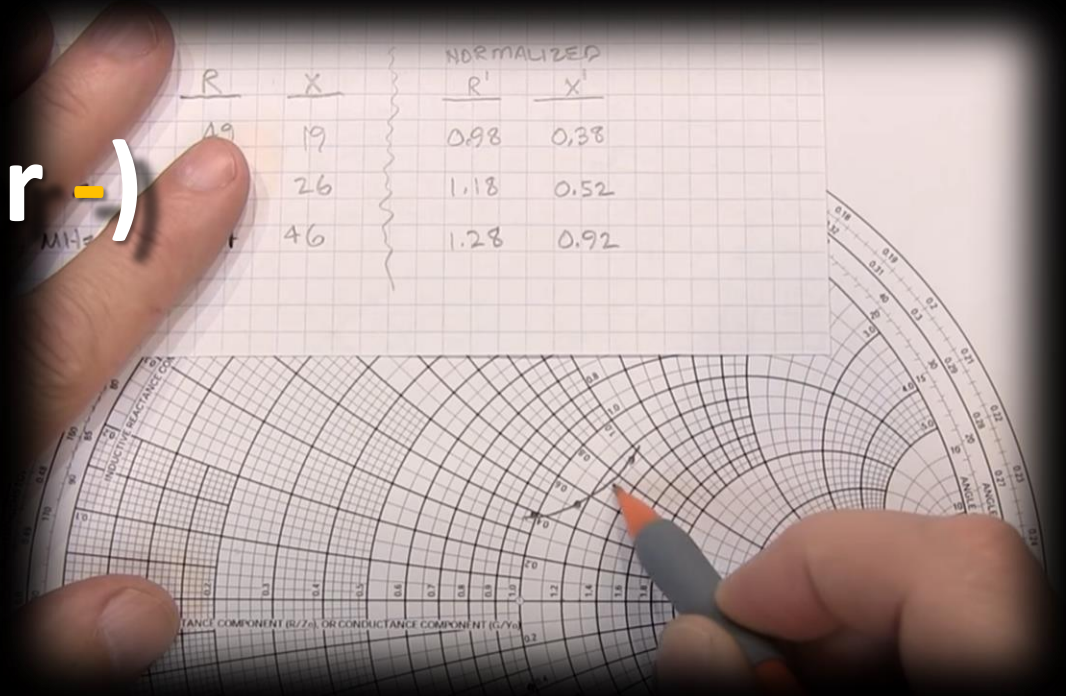
however...



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=_DIw_XheKI0

another way is to
locate the
manufacturer'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



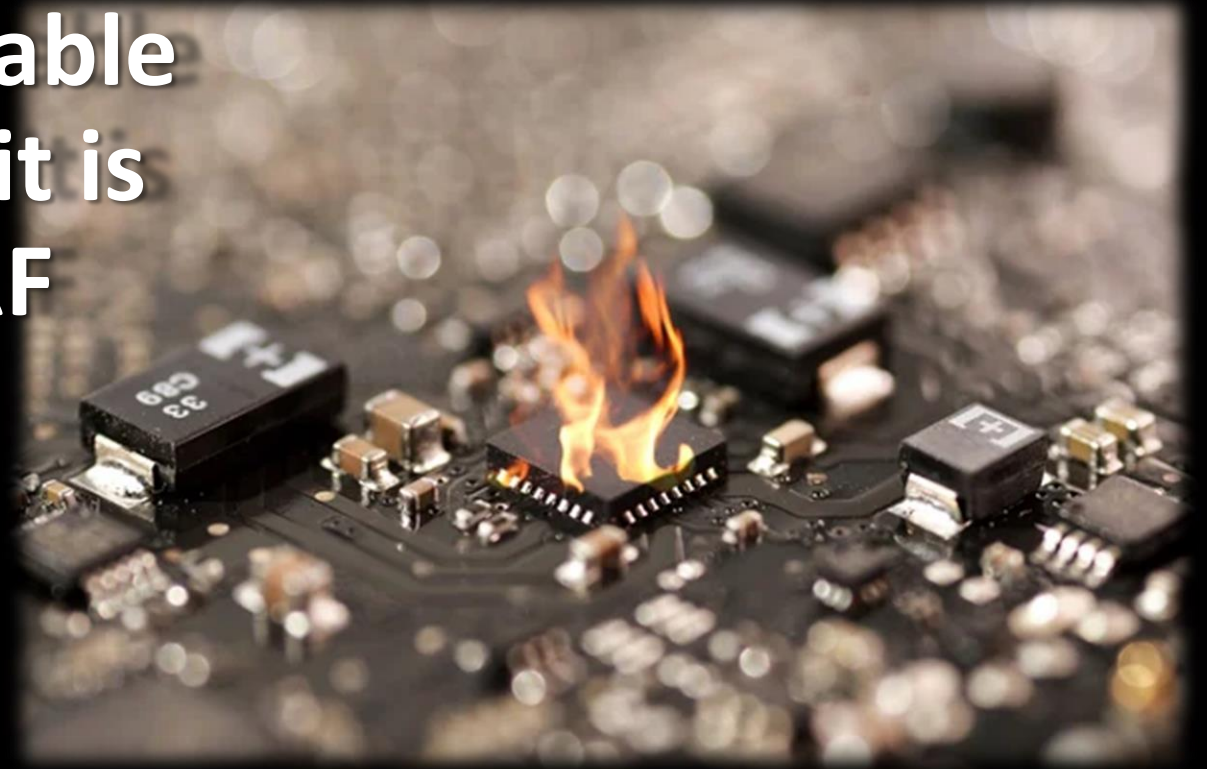
don't assume an unmarked cable
is rated at **50Ω** based on
its appearance alone



coaxial cable other than 50Ω
paired with a **50Ω transceiver**
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**



