Transmission Lines

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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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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!

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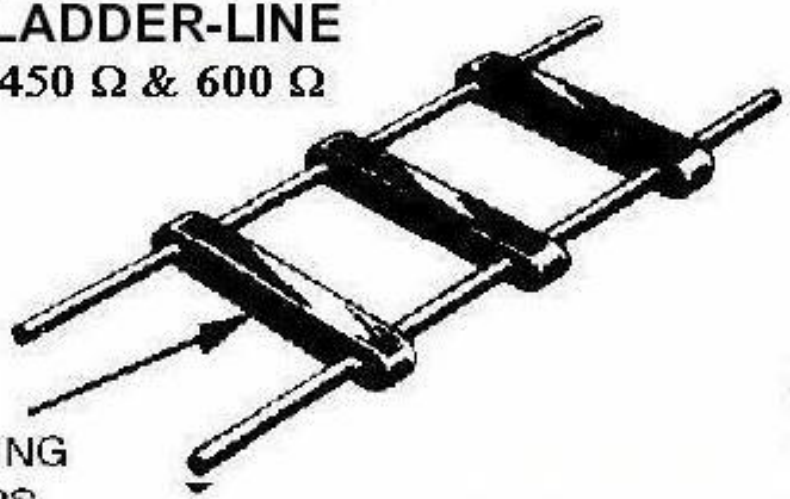
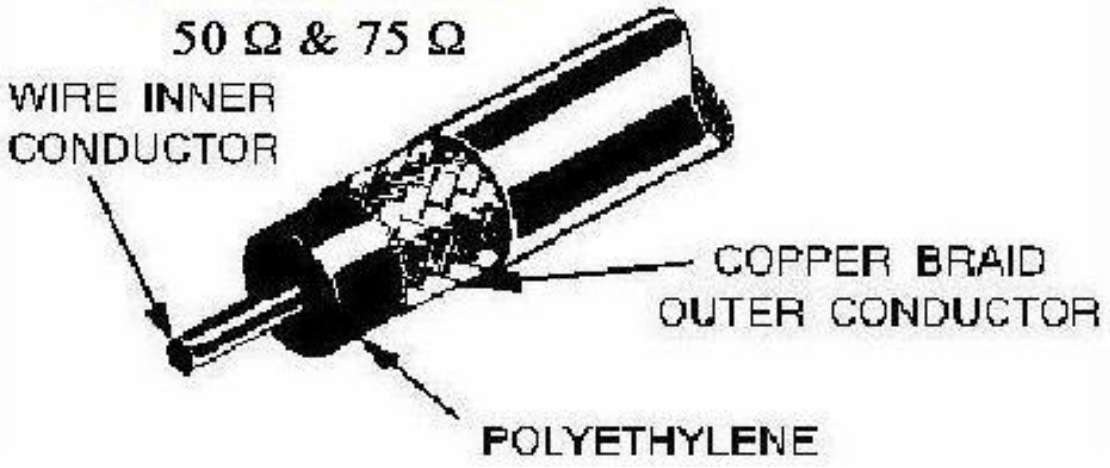
RF Transmission and Reception
Feedline Types

"LADDER-LINE
450 Ω & 600 Ω



"TWIN LEAD"
300 Ω

"COAXIAL CABLE"
50 Ω & 75 Ω



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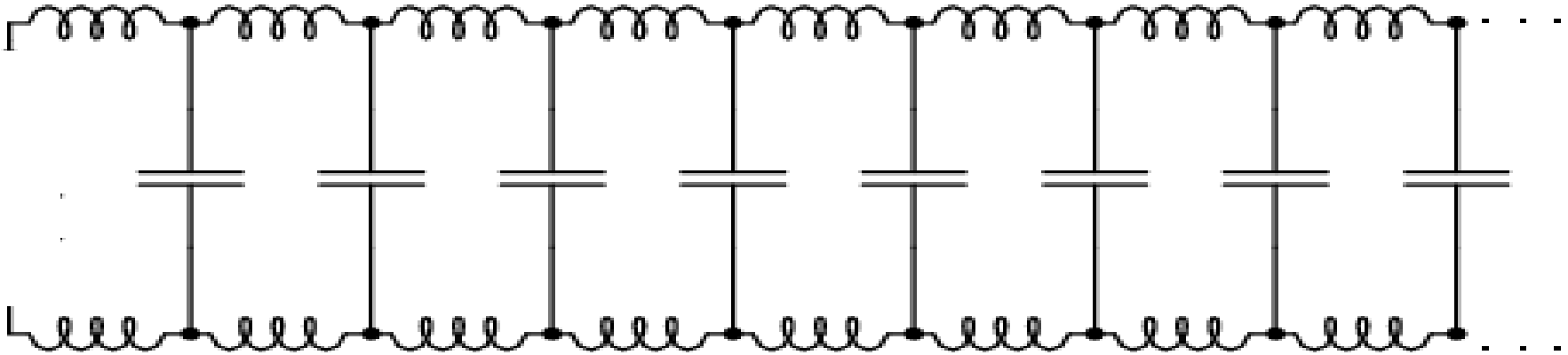
Characteristic Impedance



- 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

- 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.

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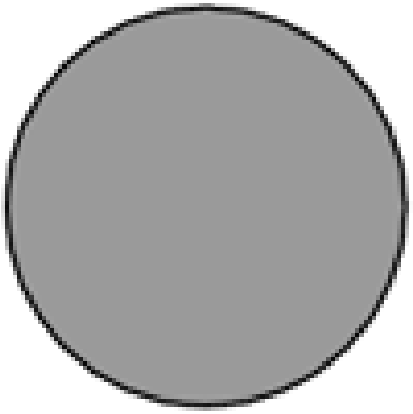
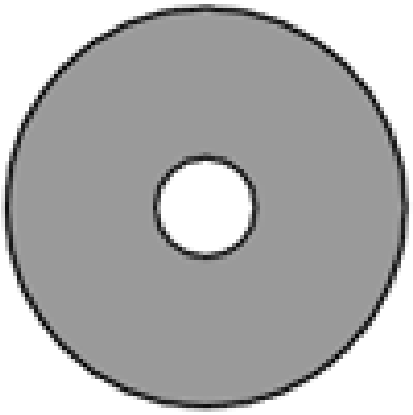


