Transmission Lines for Amateur Radio

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Types of Transmission Lines

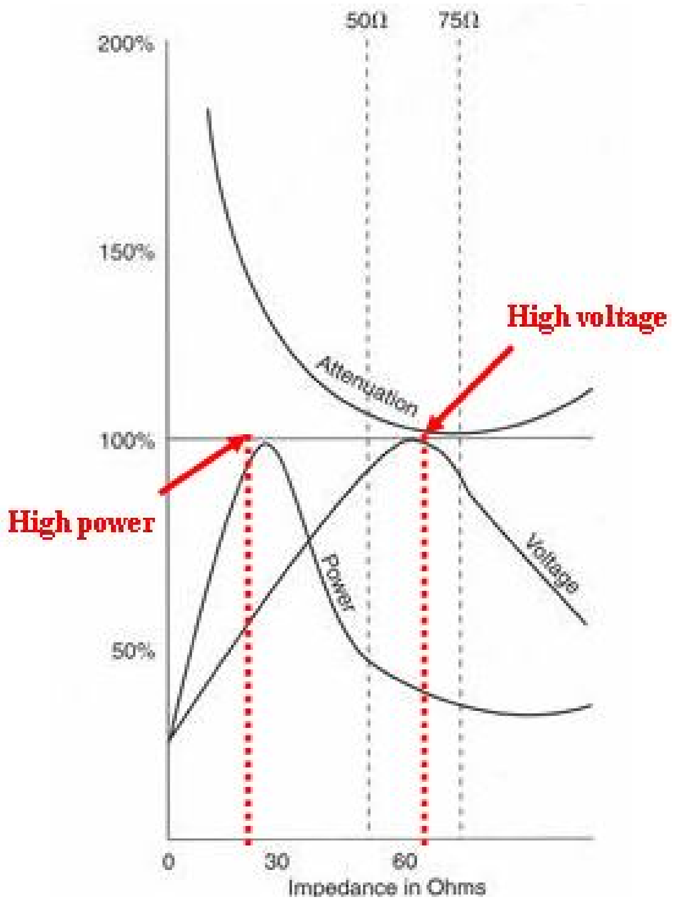
- Main types of transmission lines – coax (unbalanced), twin lead/ladder line (balanced), waveguide
- Coax – 50 Ohm for communications use, 75 Ohm for Cable TV use
- Twin Lead/Ladder Line – 300, 450 & 600 Ohms

See examples of various cable types

50 vs 75 Ohm Coaxial Cables – WHY?

50 Ohm – Best for Power Transfer (therefore for RF Communications Industry)

75 Ohm – Best for Long Distance (therefore for Cable TV Industry)



75 ohms characteristic impedance has been made a standard after it was found that dielectric filled coaxial cable exhibit low attenuation figures somewhere around 77 ohms.

The telecommunication industry thus adopted 75 ohms characteristic impedance as a standard since then. 75 ohms coaxial cable is a standard characteristic impedance cable used for long distance network connectivity, video and audio transmission and telecommunications systems (in some cases, baseband and IF stages are designed at 75 ohms characteristic impedance). Generally, all baseband video applications (analog and digital) use 75 ohms cable.

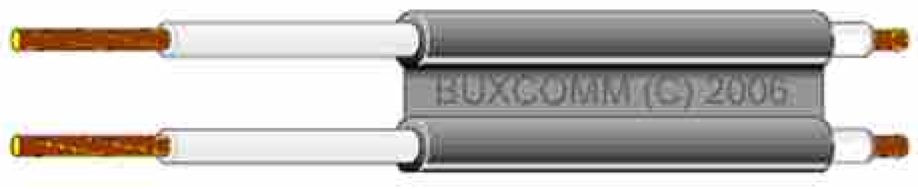
50 vs 75 Ohms

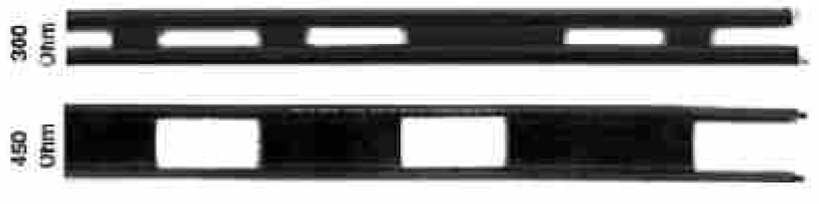
- The answers to the impedance questions have both historical and technical roots. They begin with the work done by Lloyd Espenscheid and Herman Affel, who developed and analyzed the first coaxial cable in 1929 while working for the legendary Bell Labs. Their goal was to find a transmission medium for propagating a 4 megahertz (MHz) signal (a very wide bandwidth in those early days of long-distance telephony), which was needed to carry about 1000 bandwidth-limited analog voice calls across hundreds of miles. Doing so required a transmission line that could handle both high voltage and high power.
- The two researchers analyzed the tradeoffs among key transmission line parameters of attenuation, voltage rating, and power rating (Figure 2).

50 vs 75 Ohms

- Their analysis looked at the performance of three characteristics as a function of impedance and they found:
- 1: *Attenuation (loss)* is largely a function of the dielectric in the cable. For the air-filled coaxial cable which they analyzed, the lowest loss was at about 77 Ω (it is around 50 Ω for some dielectrics, but such cables did not yet exist).
- 2: The *voltage maximum* is a function of the intensity of the electric field between the coaxial outer conductor and the inner conductor. For coaxial cable supporting RF signals in the TE_{10} electromagnetic (EM) field waveguide mode, the e-field has its maximum at around 60 Ω.
- 3: The *power handling capability* is determined by the breakdown field and impedance (V^2/Z). For air-filled coaxial cables operating below the TE_{11} mode cutoff frequency, the power transfer is at its maximum at around 30 Ω.
- As with most engineering decisions, there is no "ideal" impedance value; instead, the "best" choice involves balancing tradeoffs. The 50 Ω value is a good compromise for power and voltage, such as that output by a transmitter. In contrast, for situations where low attenuation is the primary goal, such as with low-level signals from an antenna or an analog video link, 75 Ω is a better choice.
- Further, there's another reason why 75 Ω is a desirable impedance. The "natural" impedance of a standard half-wave dipole antenna at its resonant frequency is 73 Ω, while the impedance of the widely used folded dipole antenna is 300 Ω. This means that 75 Ω is a near-perfect match for the larger dipole, while it also is easy to provide a close match to the folded dipole using a basic 4:1 balun.
- Using different impedances realizes different objectives in a single design and adds another level of complexity. In practice, the difference in loss over a short run of a few centimeters may be negligible. Further, the voltage standing-wave ratio (VSWR) when connecting a 75 Ω cable to a 50 Ω one is 1.5:1, which may be an acceptable non-unity value (in many low or medium power situations, a VSWR below 2:1 is considered acceptable).