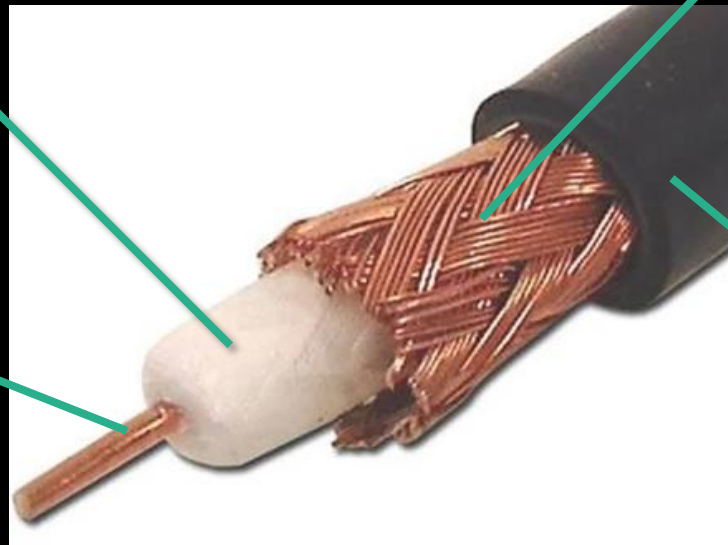
**there are 200 or more
design variations of
modern coaxial cable**



typical modern RF coaxial cable

polyethylene
(PE) insulator
(dielectric)

solid copper
center
conductor



braided copper
shield (also a
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



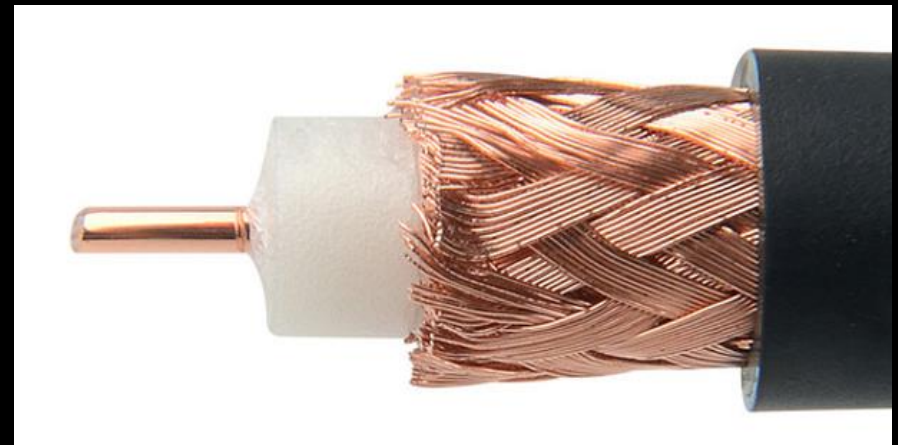
lacks flexibility



expensive



heaviest



center conductor stranded copper



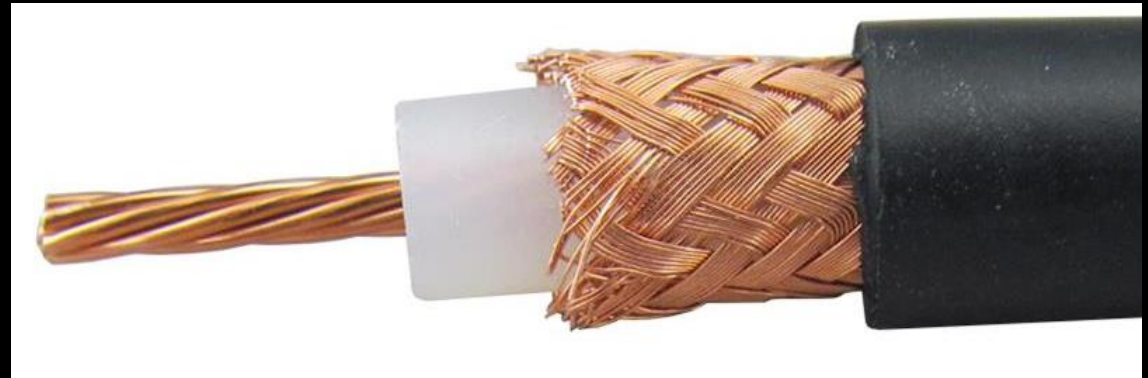
good conductor



flexible



heavy



center conductor copper clad aluminum

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



POP QUIZ!

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

coaxial shield

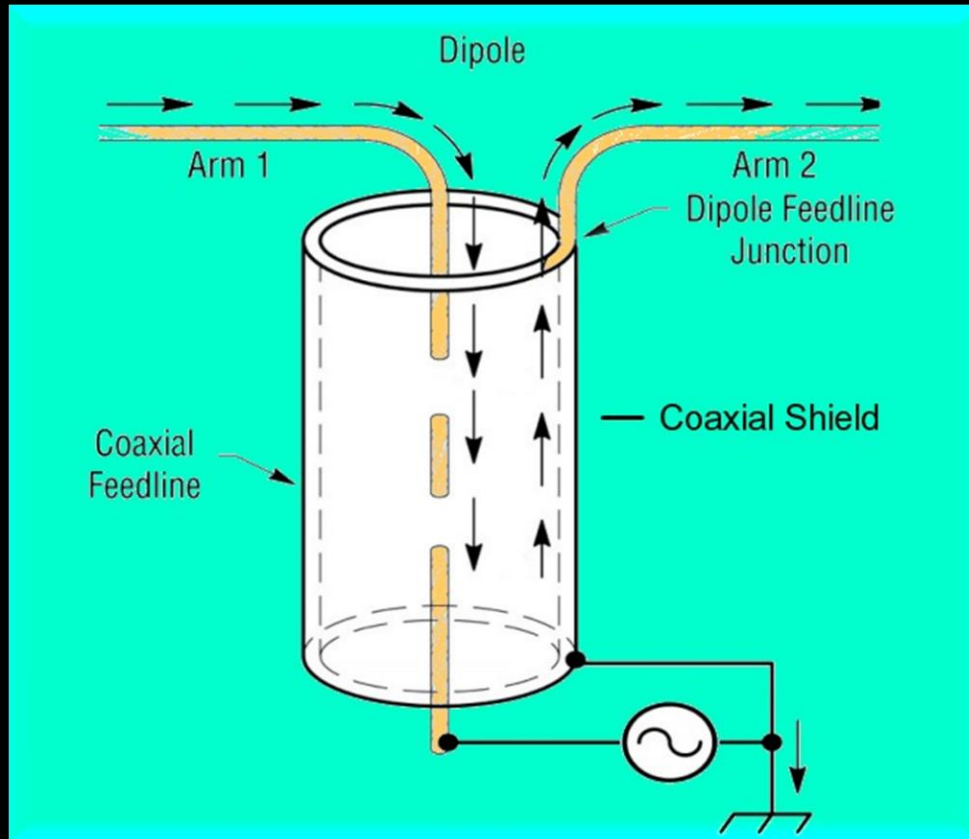
shielding is the current return path on the coaxial cable