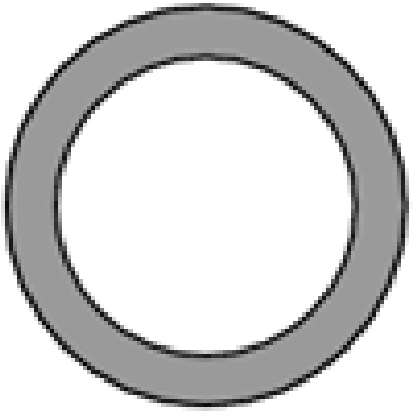
Cross-sectional area of a round conductor available for conducting DC current

"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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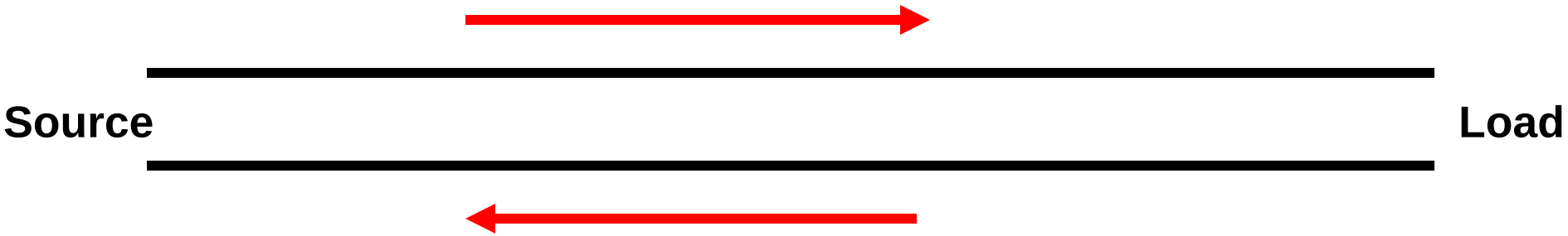
Balanced Transmission Line

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



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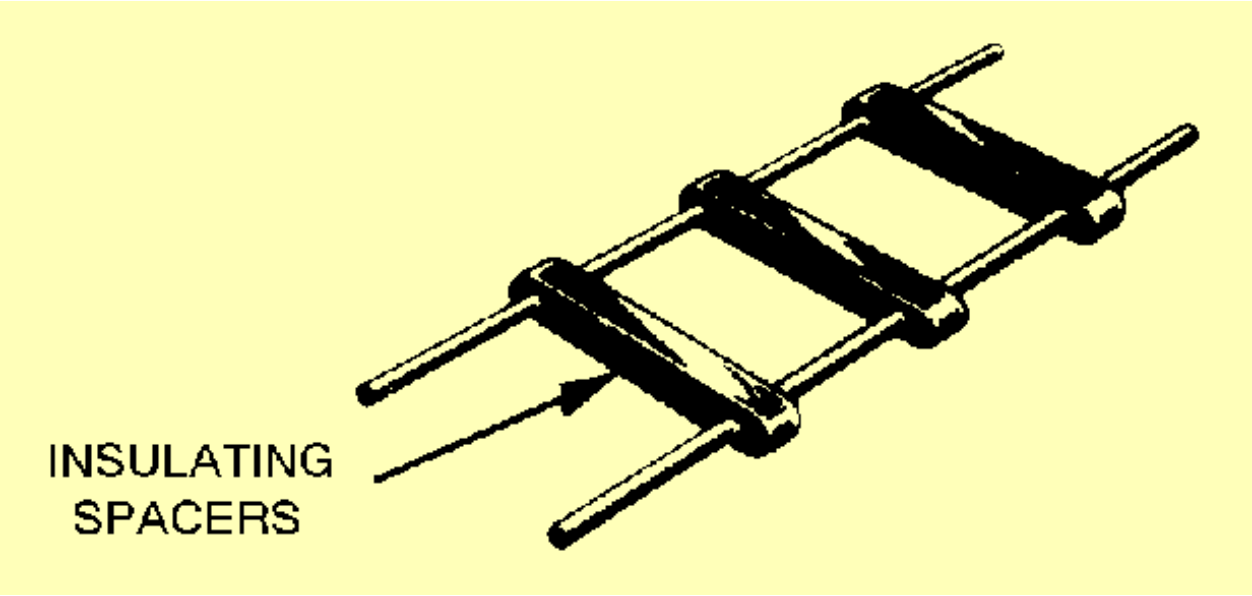
Open Wire Feedline

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



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Insulated Twin Lead

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

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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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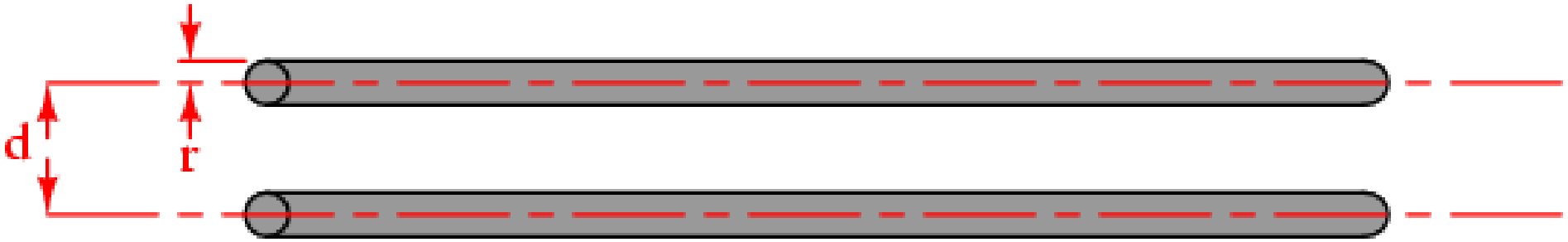
Characteristic Impedance



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

Where,

Z_0 = Characteristic impedance of line

d = Distance between conductor centers

r = Conductor radius

k = Relative permittivity of insulation between conductors

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Advantages of Balanced Line

- Lower losses at high SWR than coax cable.
- Can be made at home.
- Often cheaper than coax cable.

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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 is generally higher than what most radios are designed for, so an impedance matching device is necessary.