Twin Lead & Ladder Line





Know Your Coax

Know Your Coax – Not all RG8 is the same

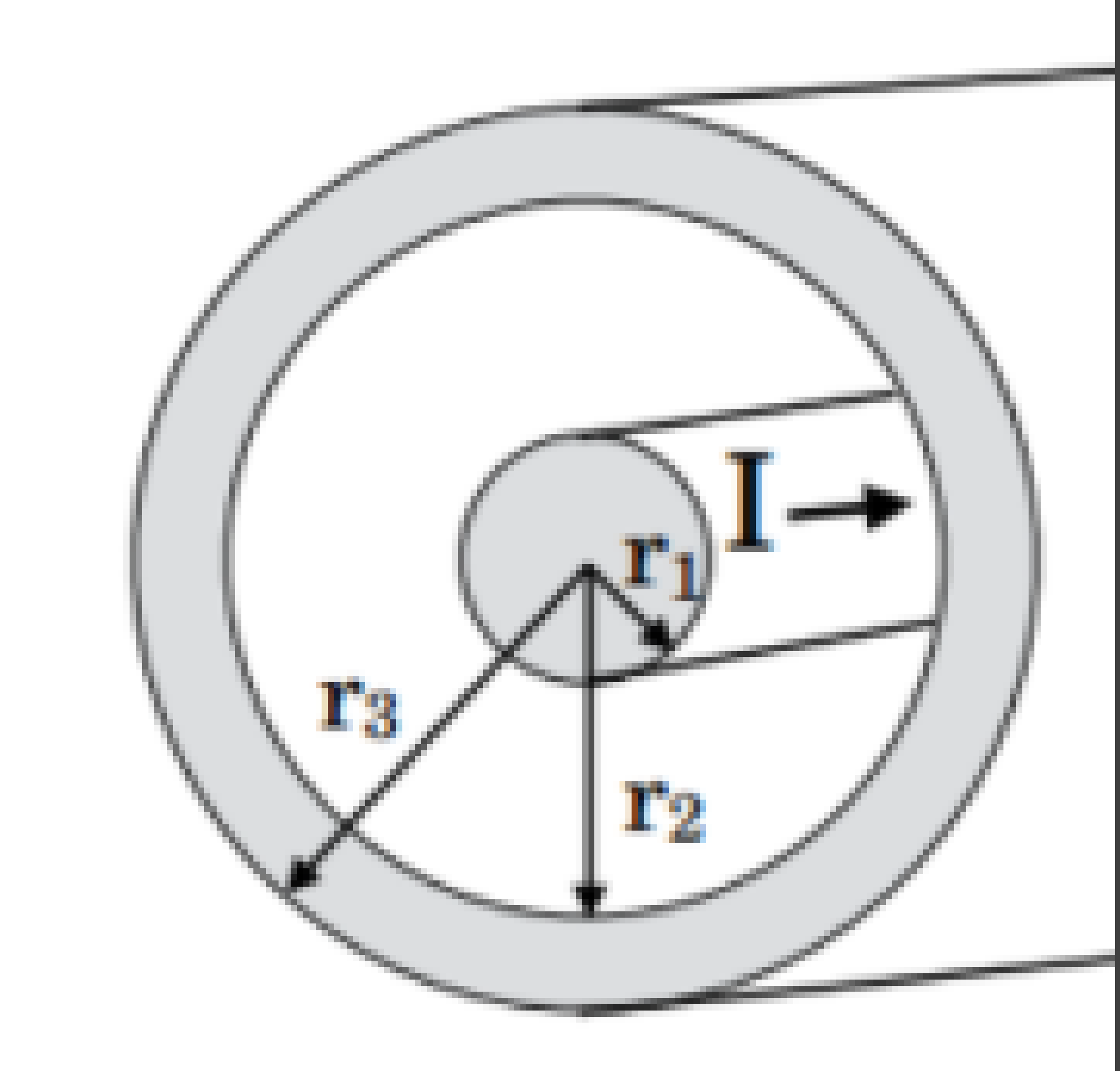
- The same is true for other coax “types”; RG8X, LMR400…
- Some key attributes that affect the RF/electrical performance:
  - Dielectric type – some have more loss than others
    - Air, Teflon, Foam, Polyethylene
  - Shield type and percentage of coverage for flexible types
    - Low grade coax has a coverage from 60 to 80% braid shield
    - Better grade coax have 95% braided coverage
    - The best coax have multiple shields providing 100% coverage
      - Some use 100% aluminum foil wrapped by tinned-copper braid
  - Center Conductor
    - Single conductor vs multi-stranded center conductor
  - RF performance vs Frequency

Mechanical and Environment Differences

- Water is the main enemy of coaxial cable
- Jacket types
  - Some are direct burial, others are not
  - Some can handle UV light, others degrade quickly, get brittle and crack
  - Some are submersible in water
- Center conductors
  - Solid (more stiff) vs Stranded (more flexible)
- Bend radius
  - This is the minimum radius required to maintain the advertised impedance. Sharp bends can change the impedance at that point and cause system loss due to reflections

