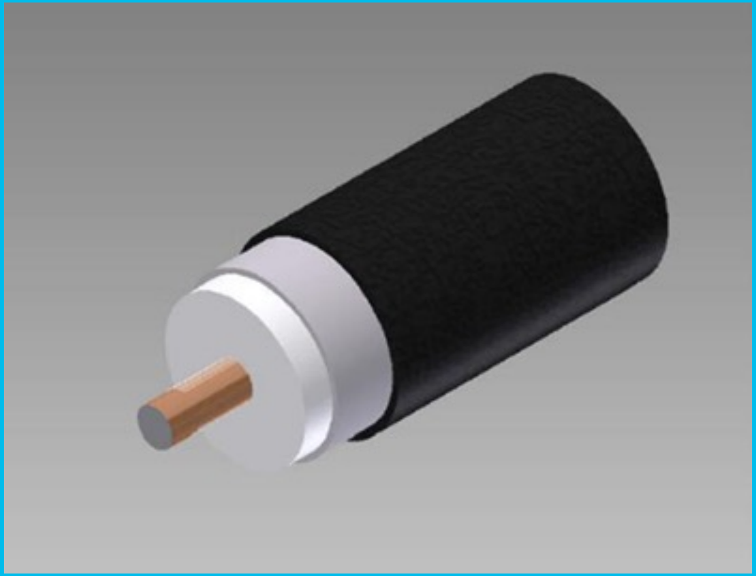
Why 75 Ω

Ron Hranac



Graphic courtesy of Amphenol Broadband Solutions

Why 75 ohms?

- Modern hybrid fiber/coax (HFC) cable networks are constructed using a combination of optical fiber and coaxial cable technology.
- The coaxial cable portion of the network uses cables with a characteristic impedance of 75 ohms (Ω).
- But why 75 Ω? Before attempting to answer that question, it will be helpful to define characteristic impedance.

Images courtesy of Toner Cable Equipment, Inc.

Characteristic impedance

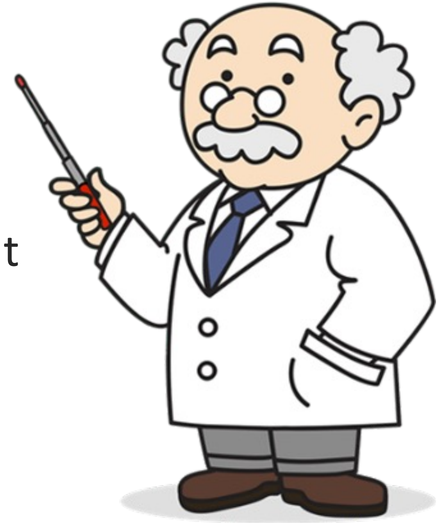
A property of a transmission line such as coaxial cable, called characteristic impedance, Z_C (sometimes Z_0), is equal to the ratio of voltage E to current I in a traveling wave propagating along that transmission line:

$$Z_C = E/I$$

It's important to note that the above ratio applies to a traveling wave, not a standing wave.

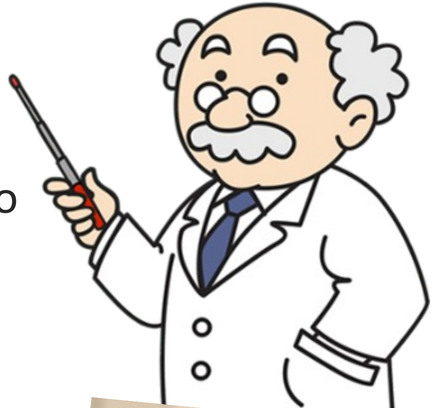
- A standing wave is caused by a superposition of two traveling waves propagating in opposite directions along the transmission line—one an incident wave, the other a reflected wave.