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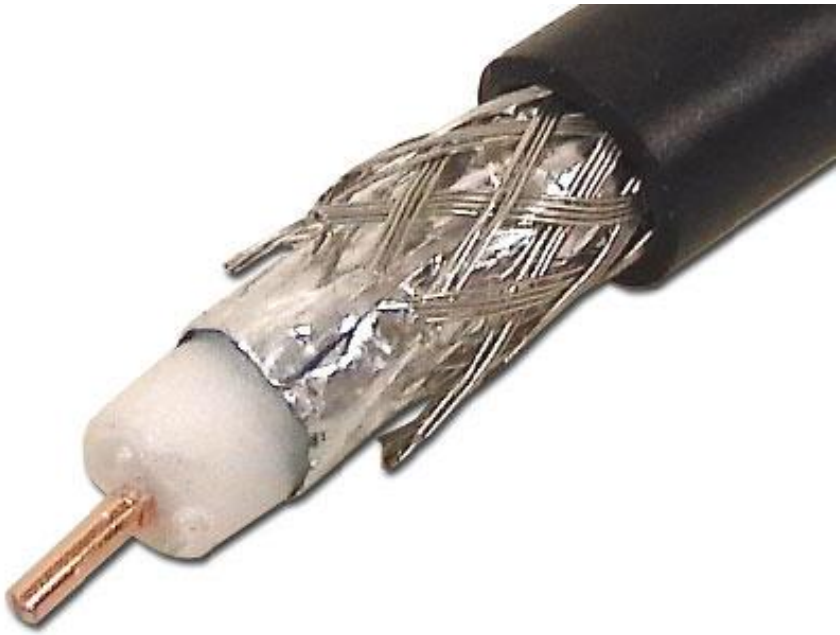
Unbalanced Transmission Line

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



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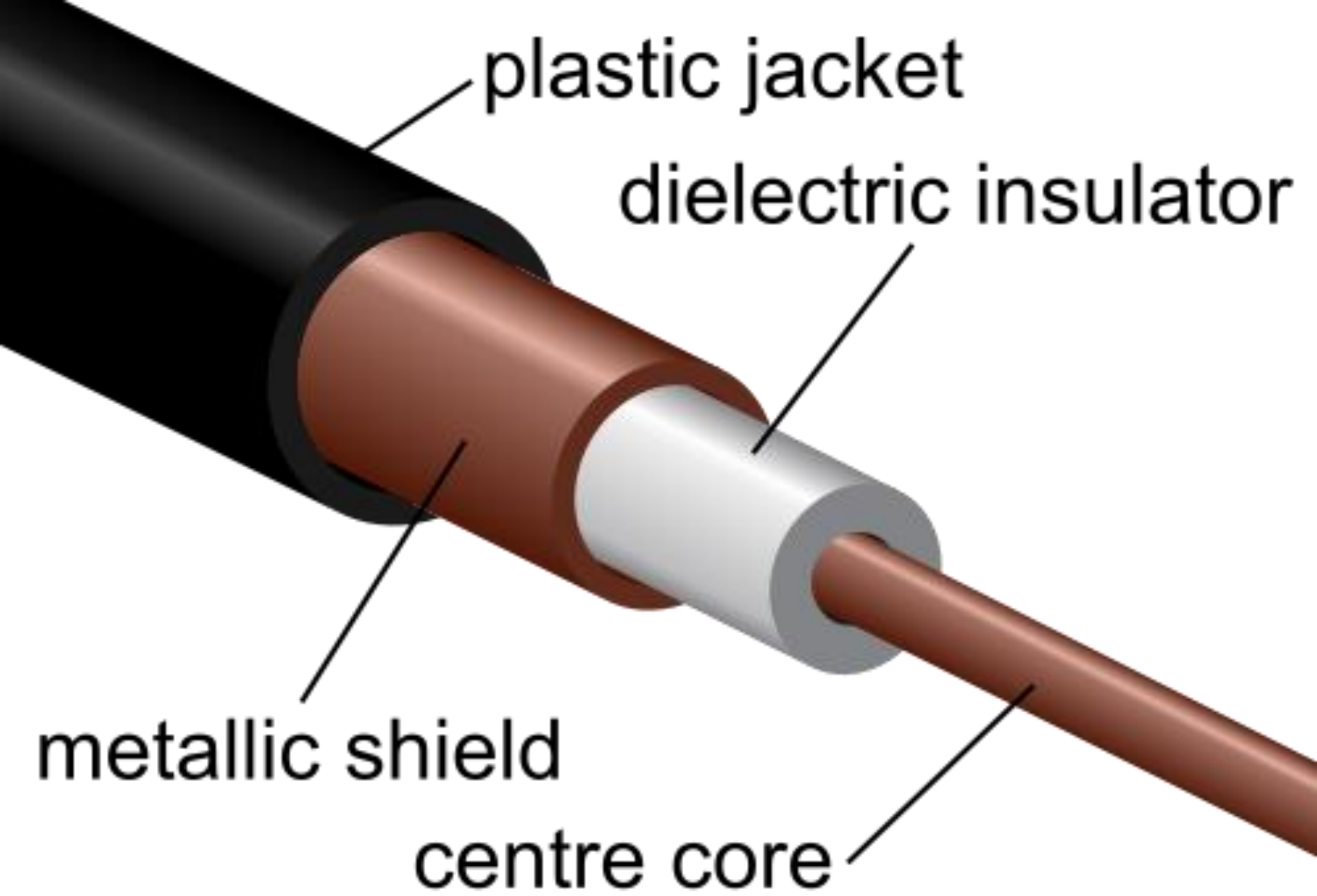

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COAXIAL CABLE

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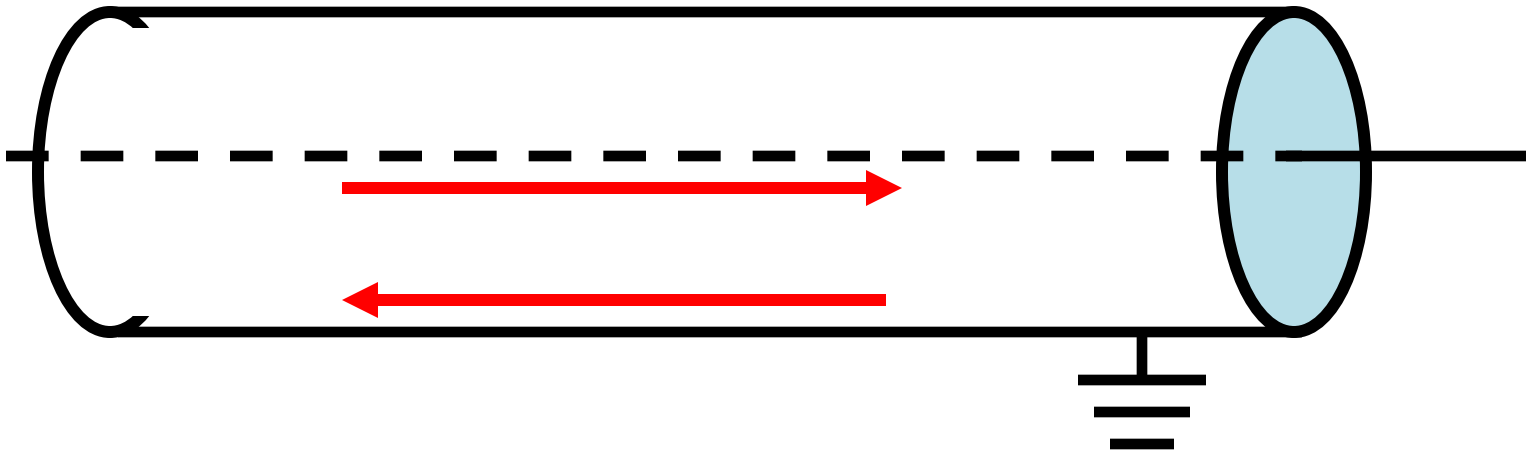
Currents in Unbalanced Line