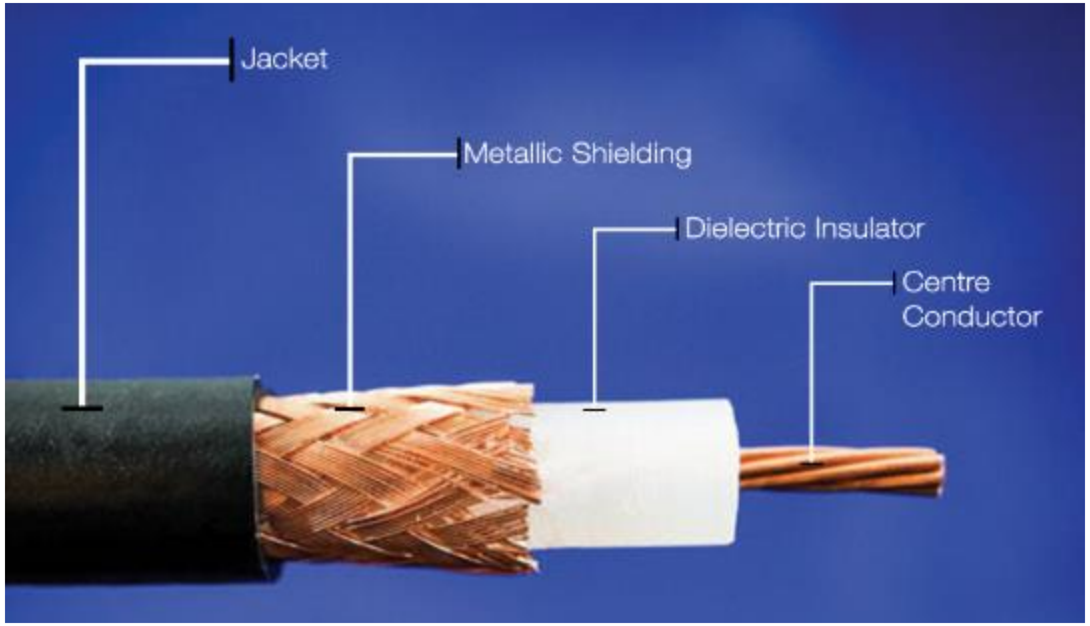
RF Performance vs Frequency

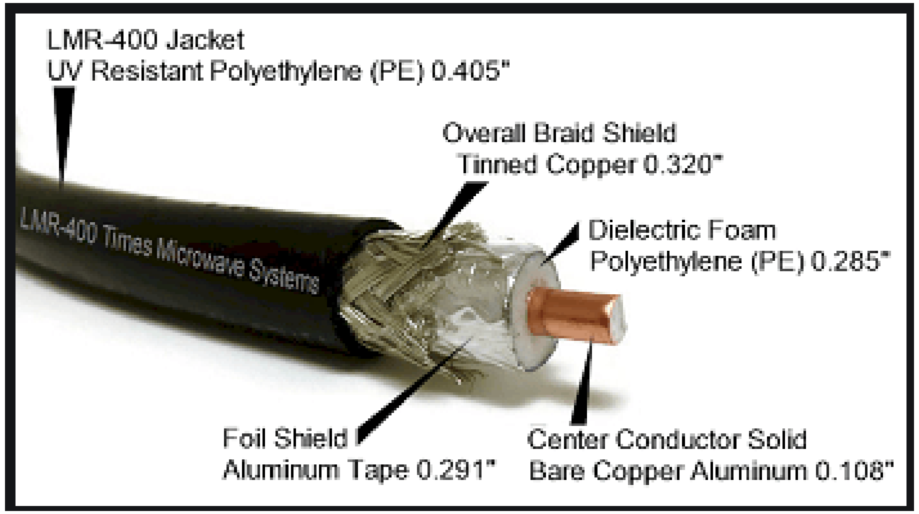
- Most RG8 and some RG8X cables are fine for HF frequencies (30 MHz and below) but bad for VHF and HORRIBLE for UHF and higher
- For LMR type cables, solid center conductors have less loss than stranded because the inner conductor/outer conductor ratio is more consistent



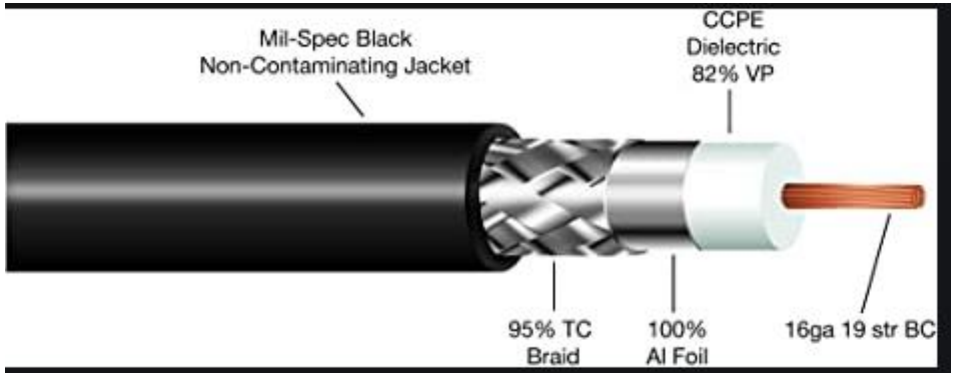
Various Dielectrics and Jacket Coverage

Typical RG8





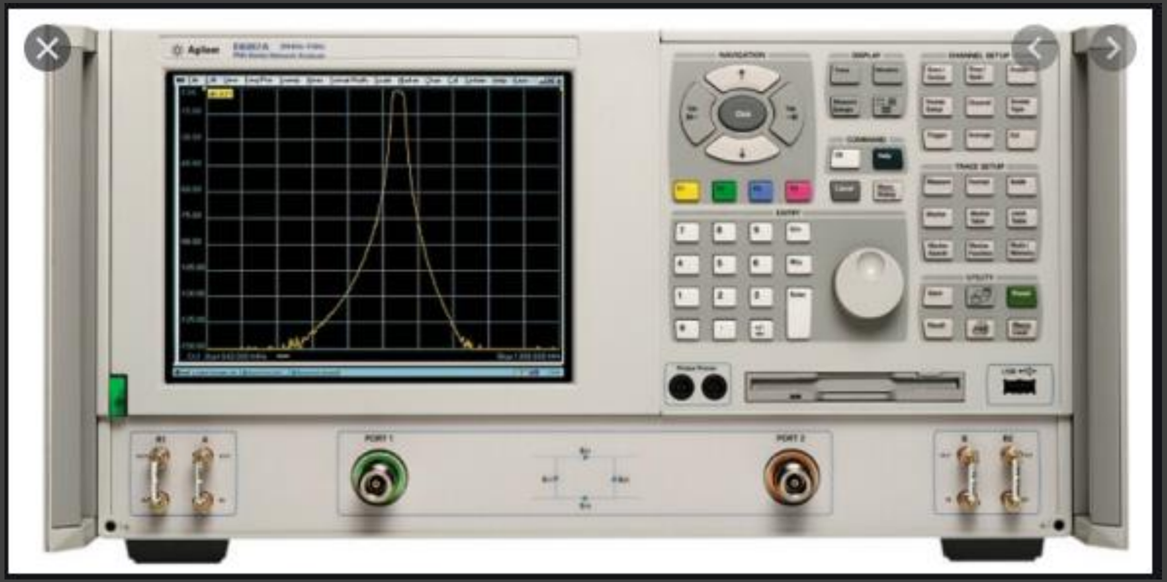
ABR Industries RG8X



Similar dielectric to 9913

S Parameters

- Maybe you have seen references to "S Parameters"? What do they mean?
- Refer to the Vector Network Analyzer shown
    - Port 1
    - Port 2
    - Each port can be configured to either be an RF source (TX) or a Receiver (RX)
- S Parameters – the numbers refer to the port of the VNA and the path of the Source-to-Receiver
    - S11 (VSWR or Return Loss to/from Port 1)
    - S12 (Path Loss from Port 1 to Port 2)
    - S21 (Path Loss from Port 2 to Port 1)
    - S22 (VSWR or Return Loss to/from Port 2)