Characteristic impedance

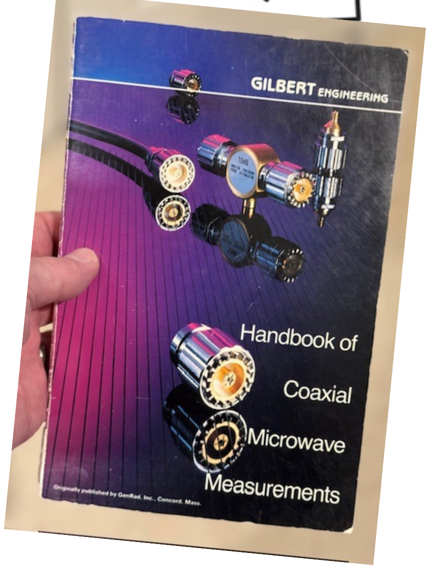


- In an *ideal lossless* transmission line such as coaxial cable, the voltage E and current I that occur as a result of the traveling wave are exactly in phase.
- In *real-world* coaxial cable, the surfaces of the conductors are not perfectly smooth, and have tiny, even microscopic, imperfections that can affect the cable's performance.
- The conductivities of the conductors—the center conductor and shield—are finite, and the flow of RF current "penetrates" the surface of the conductors somewhat.
  - For more about skin effect and skin depth, see SCTE 293-6 2024, What is … Skin Effect and Skin Depth?, available on SCTE's standards download page (https://account.scte.org/standards/library/catalog/).

Characteristic impedance



- The electromagnetic field traveling in the dielectric also penetrates slightly into the conductors. As a result, the conductor loss causes the phase of the electric field to lag slightly behind the phase of the magnetic field, which in turn causes a small capacitive reactance in the cable’s characteristic impedance.
- For more about this phenomenon, see *Handbook of Coaxial Microwave Measurements*, originally published by GenRad, Inc., and reprinted by Gilbert Engineering (now Corning-Gilbert). This publication is, unfortunately, out of print, but pdf copies can sometimes be found online.



Characteristic impedance

A transmission line's characteristic impedance is sometimes called surge impedance, and is related to the transmission line's inductance L per unit length and capacitance C per unit length. In an *ideal lossless transmission line*, the characteristic impedance is

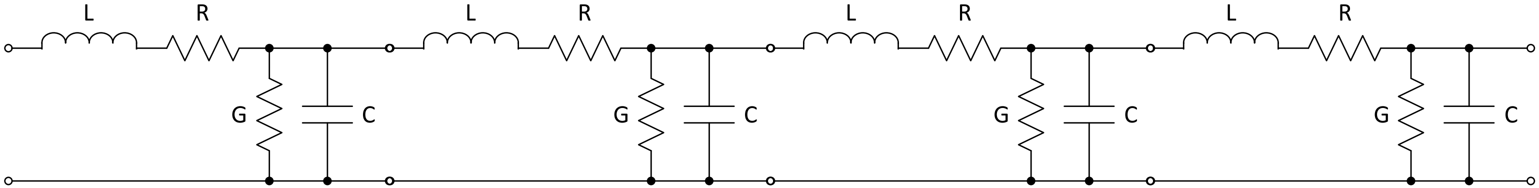
$$Z_C = \sqrt{(L/C)}$$

where

Z_C is characteristic impedance in ohms
L is inductance per unit length in henrys
C is capacitance per unit length in farads

Characteristic impedance

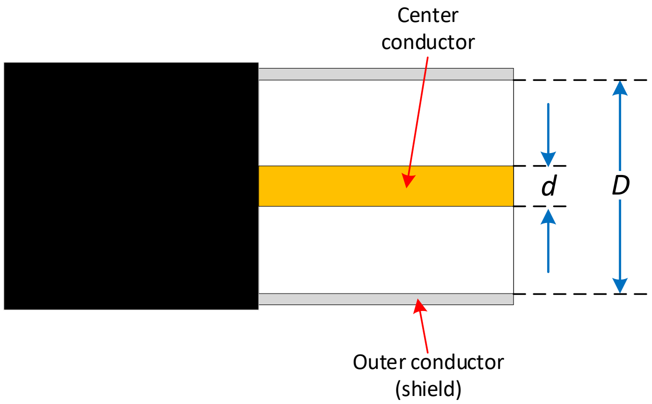
- A transmission line such as coaxial cable can be modeled as a series of distributed values of inductance (L), resistance (R), conductance (G), and capacitance (C).