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

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

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

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Advantages of Unbalanced Line

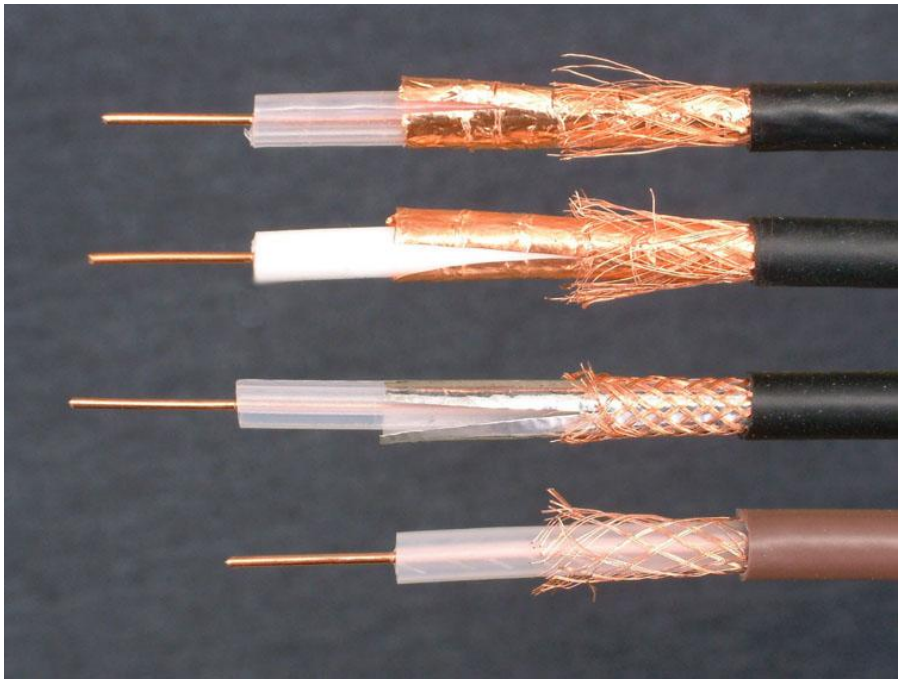
- Can be run alongside metal or buried.
- Same impedance as that required by our radios.
- Convenient to use.
- Weatherproof.

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”.

Beware Cheap Coax Cable!

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



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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.
- Typical VF
  - Open Wire Feedline 80 – 92%
  - Ladder Line 91%
  - Coax (polyethylene dielectric) 66%
  - Coax (foamed polyethylene dielectric) 84%

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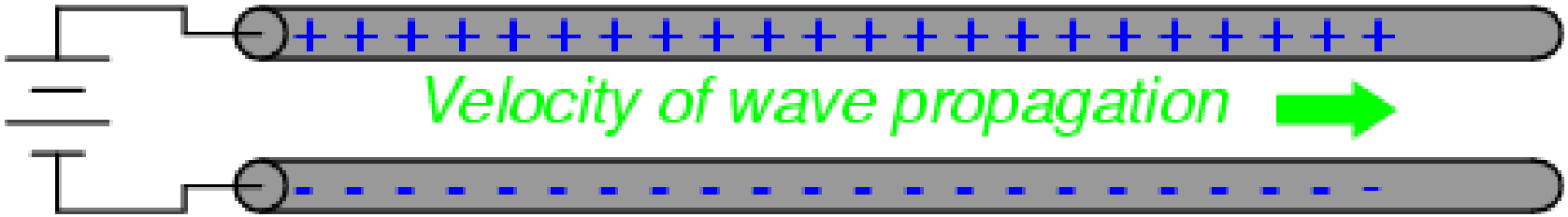

$$\text{Velocity factor} = \frac{v}{c} = \frac{1}{\sqrt{k}}$$

Where,

v = Velocity of wave propagation

c = Velocity of light in a vacuum

k = Relative permittivity of insulation between conductors

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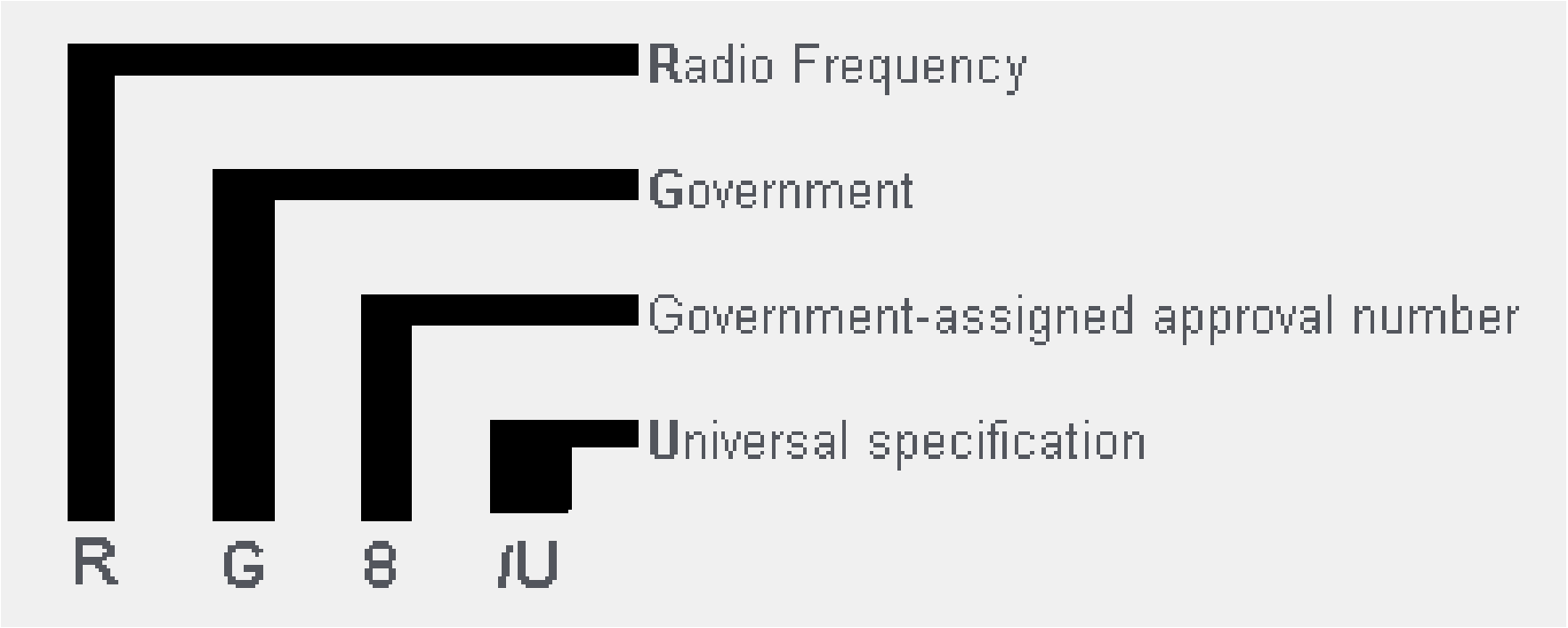
Coax Cable Designations