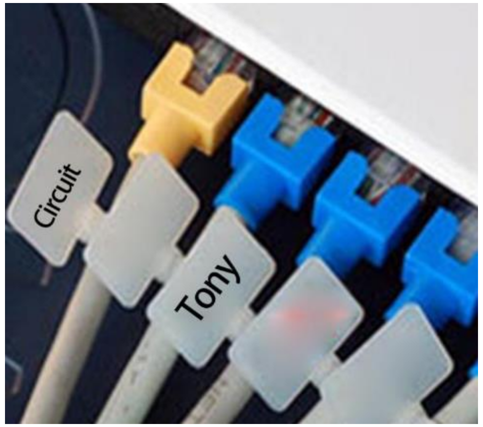


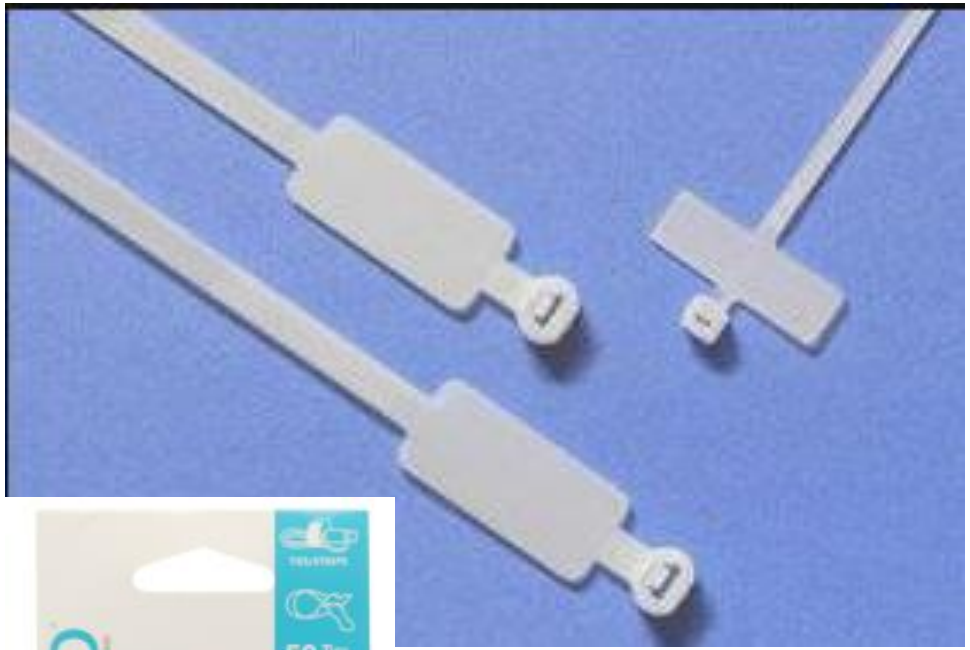
Cataloging Your Coax Jumpers

- Test the following:
  - Continuity from center conductor to center conductor on each end
  - Short circuit from center conductor to the shield
    - Static (not moving)
    - Dynamic (while moving the coax behind the connector)
  - VSWR (Return loss or S11/S22)
    - Must have a good 50 non-reactive dummy load on the opposite end of the coax
    - Static
    - Dynamic
  - Cable Loss (from end to end)

Labeling and Harnessing Methods

- Need to use method that does not wash off or peel off
- Zip ties with marker space
- Wire marker labels; self adhesive
- Velcro Thin Ties
- There are many other methods





Cataloged Cables

Measuring Cable Loss

Step 1

Input Power to Coax

Step 2

Output Power to Load

Jumper Cable Inventory – Raw Data

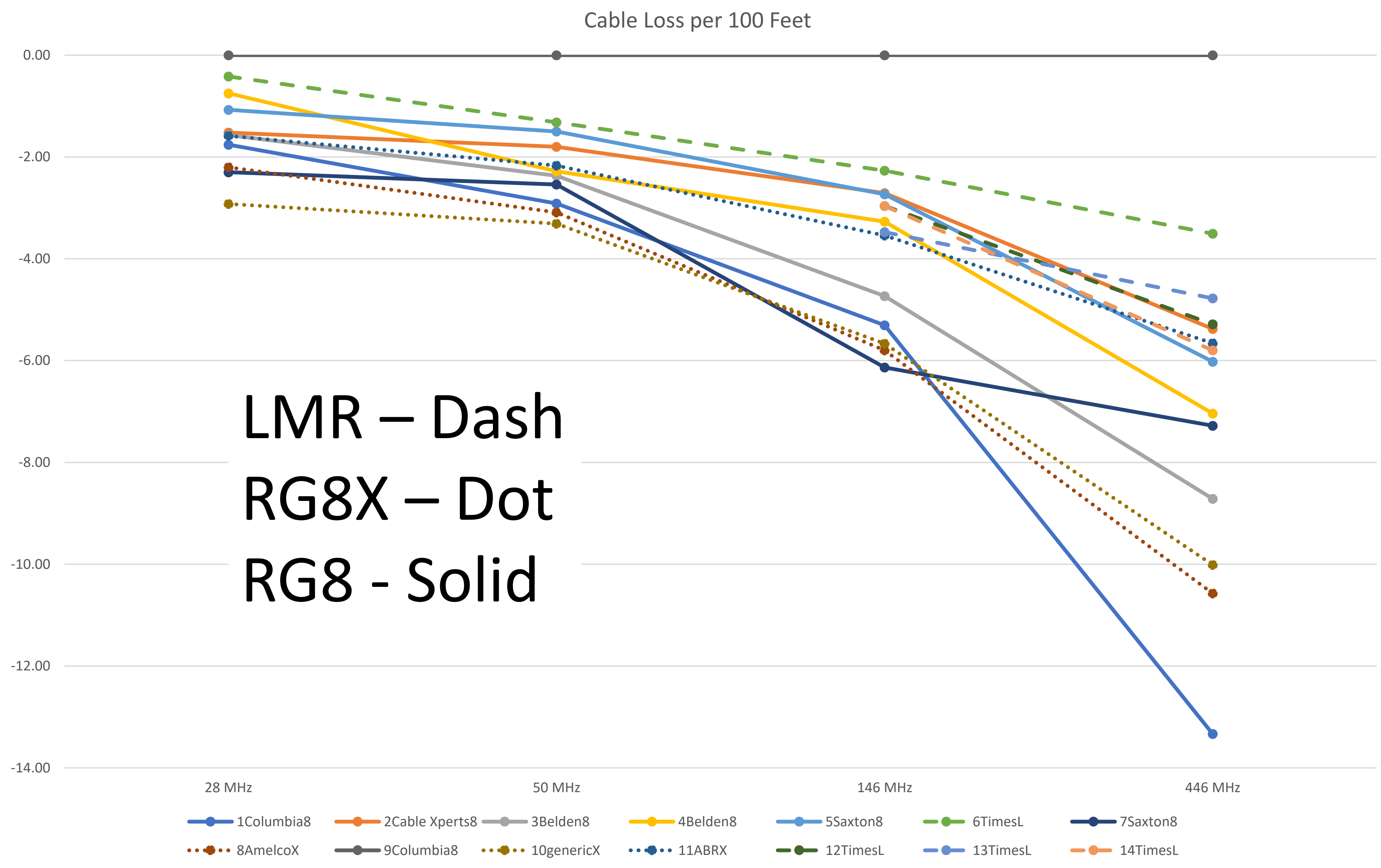
H4 =10*LOG(G4/F4)

Coaxial Cable Inventory and Measurements

					28 MHz			50 MHz			146 MHz			446 MHz		
Cable #	Type	Vendor	Type Abbr	Length (ft)	Input	Output	Loss	Input	Output	Loss	Input	Output	Loss	Input	Output	Loss
1	RG8	Columbia	8	75	84	62	-1.32	86	52	-2.18	10	4	-3.98	10	1	-10.00
2	RG8	Cable Xperts	8	44	84	72	-0.67	84	70	-0.79	10	7.6	-1.19	10	5.8	-2.37
3	8237 RG8	Belden	8	60	82	66	-0.94	86	62	-1.42	10	5.2	-2.84	10	3	-5.23
4	8237 RG8	Belden	8	29	82	78	-0.22	85	73	-0.66	10.2	8.2	-0.95	9.6	6	-2.04
5	RG8	Saxton	8	50	86	76	-0.54	82	69	-0.75	10	7.3	-1.37	10	5	-3.01
6	LMR400	Times	L	25	84	82	-0.10	82	76	-0.33	9.8	8.6	-0.57	9.3	7.6	-0.88
7	RG8	Saxton	8	18	88	80	-0.41	80	72	-0.46	9.8	7.6	-1.10	9.6	7.1	-1.31
8	RG8X	Amelco	X	64	83	60	-1.41	82	52	-1.98	9.4	4	-3.71	9.5	2	-6.77
9	RG8	Columbia	8	70			#DIV/0!			#DIV/0!			#DIV/0!			#DIV/0!
10	RG8X	generic	X	50	84	60	-1.46	82	56	-1.66	9.6	5	-2.83	9.5	3	-5.01
11	RG8X	ABR	X	100	85	59	-1.59	84	51	-2.17	9.5	4.2	-3.54	9.2	2.5	-5.66
12	LMR400	Times	L	10			#DIV/0!			#DIV/0!	9.1	8.5	-0.30	9.6	8.5	-0.53
13	LMR400	Times	L	10			#DIV/0!			#DIV/0!	9.1	8.4	-0.35	9.6	8.6	-0.48
14	LMR400	Times	L	10			#DIV/0!			#DIV/0!	9.1	8.5	-0.30	9.6	8.4	-0.58
15	LMR400	Times	L	10			#DIV/0!			#DIV/0!	7.4	7	-0.24	6.6	5.75	-0.60
16	LMR400	Times	L	10			#DIV/0!			#DIV/0!	8.1	7.8	-0.16	6.6	6	-0.41
							#DIV/0!			#DIV/0!			#DIV/0!			#DIV/0!