- At higher frequencies, the reactive terms typically dominate R and G, so when the inductance per unit length and capacitance per unit length are known, the characteristic impedance of coaxial cable can be stated as $Z_C \cong \sqrt{L/C}$.

Characteristic impedance

The **characteristic impedance**, Z_0, of coaxial cable is expressed in ohms, and is related to the ratio of the inside diameter D of the shield to the outside diameter d of the center conductor, and the dielectric constant ε (relative permittivity) of the insulating material (dielectric) separating the two conductors.



If the ratio of D to d changes, or the dielectric constant (related to VoP) changes, so will the impedance!

Characteristic impedance

The characteristic impedance of *lossless* coaxial cable with a perfectly smooth center conductor and shield is

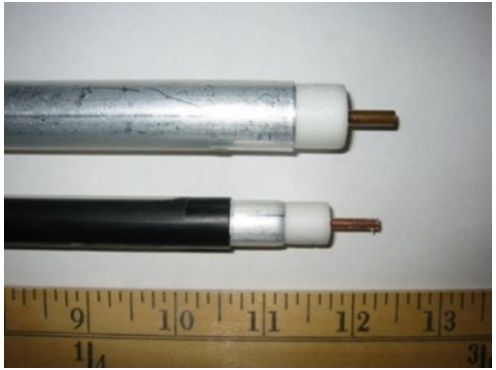
$$Z_C = \left(\frac{138}{\sqrt{\varepsilon}}\right) \times log_{10}\left(\frac{D}{d}\right)$$

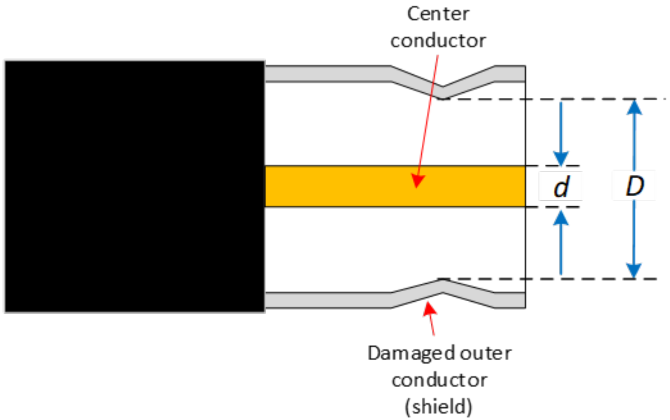
where

Z_C is the coaxial cable’s characteristic impedance in ohms
ε is the dielectric constant
D is the inside diameter of the shield
d is the outside diameter of the center conductor

Characteristic impedance

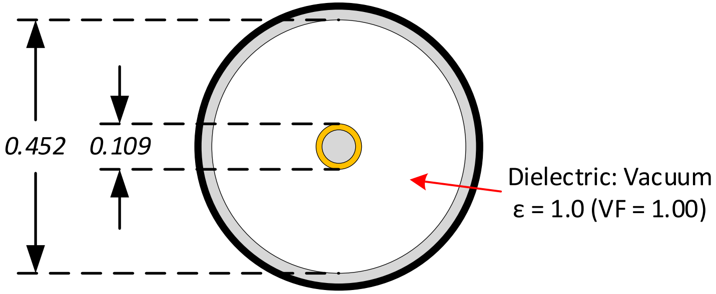
- From the equation on the previous slide, as long as the ratio of D to d remains constant (and the dielectric constant does not change), *the size of the coaxial cable does not affect its characteristic impedance*.
- That's why 0.500 inch diameter hardline cable has the same 75 Ω characteristic impedance as 0.750 inch diameter hardline cable, assuming both have the same dielectric constant.
- That relationship also shows why a kink in the cable will cause an impedance mismatch, because the ratio of D to d at the location of the kink is different than the undamaged part of the cable.