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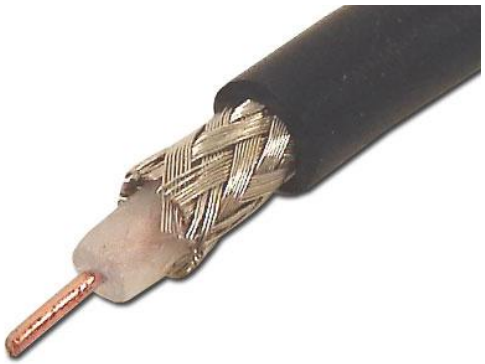
RG58/U



- 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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RG8/U

- Used to be the standard 50 Ohm cable.
- Influx of cheap “RG8 Type” cables caused US Government to change to RG213 as the standard 50 Ohm cable.
- Diameter ~ 1 cm.
- Much lower loss than RG-58.
- Full legal limit on HF.

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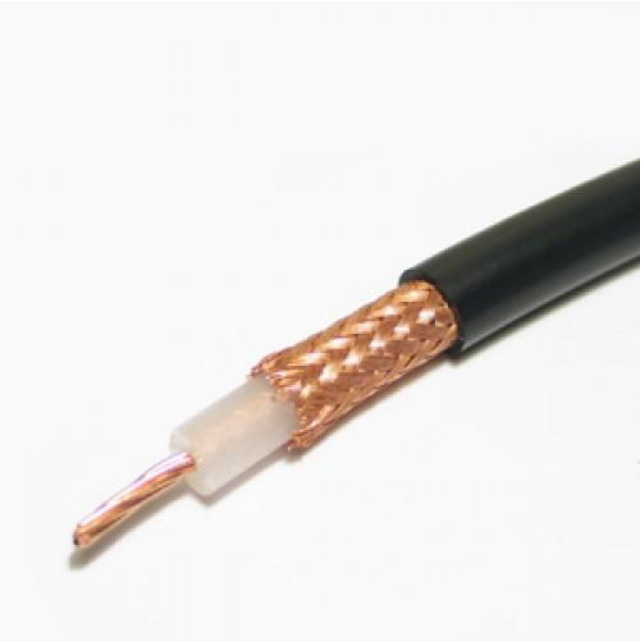
RG213/U

- Quality 50 Ohm cable.
- Full legal limit on HF.
- RG214/U is identical but has 2 shields.



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RG59/U

- 75 Ohm cable meant primarily for TV.
- Suitable for low power use on HF – 400 watts.
- Also good for specialized receive antennas.
- RG11 is a higher power version.

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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.

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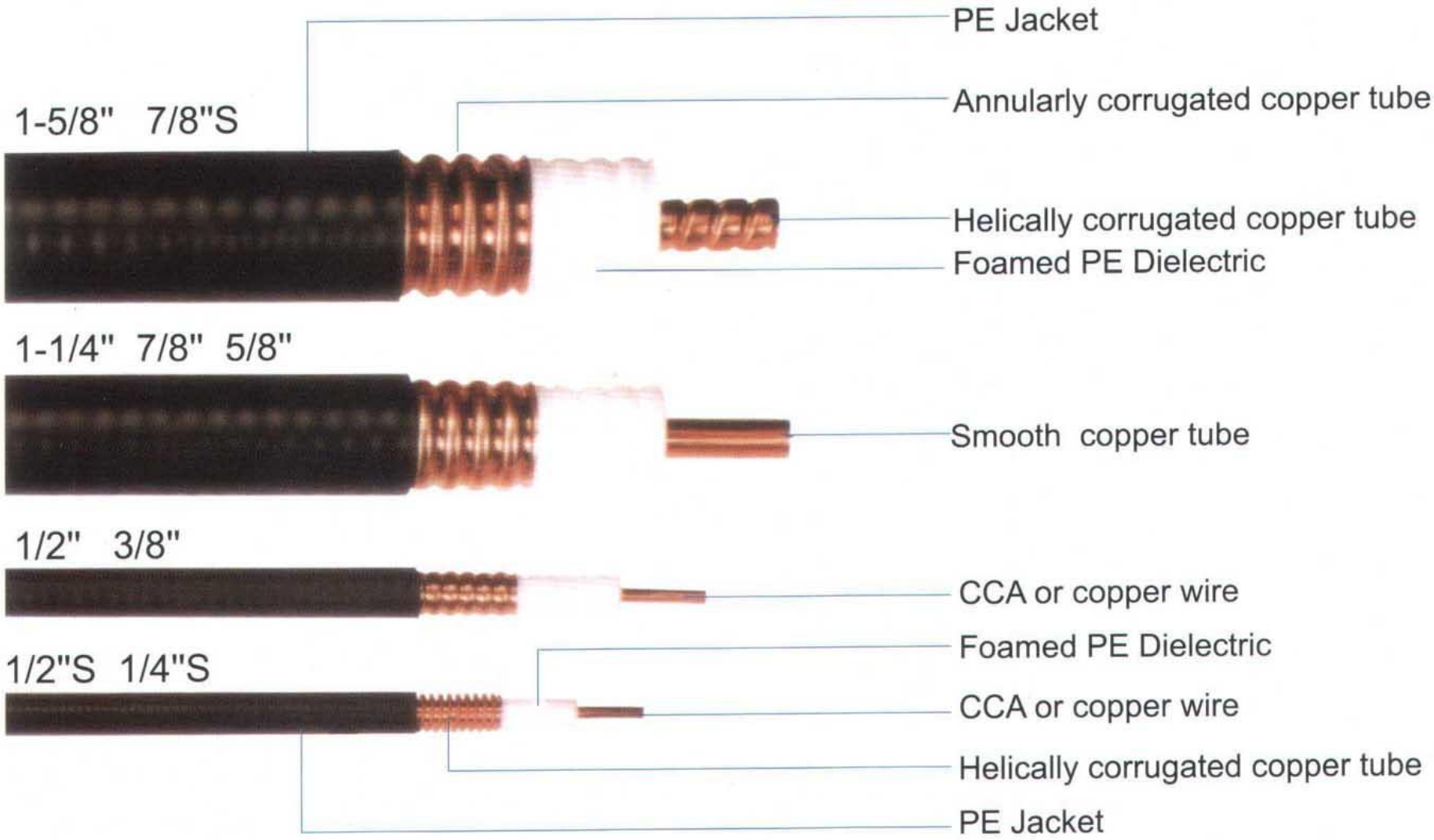