protects the transmission line from external EMI influence

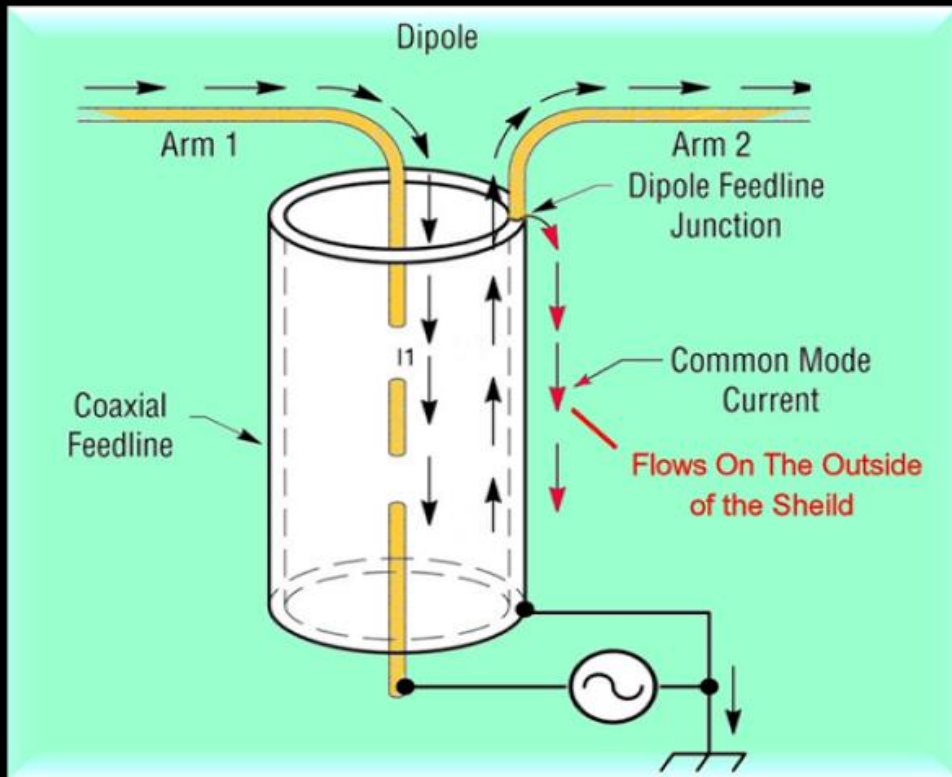
reduces EMI emissions



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

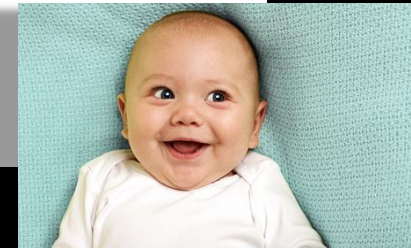
coaxial shield also carries
our nemesis...



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



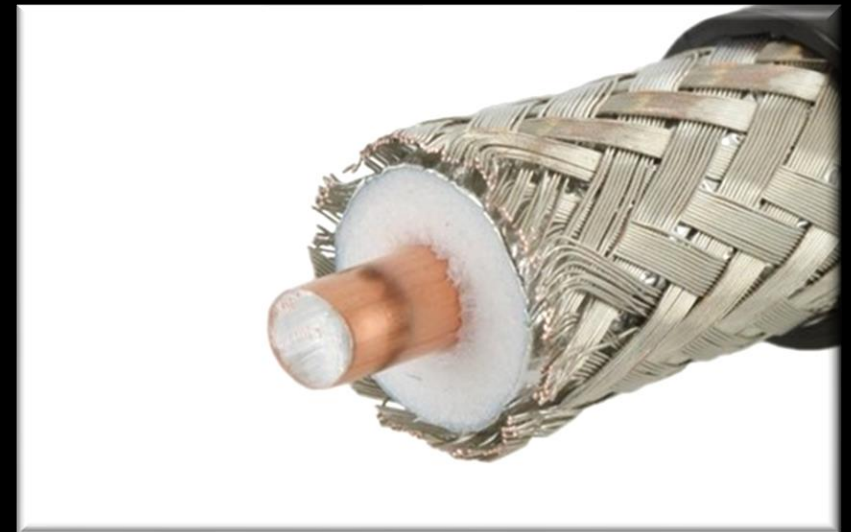
protection against
oxidation & corrosion