Scaled to 100 Feet to Compare Advertised Specs

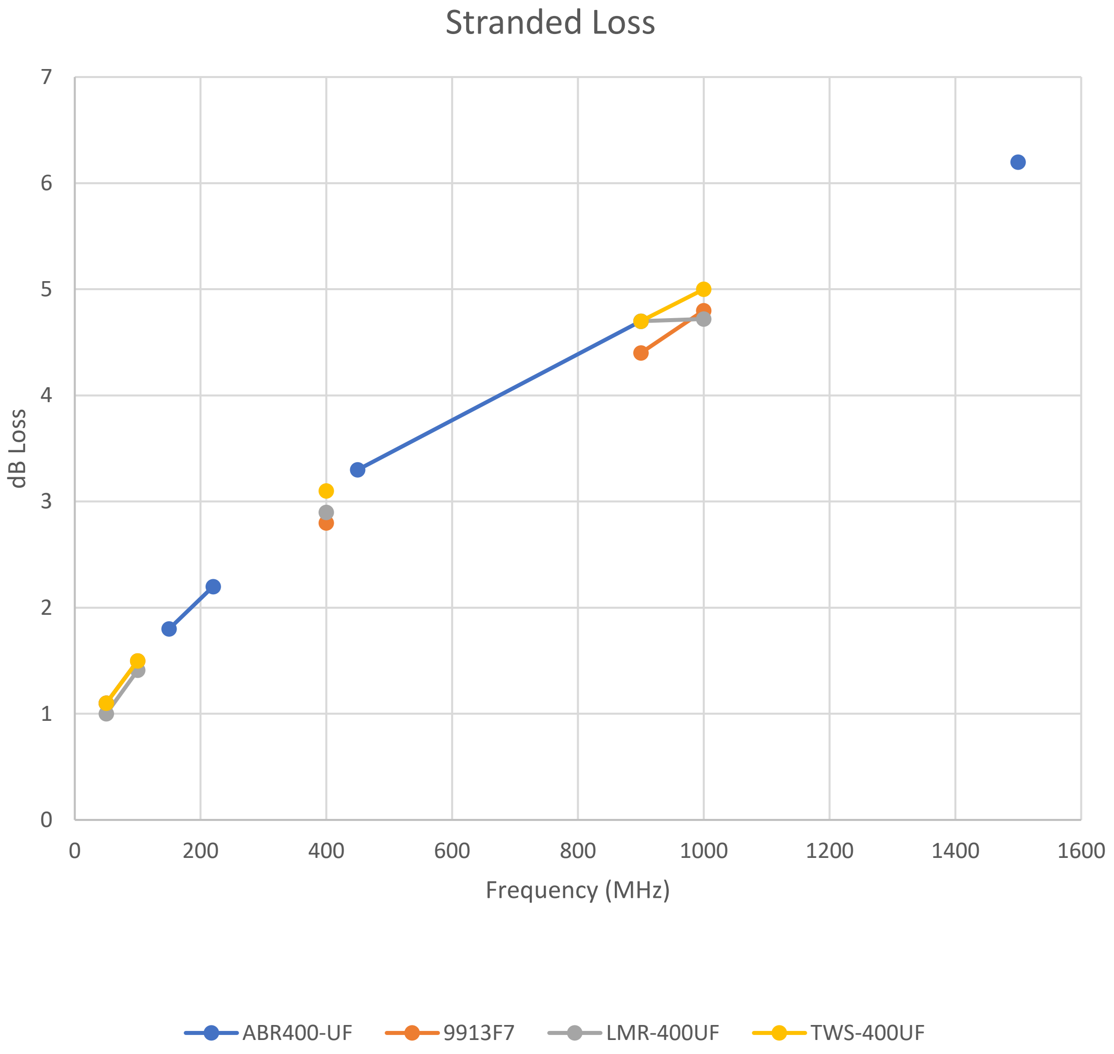
					28 MHz			50 MHz			146 MHz			446 MHz		
Cable #	Type	Vendor		Length (ft)	Input	Output	Loss	Input	Output	Loss	Input	Output	Loss	Input	Output	Loss
1	RG8	Columbia		75	84	62	-1.76	86	52	-2.91	10	4	-5.31	10	1	-13.33
2	RG8	Cable Xperts		44	84	72	-1.52	84	70	-1.80	10	7.6	-2.71	10	5.8	-5.38
3	8237 RG8	Belden		60	82	66	-1.57	86	62	-2.37	10	5.2	-4.73	10	3	-8.71
4	8237 RG8	Belden		29	82	78	-0.75	85	73	-2.28	10.2	8.2	-3.27	9.6	6	-7.04
5	RG8	Saxton		50	86	76	-1.07	82	69	-1.50	10	7.3	-2.73	10	5	-6.02
6	LMR400	Times		25	84	82	-0.42	82	76	-1.32	9.8	8.6	-2.27	9.3	7.6	-3.51
7	RG8	Saxton		18	88	80	-2.30	80	72	-2.54	9.8	7.6	-6.13	9.6	7.1	-7.28
8	RG8X	Amelco		64	83	60	-2.20	82	52	-3.09079	9.4	4	-5.79794	9.5	2	-10.5733
9	RG8	Columbia		70	0	0	#DIV/0!	0	0	#DIV/0!	0	0	#DIV/0!	0	0	#DIV/0!
10	RG8X	generic		50	84	60	-2.92256	82	56	-3.31252	9.6	5	-5.66602	9.5	3	-10.012
11	RG8X	ABR		100	85	59	-1.58567	84	51	-2.16709	9.5	4.2	-3.54474	9.2	2.5	-5.65848
12	LMR400	Times		10	0	0	#DIV/0!	0	0	#DIV/0!	9.1	8.5	-2.96225	9.6	8.5	-5.28523
13	LMR400	Times		10	0	0	#DIV/0!	0	0	#DIV/0!	9.1	8.4	-3.47621	9.6	8.6	-4.77728
14	LMR400	Times		10	0	0	#DIV/0!	0	0	#DIV/0!	9.1	8.5	-2.96225	9.6	8.4	-5.79919
15	LMR400	Times		10	0	0	#DIV/0!	0	0	#DIV/0!	7.4	7	-2.41337	6.6	5.75	-5.98761
16	LMR400	Times		10	0	0	#DIV/0!	0	0	#DIV/0!	8.1	7.8	-1.63904	6.6	6	-4.13927
0	0	0		0	0	0	#DIV/0!	0	0	#DIV/0!	0	0	#DIV/0!	0	0	#DIV/0!