Effect of dielectric on characteristic impedance

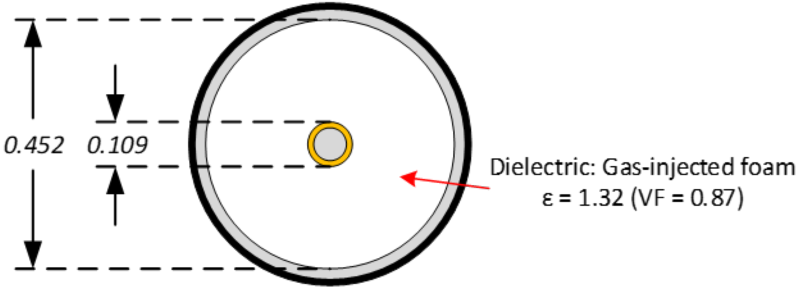
- The presence of dielectric material between the center conductor and shield will *reduce* the characteristic impedance compared to no dielectric material.
- Here's an example: Assume a 0.500 inch diameter hardline cable with a vacuum between the center conductor and shield.
- Given the values of d = 0.109 inch and D = 0.452 inch, and a vacuum between the two conductors (ε = 1.0), the calculated characteristic impedance is 85.24 Ω.



Z_0 = 85.24 Ω

Effect of dielectric on characteristic impedance

Adding a dielectric material between the conductors that has a dielectric constant ε = 1.32, the calculated characteristic impedance is 74.16 Ω, as illustrated at right.

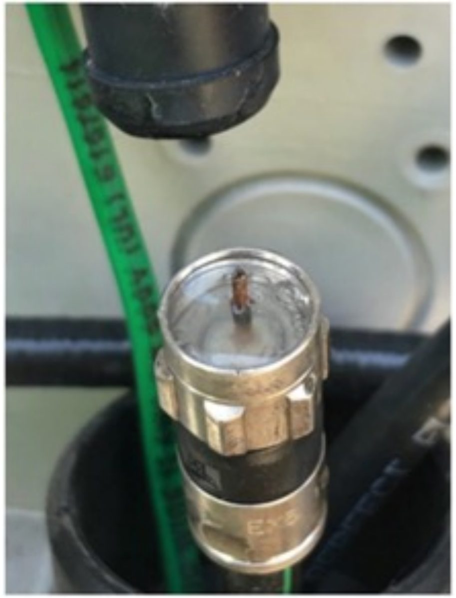


$Z_0 = 74.16\ \Omega$

Note: Coaxial cable published specifications generally do not include the dielectric constant. Most published specifications do, however, include the cable's velocity of propagation or velocity factor (velocity of propagation in decimal form), from which one can calculate dielectric constant using the formula $\varepsilon = 1/(VF)^2$. For the example shown above, the cable's VF is 0.87, which is the same as 87% velocity of propagation.

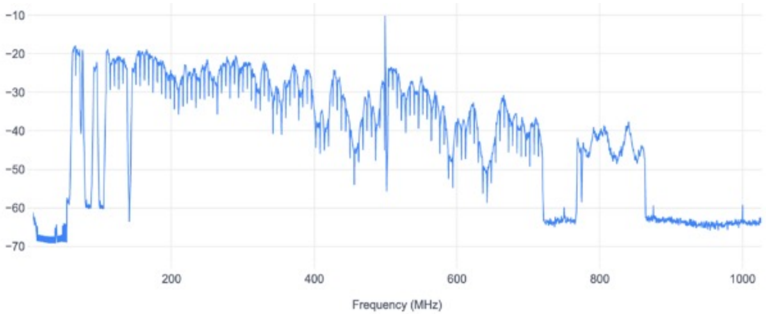
Effect of dielectric on characteristic impedance

- The dielectric constant itself also affects the cable's characteristic impedance.
- For fixed conductor dimensions, varying a cable's dielectric constant will change the characteristic impedance.
- If the dielectric constant of an existing dielectric material is changed for whatever reason, the cable's characteristic impedance will also change.
- For instance, the presence of water in a coaxial cable's foam dielectric will change the dielectric constant, causing the cable's characteristic impedance to change, degrading the performance of that cable.