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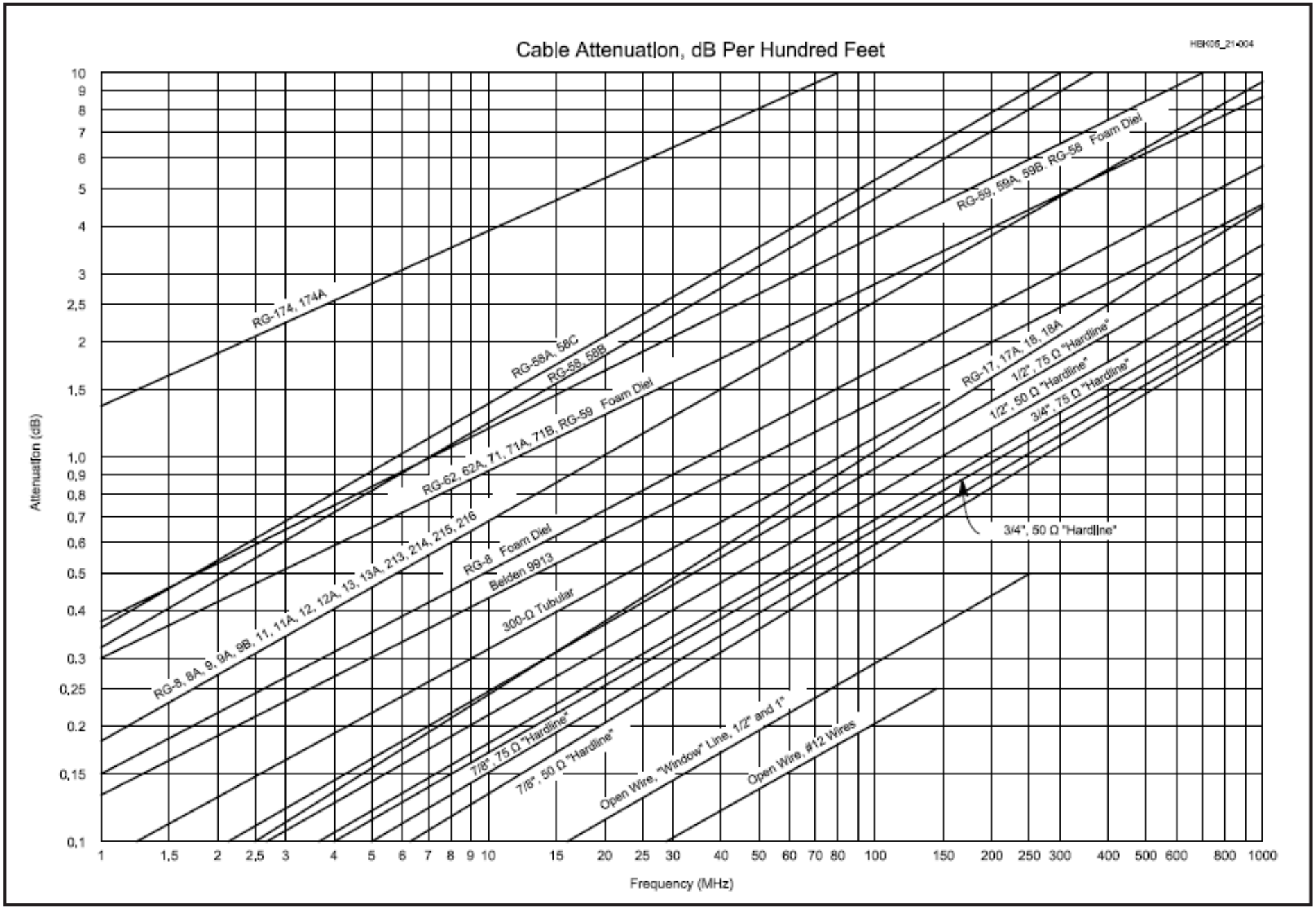
Nominal Characteristics of Commonly Used Transmission Lines

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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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 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 and silver coating.

PL259 and SO239

- Called “UHF” connectors.
- Good on HF, somewhat useful on 2M, not any higher in frequency however.
- Connects to RG8/U and RG213/U cable.
- PL259 plugs into SO239.
- NOT weatherproof!

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Using PL259 with RG58/U

- An UG175 adaptor is needed to attach a PL259 to RG58/U.
- Get the right one – similar looking adaptors exist for RG59, but have a different diameter.