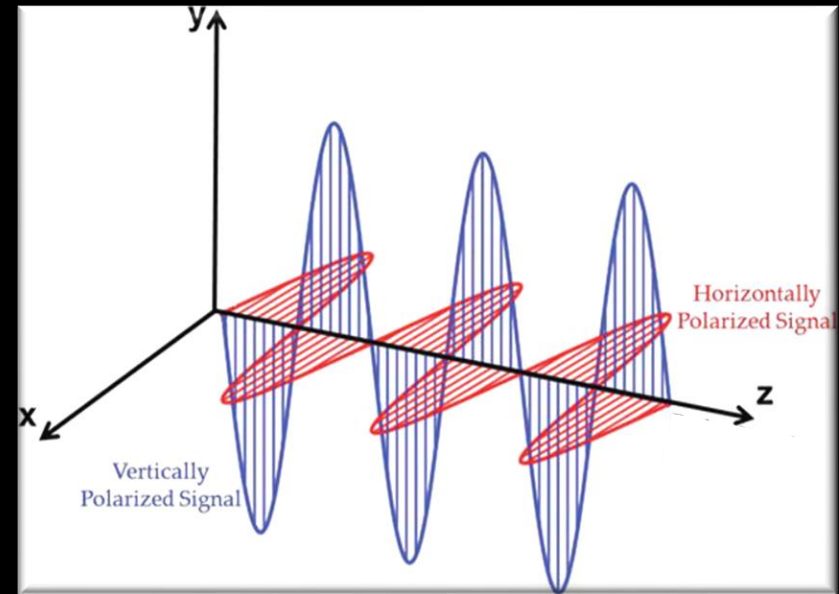
dielectric insulator

dielectric insulates
the center conductor

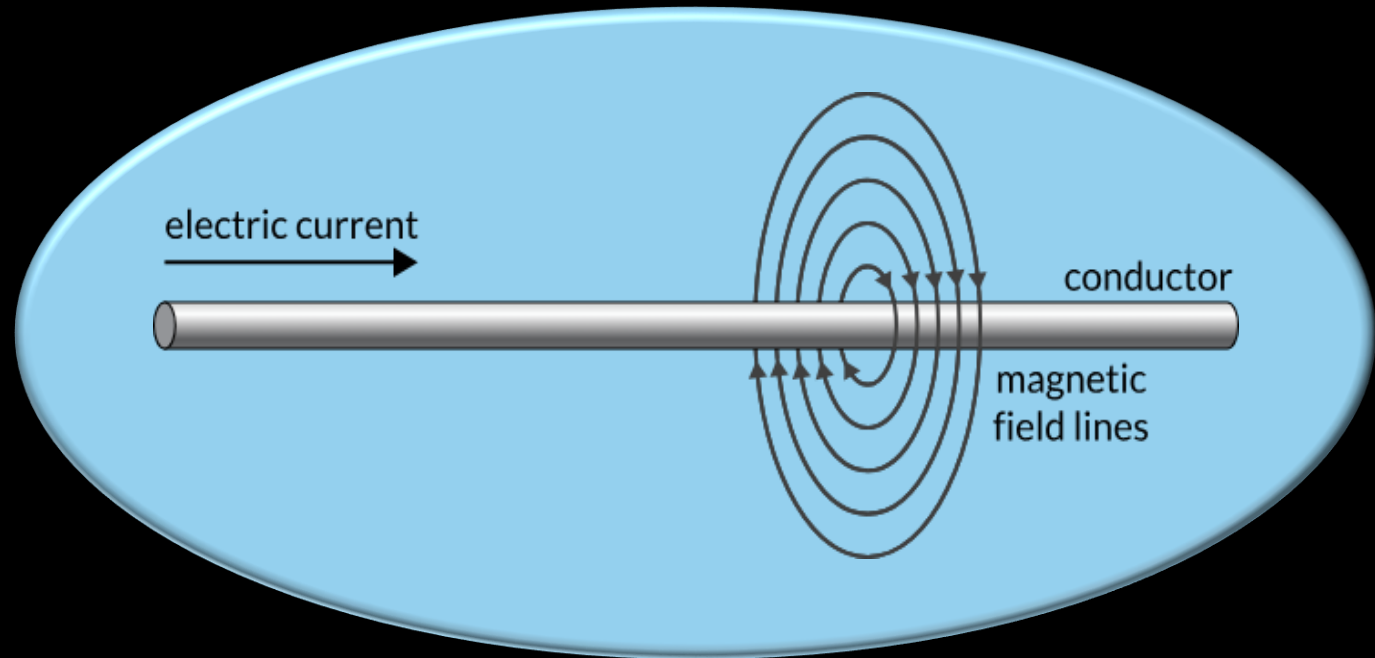
dielectric centers the center
conductor within the cable
(shield) to prevent loss



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

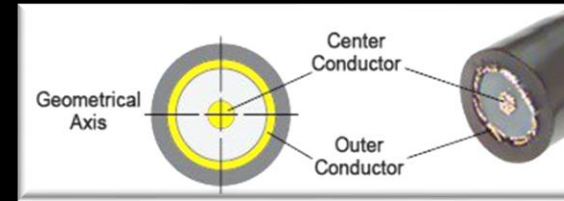


excessive current damage



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 (V_p) - the speed at which the RF signal travels within the cable

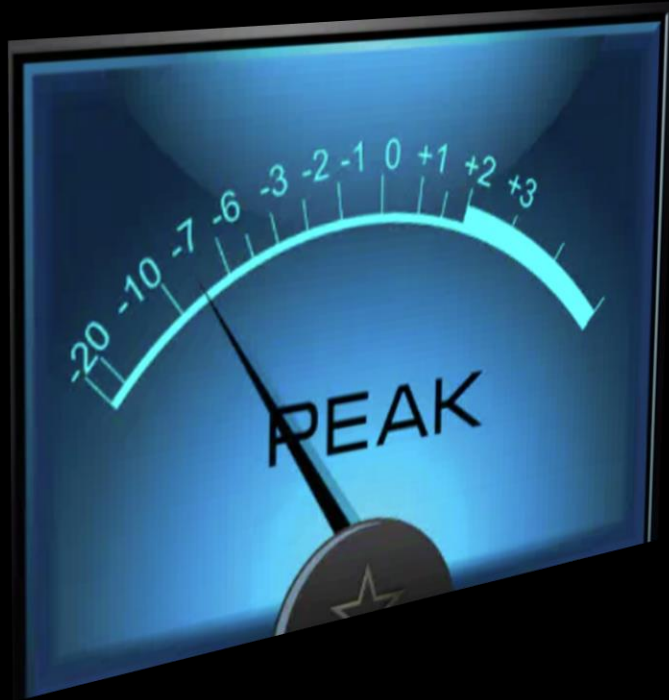
Electrical Specifications			
Performance Property	Units	US	(metric)
Velocity of Propagation	%	84	
Dielectric Constant	NA	1.58	
Time Delay	nS/ft (nS/m)	1.20	(3.92)
Impedance	ohms	50	
Capacitance	pF/ft (pF/m)	23.9	(78.4)
Inductance	uH/ft (uH/m)	0.060	(0.20)
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attenuation is loss