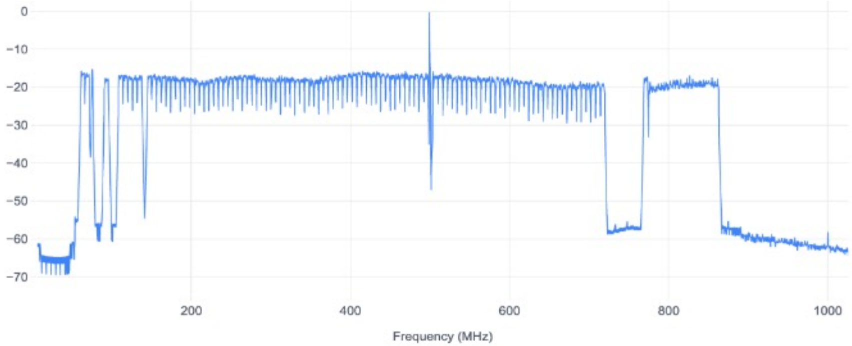


Effect of dielectric on characteristic impedance

Water-soaked drop cable

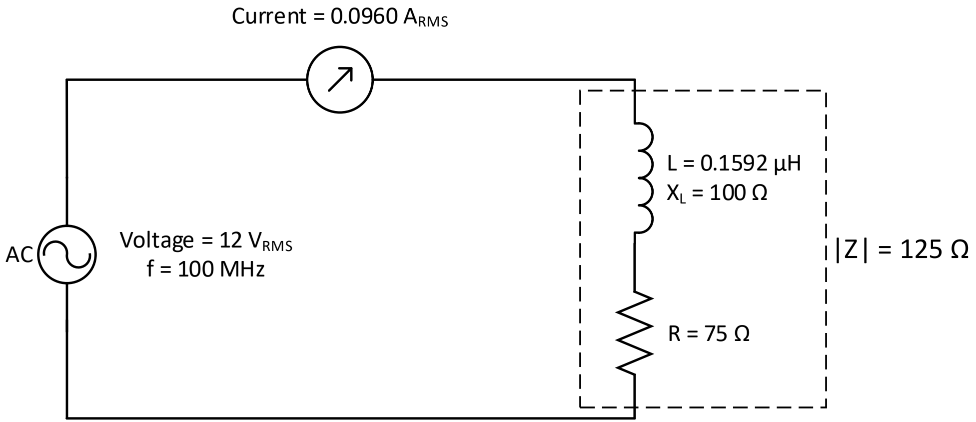


After drop replacement



Characteristic impedance vs. electrical impedance

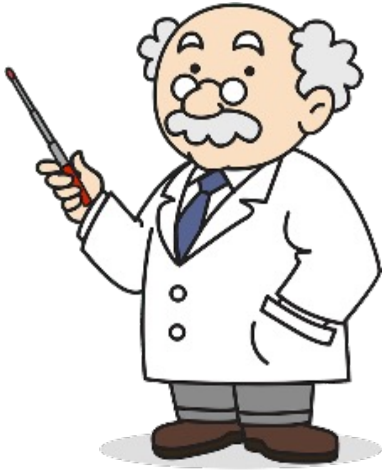
- An important point: *Characteristic impedance* should not be confused with *electrical impedance*.
- Impedance in an electric circuit can change with frequency.
- Generally speaking, the characteristic impedance of coaxial cable within the radio frequency (RF) range we use in our networks does not change significantly as long as the dielectric constant does not vary, and the ratio of the inside diameter D of the shield to the outside diameter d of the center conductor remains constant.



Okay, why 75 ohms?

Why 75 ohms?

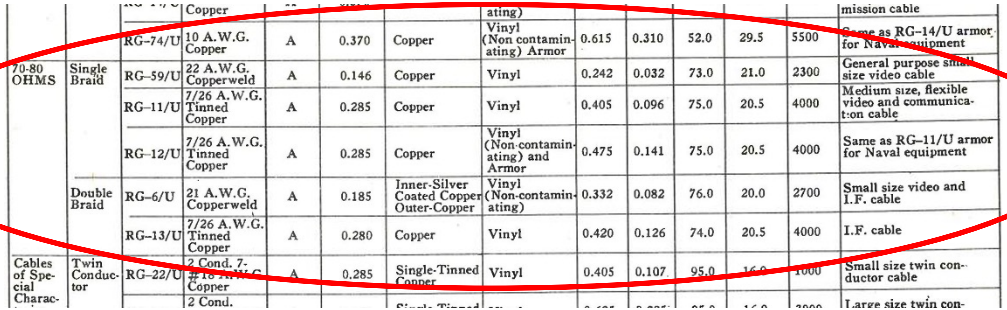
- The beginning of this presentation begins with “The coaxial cable portion of the network uses cables with a characteristic impedance of 75 ohms (Ω).”
- One question that comes up from time to time is why 75 Ω and not, say, 50 Ω? After all, 50 Ω characteristic impedance cables have long been used in broadcasting and radio communications.
- Let’s look at some of the reasons that might provide an answer.