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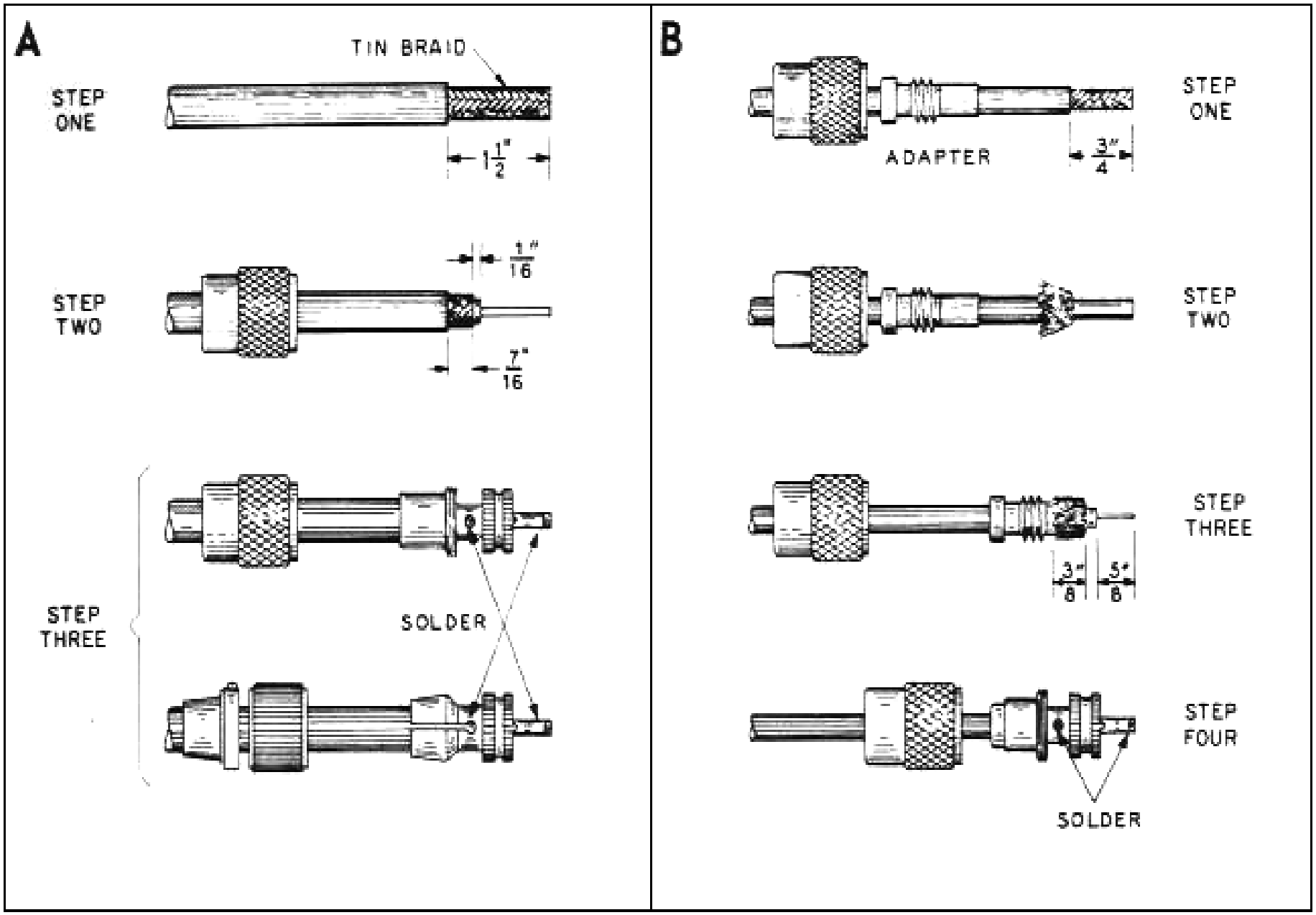
A
TIN BRAID
STEP ONE
1 1/2"
1/16"
STEP TWO
7/16"
STEP THREE
SOLDER
B
STEP ONE
ADAPTER
3/4"
STEP TWO
STEP THREE
3/8"
5/8"
STEP FOUR
SOLDER

BNC Connectors

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

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N Connectors

- Named after Paul Neill, of Bell Labs.
- Fits RG8/u, RG213/U and other cables.
- Good to 11 GHz or higher, at full legal limit in lower bands.
- Waterproof.

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F Connectors

- Used on RG59 and RG6 for TV applications.
- Some use them for receive antennas.
- Easy to attach, but not very strong or waterproof.

Adaptors

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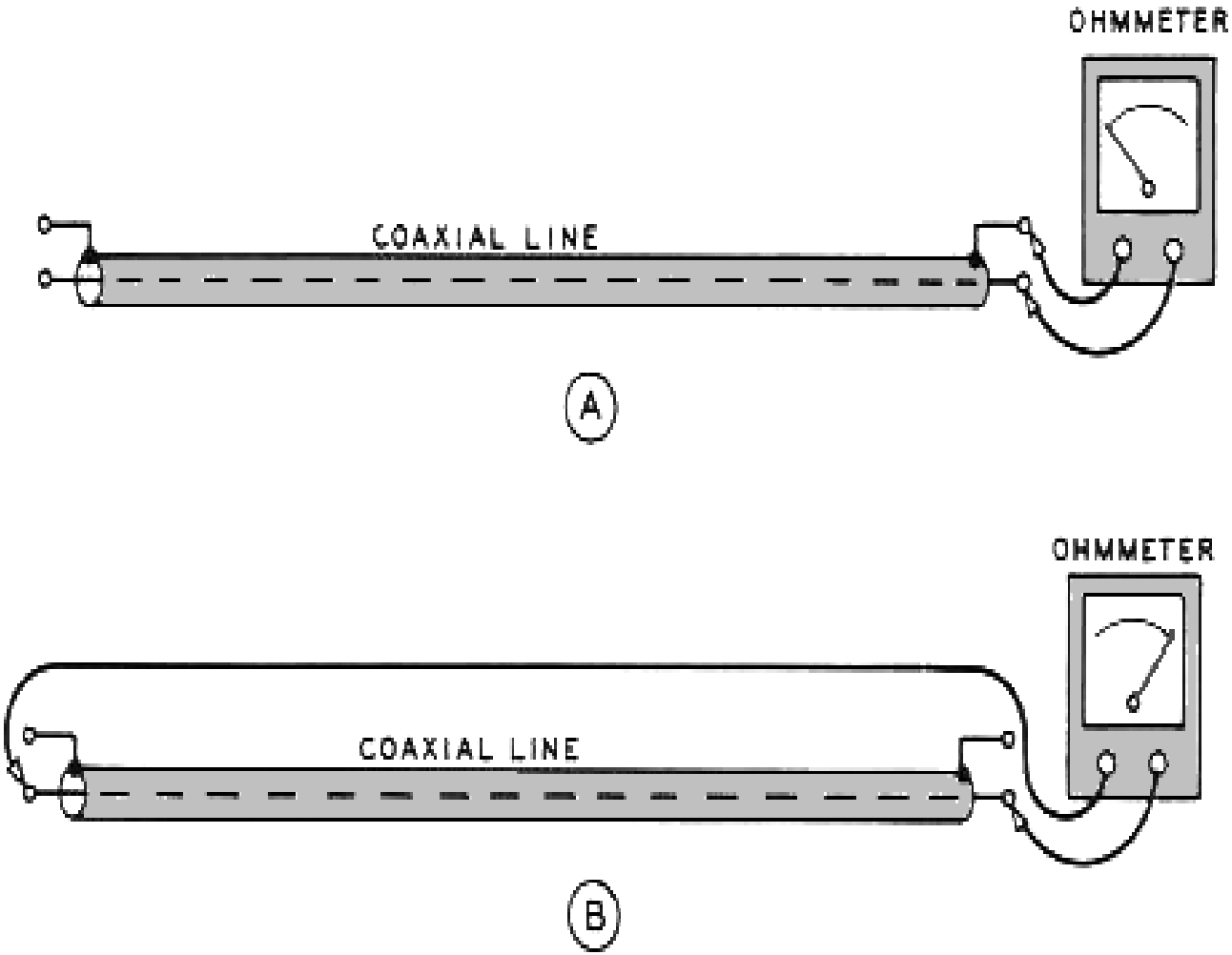
OHMMETER
COAXIAL LINE
A
OHMMETER
COAXIAL LINE
B