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



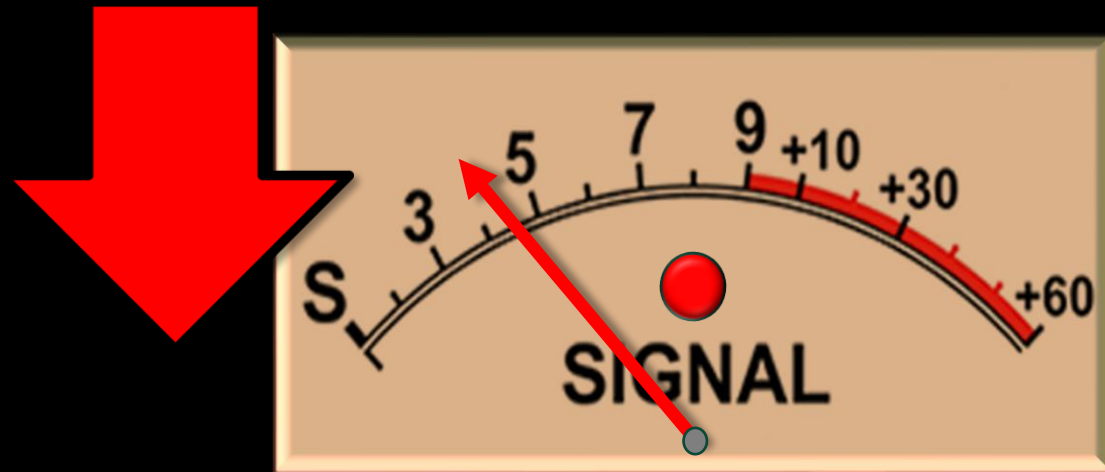
insertion loss



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)