Why 75 ohms?

Availability of surplus coaxial cable

- One reason given is the widespread availability of military surplus 75 Ω (nominal) characteristic impedance coaxial cable after the end of World War II. Many early cable systems were built using some of that surplus cable, such as RG-11/U and RG-59/U.



			Copper				ating)						mission cable
		RG–74/U	10 A.W.G. Copper	A	0.370	Copper	Vinyl (Non contaminating) Armor	0.615	0.310	52.0	29.5	5500	Same as RG–14/U armor for Naval equipment
70-80 OHMS	Single Braid	RG–59/U	22 A.W.G. Copperweld	A	0.146	Copper	Vinyl	0.242	0.032	73.0	21.0	2300	General purpose small size video cable
		RG–11/U	7/26 A.W.G. Tinned Copper	A	0.285	Copper	Vinyl	0.405	0.096	75.0	20.5	4000	Medium size, flexible video and communication cable
		RG–12/U	7/26 A.W.G. Tinned Copper	A	0.285	Copper	Vinyl (Non-contaminating) and Armor	0.475	0.141	75.0	20.5	4000	Same as RG–11/U armor for Naval equipment
	Double Braid	RG–6/U	21 A.W.G. Copperweld	A	0.185	Inner-Silver Coated Copper Outer-Copper	Vinyl (Non-contaminating)	0.332	0.082	76.0	20.0	2700	Small size video and I.F. cable
		RG–13/U	7/26 A.W.G. Tinned Copper	A	0.280	Copper	Vinyl	0.420	0.126	74.0	20.5	4000	I.F. cable
Cables of Special Charac-	Twin Conductor	RG–22/U	2 Cond. 7- #18 A.W.G. Copper	A	0.285	Single-Tinned Copper	Vinyl	0.405	0.107	95.0	16.0	1000	Small size twin conductor cable
			2 Cond.										Large size twin con-

From the **INDEX of ARMY-NAVY R-F TRANSMISSION LINES and FITTINGS** (ARMY No. 71-4925, NAVSHIPS 900102), June 1945

Why 75 ohms?

Coaxial cable attenuation-versus-impedance

- Another reason given is the attenuation of 75 Ω characteristic impedance coaxial cables of a given size compared to cables with similar physical characteristics but other impedances.

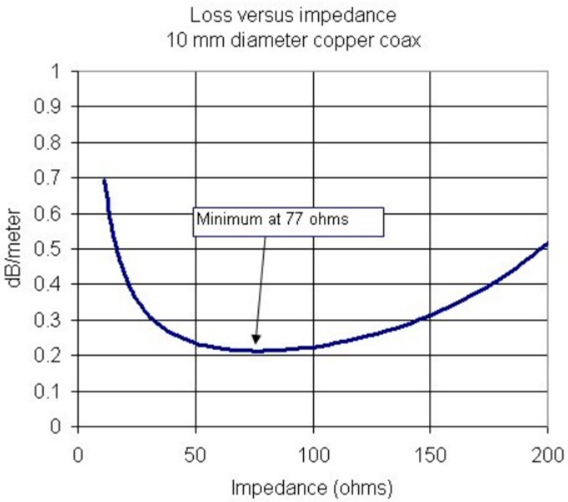
- This goes back to research conducted by **Lloyd Espenscheid** and **Herman Affel** of Bell Telephone Laboratories in the late 1920s and early ’30s. The two were working on solutions to transport 4 MHz signals long distances using coaxial cable, the latter patented by the pair in 1929 (the patent was granted in 1931).