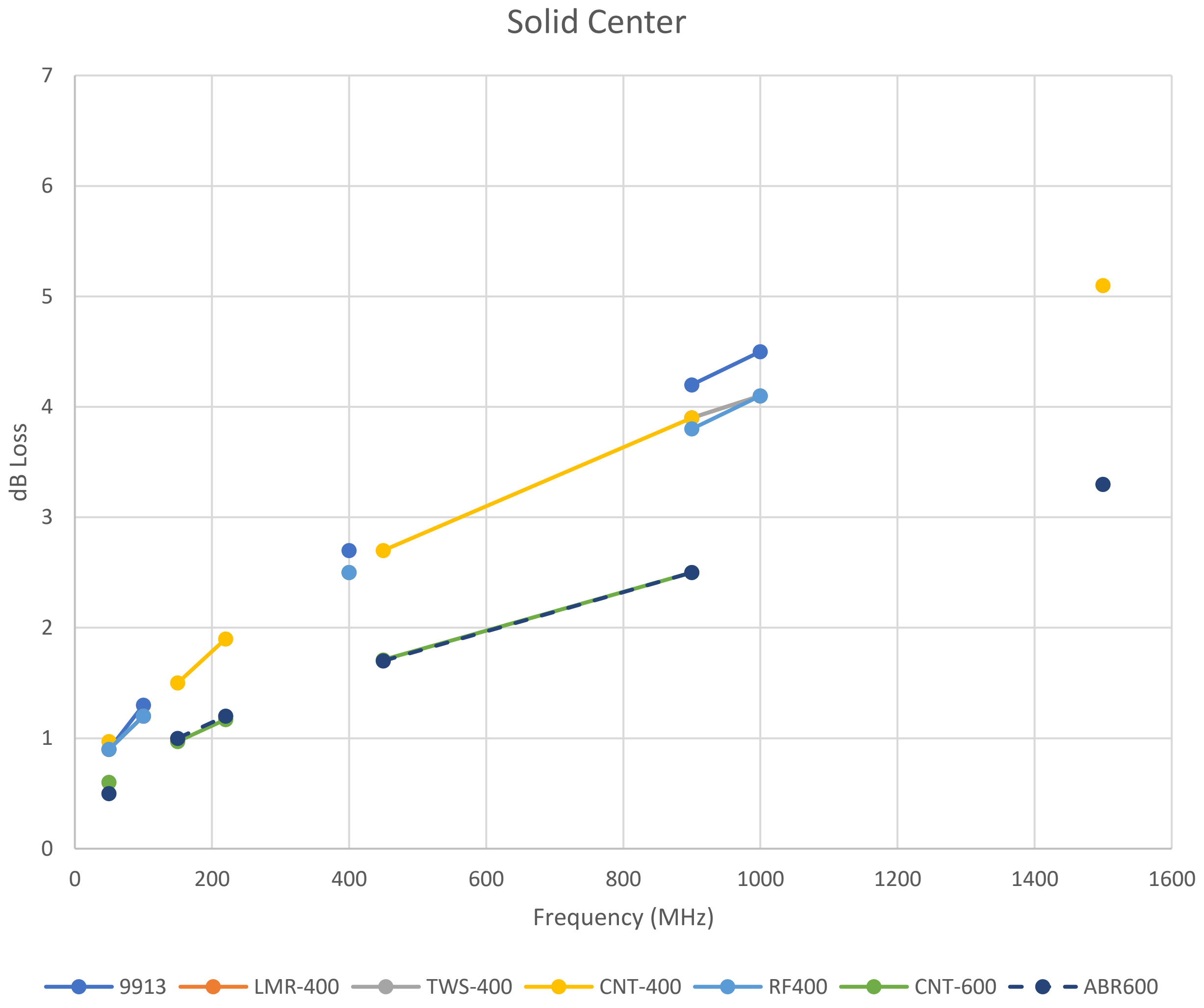

Cable Loss per 100 Feet
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
28 MHz
50 MHz
146 MHz
446 MHz
LMR – Dash
RG8X – Dot
RG8 - Solid
1Columbia8
2Cable Xperts8
3Belden8
4Belden8
5Saxton8
6TimesL
7Saxton8
8AmelcoX
9Columbia8
10genericX
11ABRX
12TimesL
13TimesL
14TimesL

Comparing LMR Type Cables

Coax Comparison	Attenuation per 100 feet (-dB)											
Cost per foot	$ 1.09	$ 1.09	$ 1.49	$ 0.99		$ 0.99	$ 0.99	$ 0.79	$ 1.29	$ 0.99	$ 2.00	
	Stranded Center Conductor					Solid Center Conductor						
Freq (MHz)	ABR400-UF	9913F7	LMR-400UF	TWS-400UF		9913	LMR-400	TWS-400	CNT-400	RF400	CNT-600	ABR600
50	1.1	1.1	1	1.1	50	0.9	0.9	0.9	0.97	0.9	0.6	0.5
100		1.5	1.41	1.5	100	1.3	1.2	1.2		1.2		
150	1.8				150				1.5		0.97	1
220	2.2				220				1.9		1.17	1.2
400		2.8	2.9	3.1	400	2.7	2.5	2.5		2.5		
450	3.3				450				2.7		1.71	1.7
900	4.7	4.4	4.7	4.7	900	4.2	3.9	3.9	3.9	3.8	2.5	2.5
1000		4.8	4.72	5	1000	4.5	4.1	4.1		4.1		
1500	6.2				1500				5.1		3.3	3.3

LMR400 Stranded vs Solid Center Conductor





Type N vs UHF PL-259 - Mechanical

- Type N Pros
  - Watertight connector
  - 50 Ohm for minimal loss

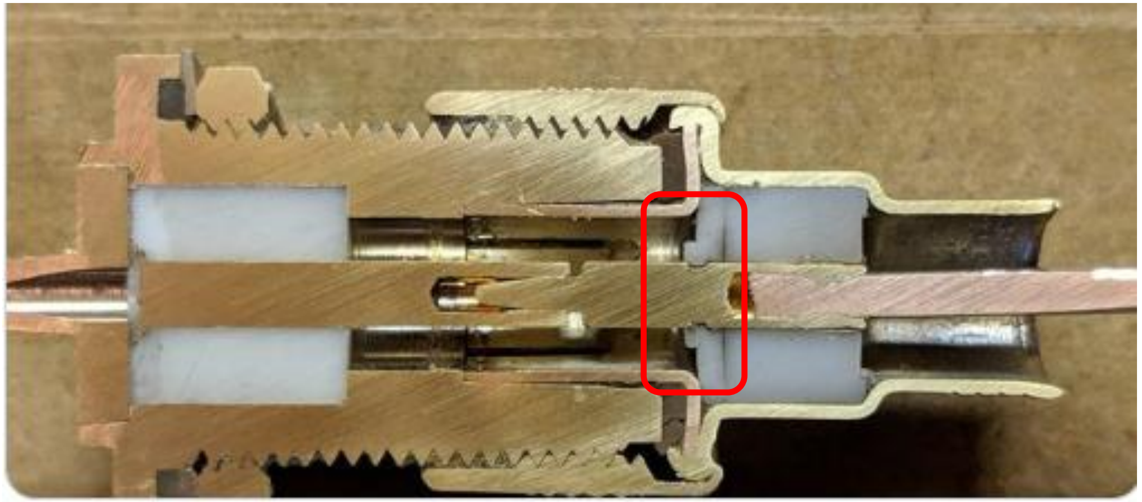
Type N Cons
  - Center conductor pin slides in Teflon insulator – not captured
  - Cable is held by shield wires via clamp – medium pull strength
  - Avoid crimp connector types when good mechanical strength is needed
  - Higher connector cost