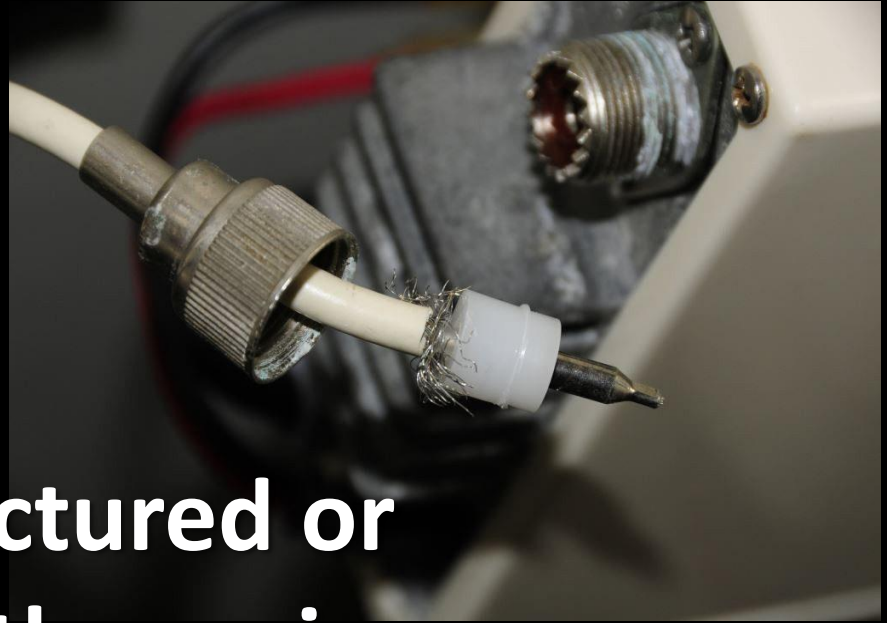


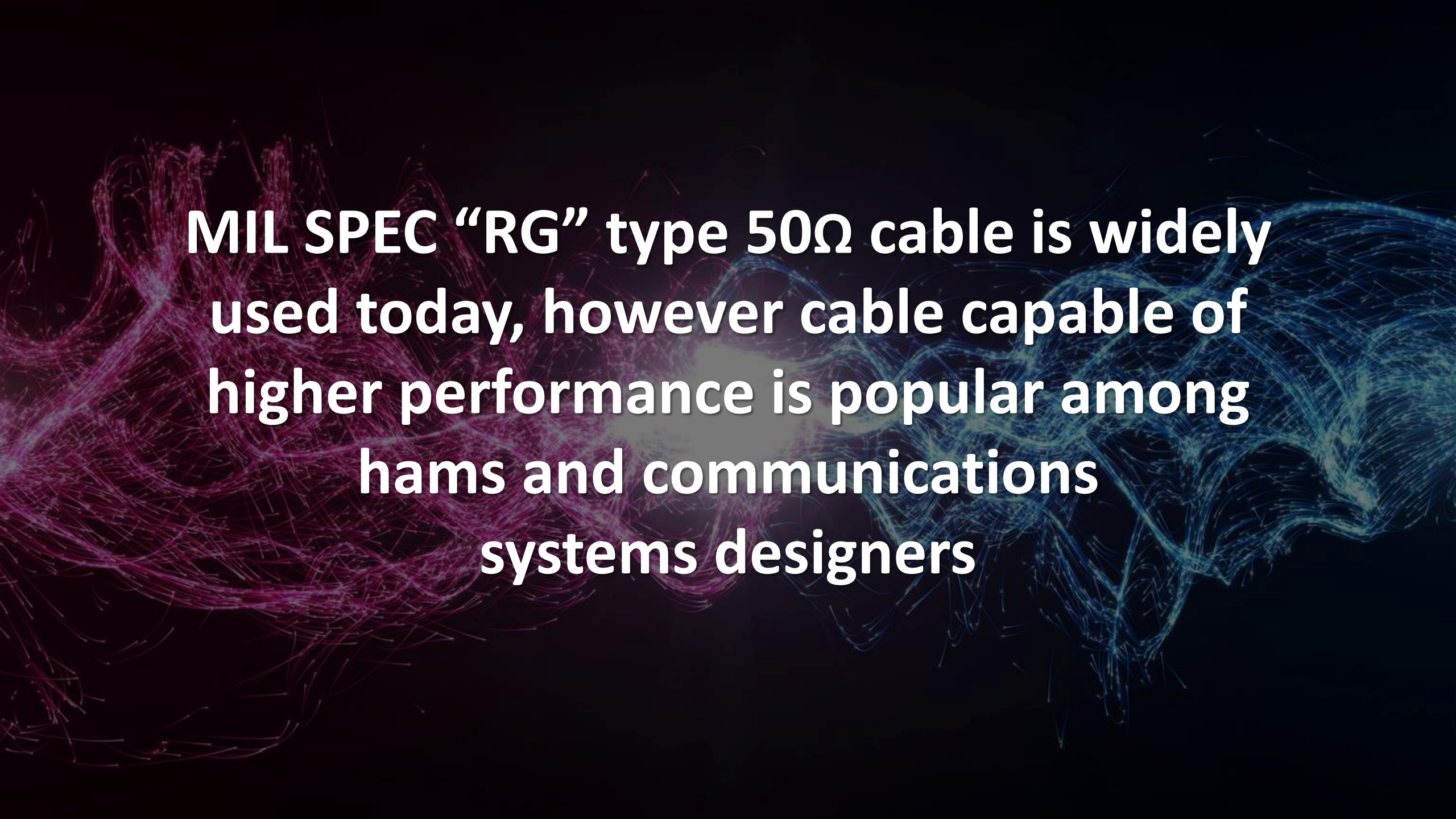
insertion loss - attenuation

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



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

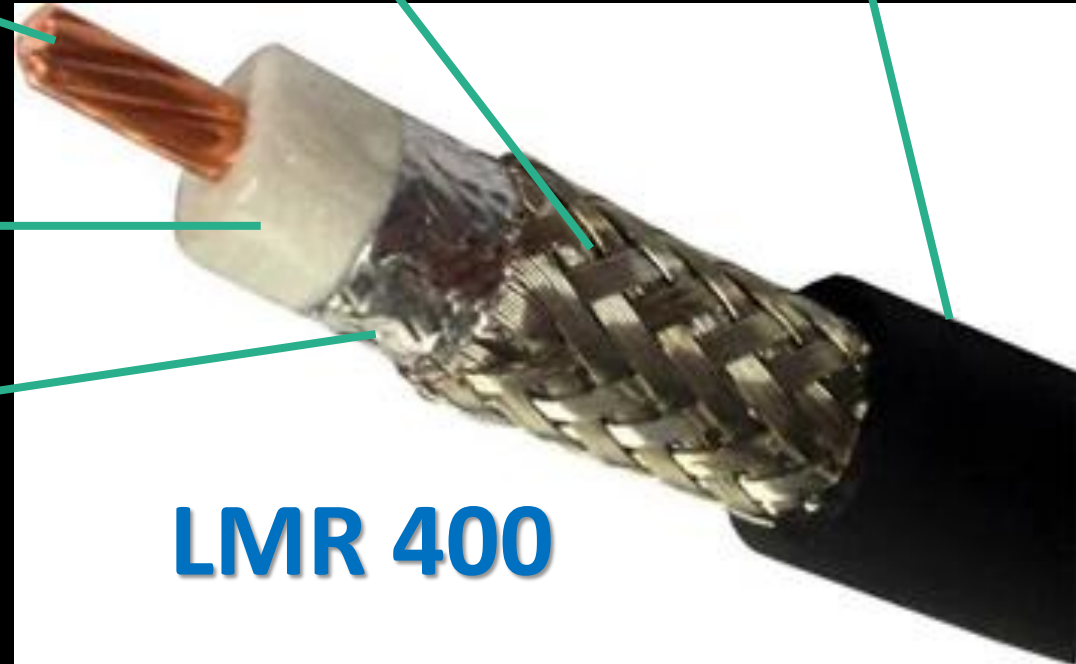
**tinned copper shield -
resists corrosion**