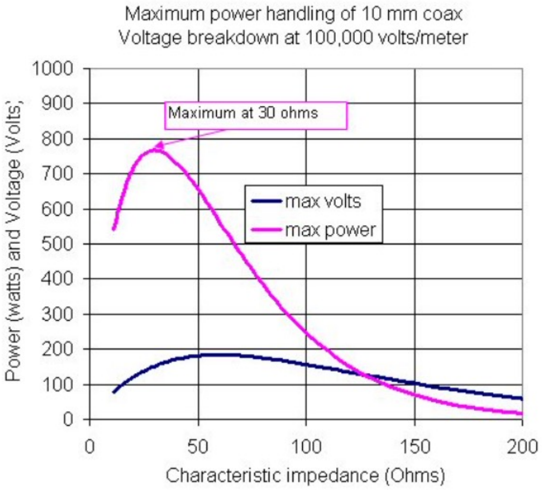
Lloyd Espenschied (left) with Herman Affel, c. 1950–1960
Source: Wikipedia, AT&T Archives and History Center

Why 75 ohms?

Coaxial cable attenuation-versus-impedance (cont’d)

- For air dielectric coaxial cables, the best attenuation-versus-impedance was found to occur at about 77 Ω characteristic impedance; the maximum peak power handling at about 30 Ω; and the maximum voltage at about 60 Ω.



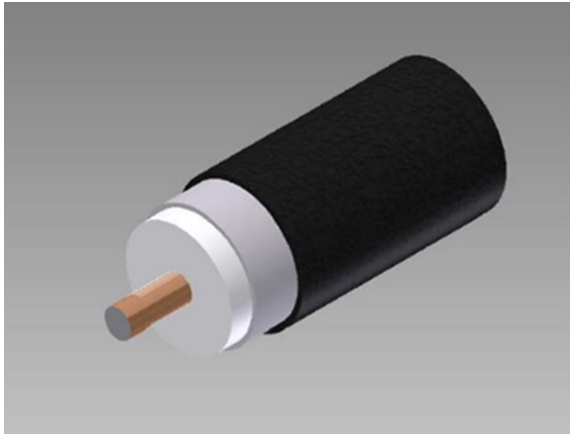


Graphs from Microwaves101.com

Why 75 ohms?

Coaxial cable attenuation-versus-impedance (cont'd)

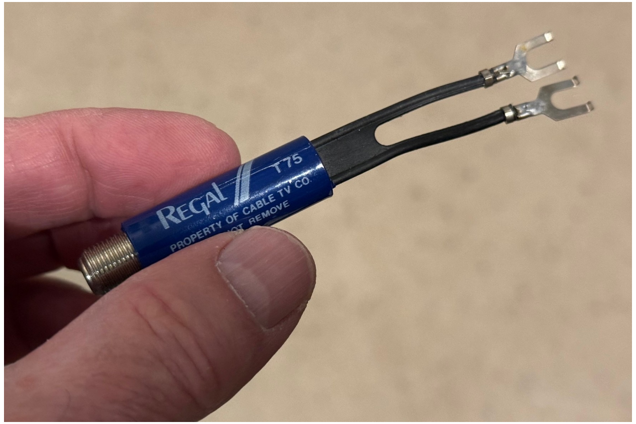
- Before the widespread adoption of optical fiber technology and the birth of what is now known as hybrid fiber/coax (HFC) network architectures, many cable networks had lengthy trunk amplifier cascades. The use of lower attenuation coaxial cable meant somewhat fewer amplifiers in those trunk cascades.
- ***Note:*** *The addition of a dielectric (other than air) reduces coaxial cable's characteristic impedance and increases its attenuation. The primary factors that affect coaxial cable attenuation are metallic conductor losses, dielectric characteristics (dielectric constant), type of shielding (e.g., solid versus braid), and the presence of impedance mismatches.*



Why 75 ohms?