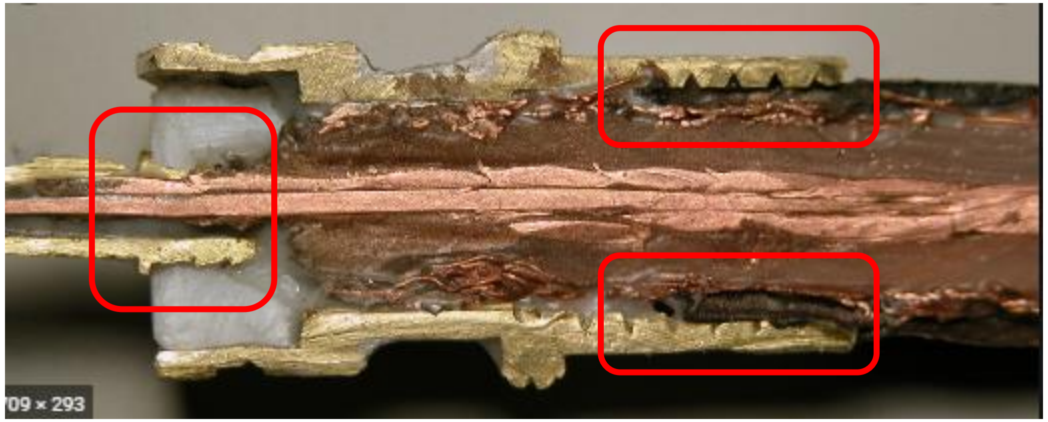
- PL-259 Pros
  - Center pin is molded into the connector insulator
  - Center conductor is soldered into center pin for good mechanical strength
  - Outer conductor threads into the coax jacket for very good linear strength
  - Low cost connector

PL-259 Cons
  - Requires additional waterproofing
  - Not a 50 Ohm connector
  - Avoid crimp connector types when good mechanical strength is needed

This is what happens when 75 feet of LMR400 is suspended from a Type N Male connector

Cross section of Type N and PL 259 connectors

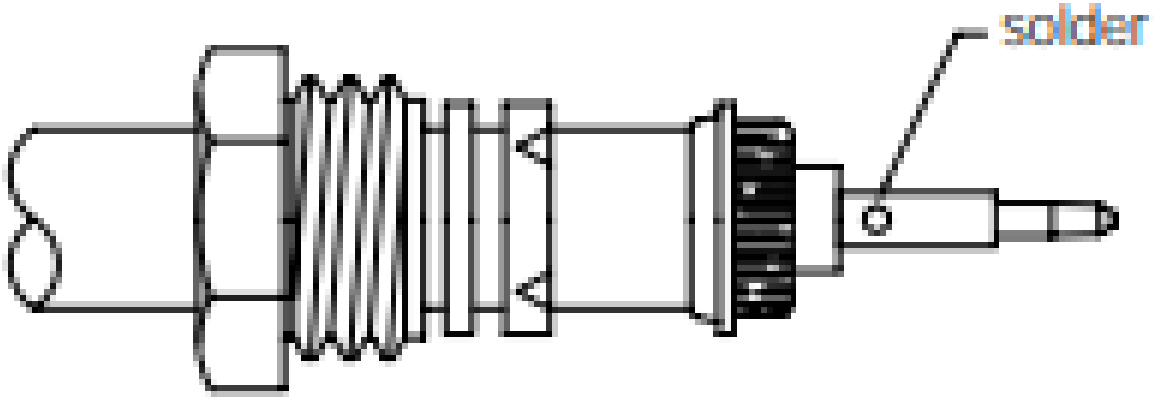




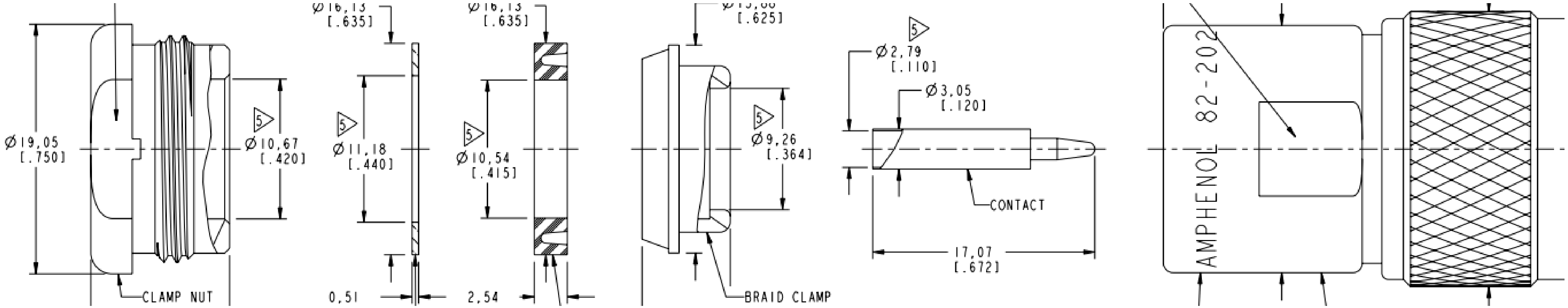
Note the areas highlighted in red.

- For Type N – this is mainly for centering the pin at the correct depth
- For PL-259 – note that there are several barbs and threads that grab the coaxial cable conductor and jacket