**moisture/UV resistant
outer jacket**

**stranded center
conductor
greater flexibility**

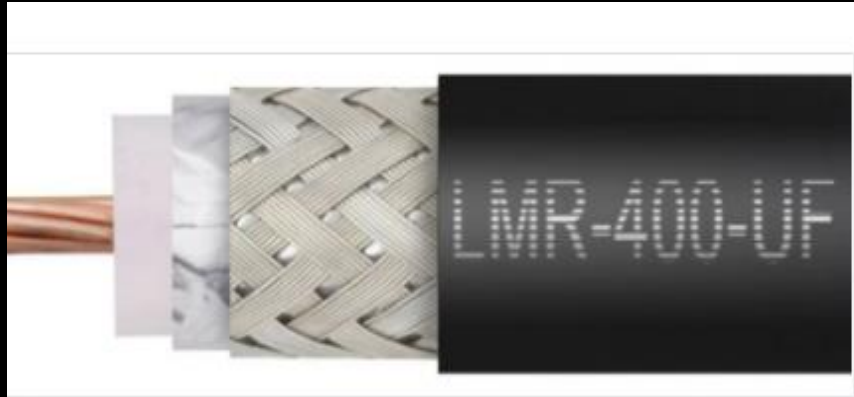
high constant dielectric

**foil shield - greater
protection from
RF/EMI**



LMR 400

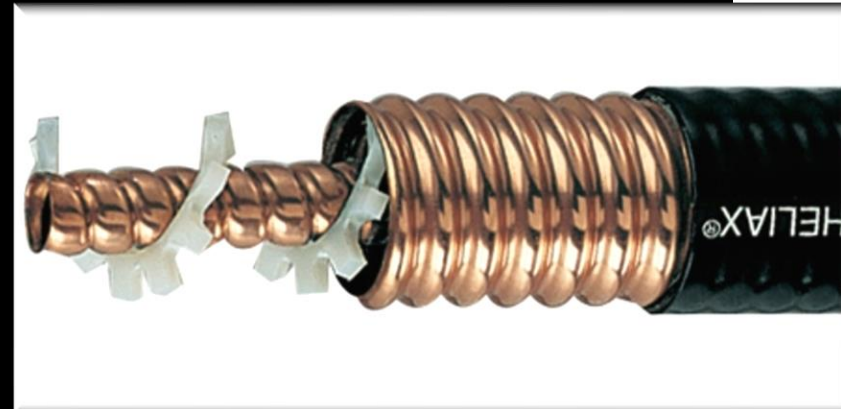
LMR type coaxial cables



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



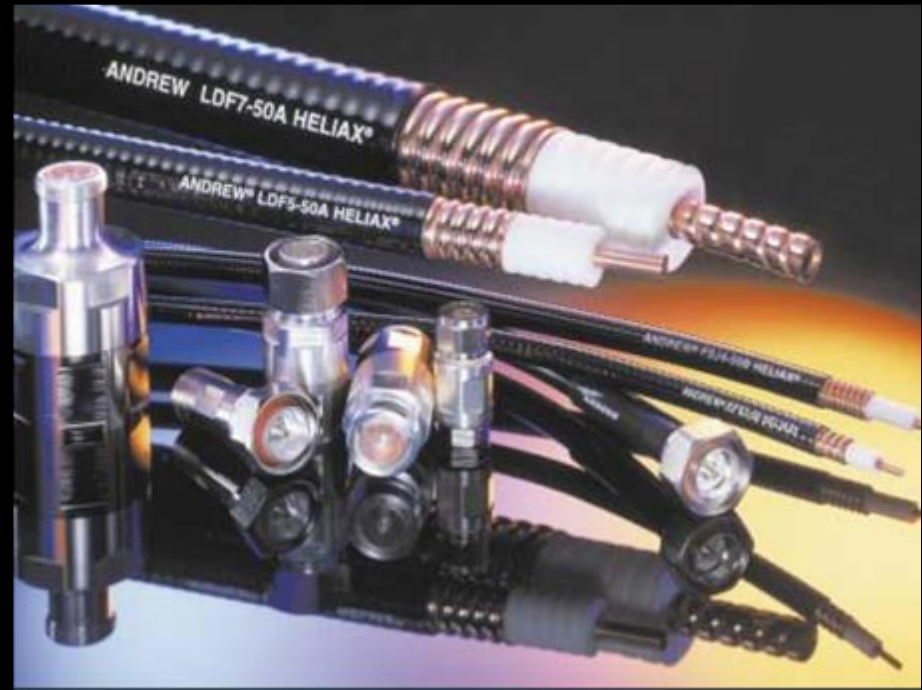
the solution was “**hardline**”
also known **Heli**ax or **F4**
type cable created by the
Andrew Corporation



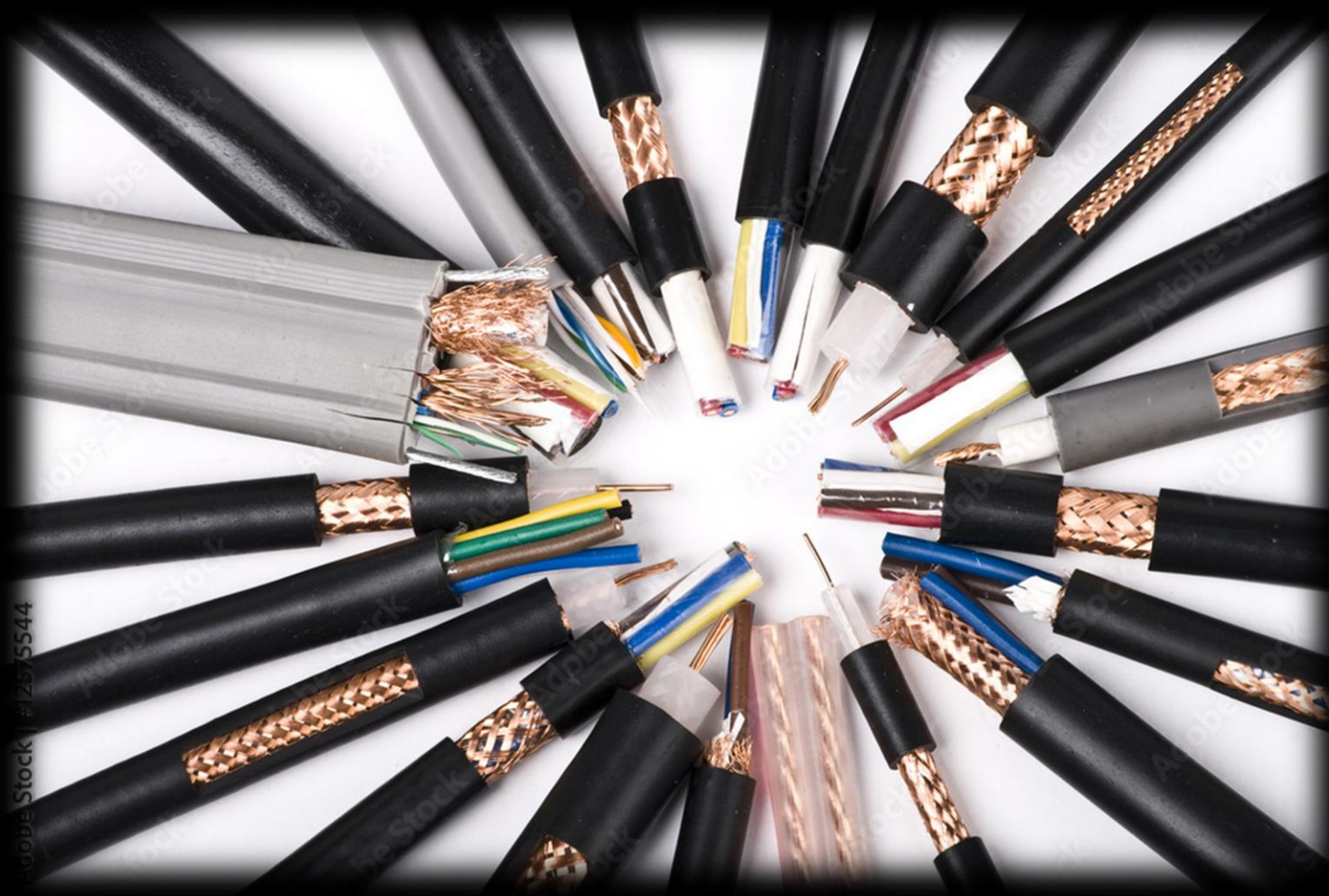
low-loss and high-
power capability along
with high strength
make **hardline** well
suited for commercial
applications