Ease of impedance matching to TV tuner

- One anecdotal reason given by some for the use and availability of 75 Ω characteristic impedance coax in cable TV applications is the ease of matching 75 Ω to the 300 Ω input impedance of older analog TV tuners.
- A relatively simple 4:1 balun (2:1 turns ratio) can be used to convert between the tuner's 300 Ω (balanced) input and the 75 Ω characteristic impedance (unbalanced) coaxial cable.
- This reason seems unlikely, though, given that designing and manufacturing a 6:1 balun (2:45:1 turns ratio) to convert between 300 Ω and 50 Ω could have been done.

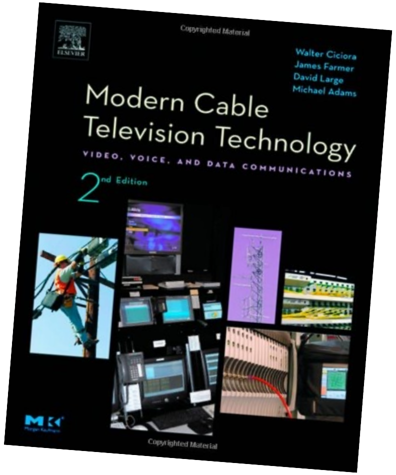


Why 75 ohms?

Close to impedance of half-wave dipole antenna

- Section 10.2.5 of *Modern Cable Television Technology, 2nd Ed.*, notes "…the loss minimum is at about 80 ohms, for air dielectric (dielectric constant = 1.0), and decreases as the dielectric constant increases." That section goes on to state "…75 ohms may have been chosen because it is also close to the feed-point impedance of a half-wave dipole antenna. In order to minimize the need for repeaters, wide area distribution systems universally use 75-ohm cables."

- The discussion about attenuation as a function of impedance is consistent with the results of work by Espenscheid and Affel mentioned previously. It's more difficult to know for certain whether the availability of 75 Ω coaxial cable is related to a half-wave dipole's feedpoint impedance.



Why 75 ohms?

Close to impedance of half-wave dipole antenna (cont'd)

- The feedpoint complex impedance of a thin, lossless half-wave dipole in free space is $Z = 73 + j43.5\ \Omega$, which some simply call 73 Ω. But that scalar value leaves out important information: the complex impedance's reactance.
- A dipole's end-to-end length is typically shortened a few percent from a free space half-wavelength value to achieve resonance, usually defined as a purely resistive feedpoint impedance (that is, with no reactance), or with negligible reactance. Practically speaking, a half-wave dipole's feedpoint impedance is affected by the antenna's height above ground, proximity to nearby objects, etc., so the element lengths are often adjusted to achieve minimum standing wave ratio (SWR) at the input to a feedline connected to the dipole.

Why 75 ohms?

Close to impedance of half-wave dipole antenna (cont’d)

- All of that said, 75 Ω characteristic impedance coaxial cable is sometimes used to feed half-wave dipole antennas, but so is 50 Ω coaxial cable, and even 300 Ω twinlead and 450 Ω ladder or window line.

Left to right:

- 75 Ω hardline coaxial cable (0.750 inch diameter)
- 75 Ω Series 6 coaxial cable (a.k.a. RG-6)
- 300 Ω twinlead
- 450 Ω ladder line (a.k.a. window line)
- 50 Ω RG-8 type coaxial cable
- 50 Ω RG-8X type coaxial cable
- 50 Ω RG-58 type coaxial cable

Wrapping Up

- So, why does the cable TV industry use coaxial cable with a characteristic impedance of 75 Ω?
- The actual reason or reasons may have been lost to history.
- The most likely reasons have to do with the widespread availability of surplus 75 Ω characteristic impedance coax after the end of WWII, and the attenuation-versus-impedance relationship described by **Lloyd Espenscheid** and **Herman Affel** of Bell Telephone Laboratories in the late 1920s and early ’30s.

Image courtesy of Amphenol Broadband Solutions

Wrapping Up

- Coaxial cable has been used in our networks since the very early days of the industry.
- The manufacture of coaxial cable is very sophisticated, with careful control of line speeds and other mechanical processes, specialized dielectric chemistry, test and measurement, packaging (think reel design and similar), and more.
- All of this ensures more uniform characteristic impedance, attenuation, and other performance characteristics to as high as 3 GHz.

Image courtesy of Amphenol Broadband Solutions