Amphenol Type N Male Connector

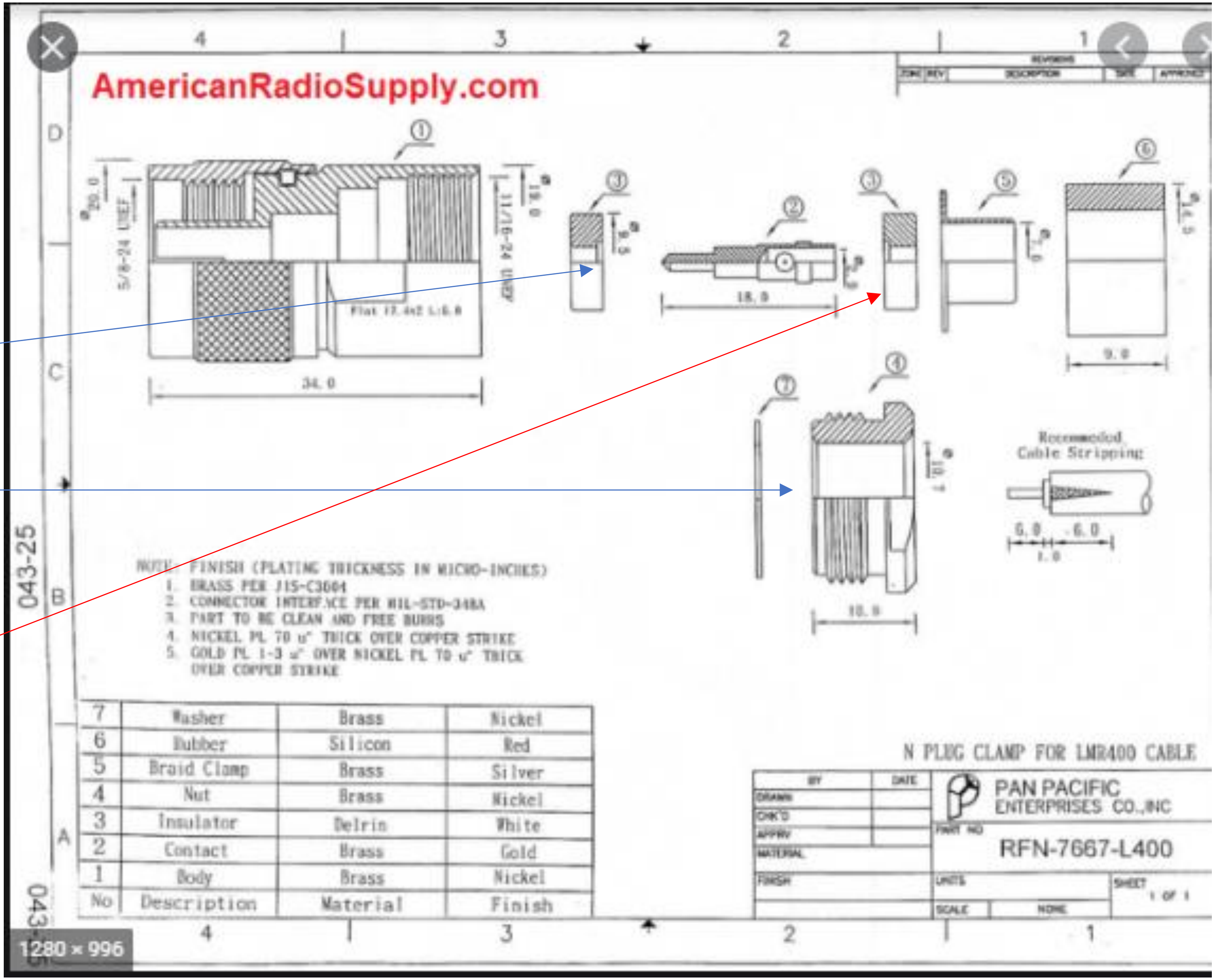


- Exploded View
    - The male center conductor pin has a smooth surface that does not “grab” the interior of the center insulator. Therefore it is easy to pull out



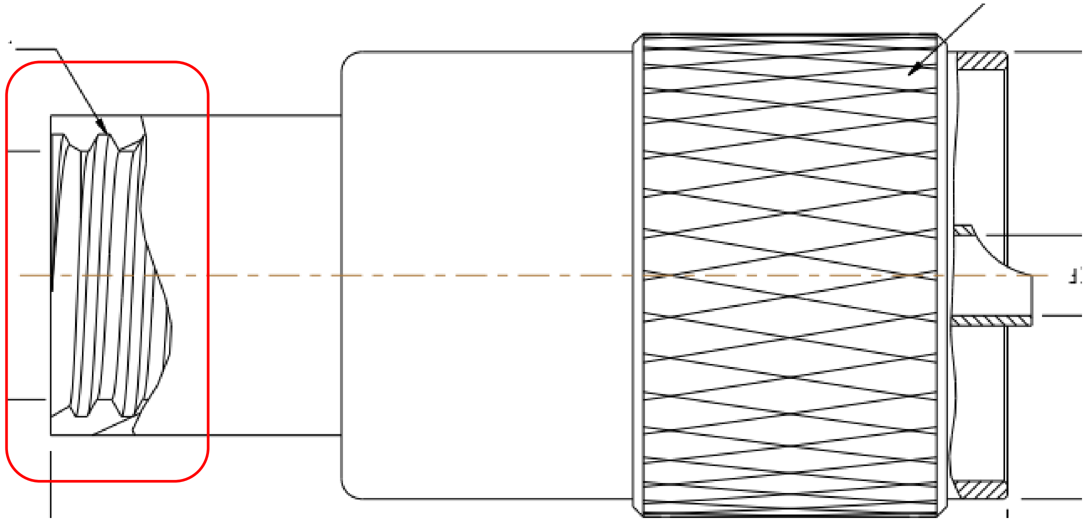
Type N with Clamp

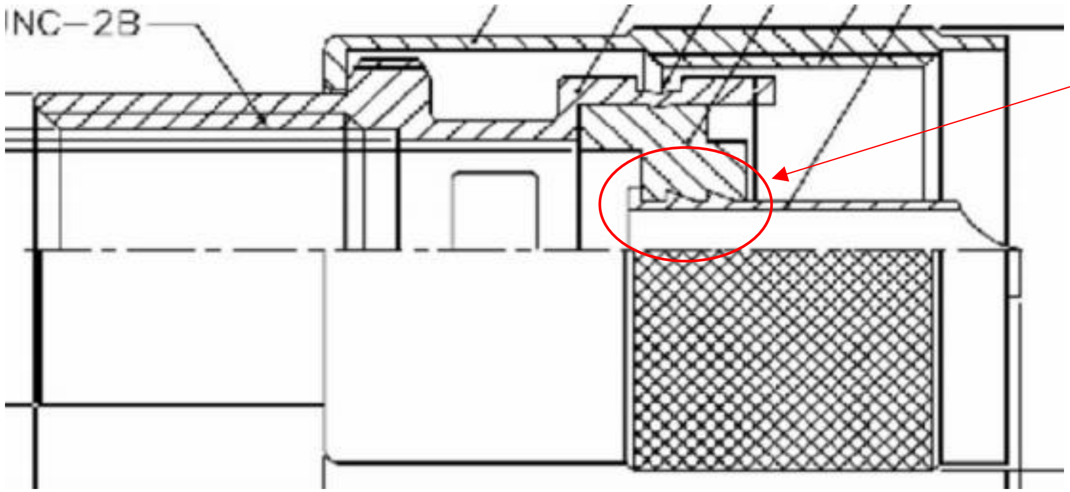
- Center pin can pull out of insulator
- Clamp Nut compresses the braid against the inside of the connector body but what is to prevent the braid from slipping out?
- With this design, there is an extra insulator which should provide additional pull strength but this is not included in most Type N connector models



PL-259 Connector Cross-Section

Inside of outer conductor is threaded and grips into the coaxial cable jacket for additional pull strength as well as limited weather sealing





Note the barbs of the center conductor as they grab the center insulator

References

- https://www.rfcables.org/articles/18.html
- https://www.digikey.com/en/blog/the-reasons-for-50-ohm-and-75-ohm-transmission-lines#:~:text=As%20with%20most%20engineering%20decisions,:1%20is%20considered%20acceptable).
- Gain/Loss calculator
  - http://www.sengpielaudio.com/calculator-amplification.htm
- Cable Specs
  - http://rfelektronik.se/manuals/Datasheets/Coaxial_Cable_Attenuation_Chart.pdf
- KE5EE monster antenna farm
  - https://www.qrz.com/db/KE5EE?fbclid=IwAR3rvbwi05g6NB00hTk5npldvGUbb80Vec6hvNpK5tpRrX6kjS2Rm-mjpMU