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)

✓ application type

✓ power capacity

✓ weight

✓ frequency range

✓ build materials

✓ velocity factor

✓ 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

DX Engineering Coaxial Cable Reference Chart

DXE-400MAX Low-Loss Cable 50 ohm

Low-loss, gas-injected foam polyethylene dielectric bonded tape foil covered by a braided copper shield.

Attenuation/100 ft	Power Rating	Efficiency %
0.3 dB @ 3 MHz	6.0 kW	92%
0.3 dB @ 10 MHz	4.4 kW	92%
0.4 dB @ 30 MHz	2.8 kW	83%
1.1 dB @ 100 MHz	2.1 kW	78%
1.8 dB @ 150 MHz	1.2 kW	65%
3.3 dB @ 400 MHz	0.7 kW	41%

DXE-4U Low-Loss 50 ohm Foam Dielectric Cable

Low-loss, gas-injected foam polyethylene dielectric.

Attenuation/100 ft	Power Rating	Efficiency %
0.4 dB @ 3 MHz	5.1 kW	91%
0.5 dB @ 10 MHz	3.1 kW	81%
1.3 dB @ 30 MHz	1.8 kW	74%
1.5 dB @ 100 MHz	1.1 kW	72%
2.2 dB @ 150 MHz	1.0 kW	65%

DXE-8X Low-Loss 50 ohm Foam Dielectric Cable

Low-loss, gas-injected foam polyethylene dielectric.

Attenuation/100 ft	Power Rating	Efficiency %
0.6 dB @ 3 MHz	3.0 kW	86%
0.6 dB @ 10 MHz	2.2 kW	81%
1.4 dB @ 30 MHz	1.2 kW	69%
2.0 dB @ 100 MHz	0.8 kW	62%
3.8 dB @ 150 MHz	0.4 kW	42%

DXE-213U MIL-Spec 50 ohm Cable

Solid Polyethylene Dielectric.

Attenuation/100 ft	Power Rating	Efficiency %
0.4 dB @ 3 MHz	3.0 kW	86%
0.6 dB @ 10 MHz	2.2 kW	81%
1.0 dB @ 30 MHz	1.2 kW	69%
1.3 dB @ 100 MHz	0.8 kW	62%
2.4 dB @ 150 MHz	0.4 kW	42%

BELDEN

Product: 9913EF

50 Ohm Wireless Transmission Coax, RG-8, 10 AWG Str BC, Foil + 90% TC Braid, PVC Jkt, Flexible

Product Description

50 Ohm Wireless Transmission Coax, RG-8, 10 AWG (7x18) Bare Copper Conductor, PE Insulation, Foil + 90% Tinned Copper Braid Shield, PVC Jacket, Flexible

Technical Specifications

Substrate Applications: Point-to-point and point-to-multipoint wireless antenna communication, Wireless microphones, Two-Way Radio, Antenna (Jumper) Radio, Low Power FM, GPS, RFID (Radio Frequency Identification)

Construction Details

Step	Stranding	Num. Conductors	Material
1	10 AWG	7x18	BC, Bare Copper

Physical Properties

Material	Min. Insulation Coverage	Color Code
10 - Polyethylene (Foam)	0.236 (0.17) 21 mm	White

Electrical Characteristics

Frequency	Min. Attenuation
10 MHz	0.8 dB/100ft
50 MHz	1.1 dB/100ft
100 MHz	1.8 dB/100ft
200 MHz	2.0 dB/100ft
400 MHz	3.0 dB/100ft
750 MHz	4.0 dB/100ft
1000 MHz	4.7 dB/100ft



DRF-400™
by Davis RF

a direct equivalent to the popular brand of the Times Microwave coax -400. DRF-400 is manufactured in the US by Davis RF with over 20 years in producing and engineering high quality cables like Bury-FLEX™ and Aerial rave™. All trademarks noted are those of DAVIS RF Co.

connectors is quite simple with the recommended tools and connectors.

Pricing Table

QTY	<100 ft	<499 ft	<999 ft	>1000 ft
COST	\$1.08/ft	\$1.00/ft	\$.94/ft	\$.88/ft



Physical Characteristics

ES	50 Ohms
ES	23 pF/FT
	85% nom.
Attenuation dB / 100 FT	.7
	.9
	1.5
	1.9
	2.7
	3.9
	5.1
	6.0

Physical Properties

Conductor:	10 AWG Solid Bare Copper Clad
Dielectric:	Foamed PE
Shield 1:	Bonded Aluminum (100% Coverage)
Shield 2:	Tinned Copper Braid (95% Coverage)
Jacket:	Black Low Density PE .405" nom OD
Cable Weight:	.068 lbs/ft nom.
Bend Radius:	1" min.

Suitable for Indoor and Outdoor Applications.

out our "RF Connectors" page for the appropriate connectors.

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