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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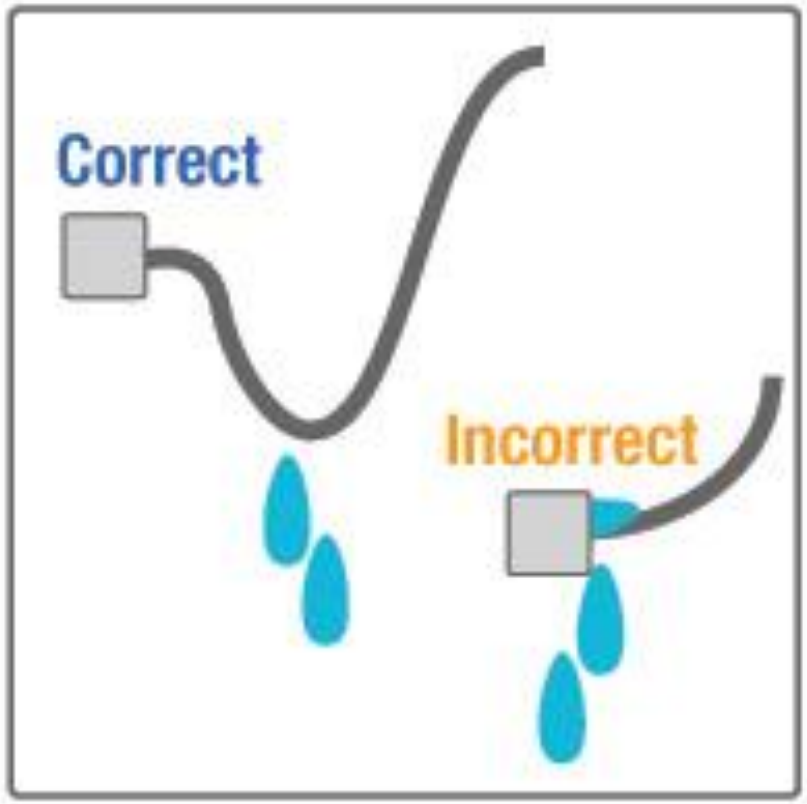
Drip Loop



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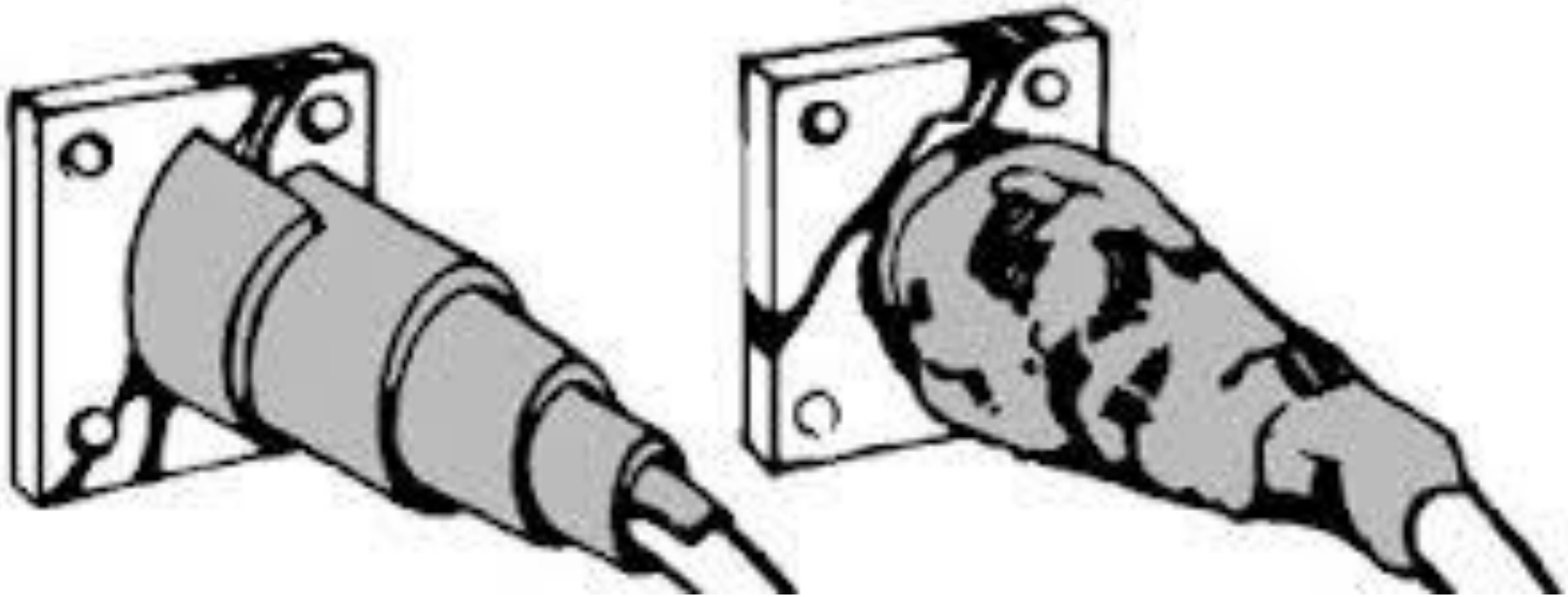

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Baluns

- **Bal**anced to **Un**balanced
- Enables the transition from a balanced feedline to an unbalanced feedline and vice versa.
- Can be made with toroid or straight ferrites, or coax cable.

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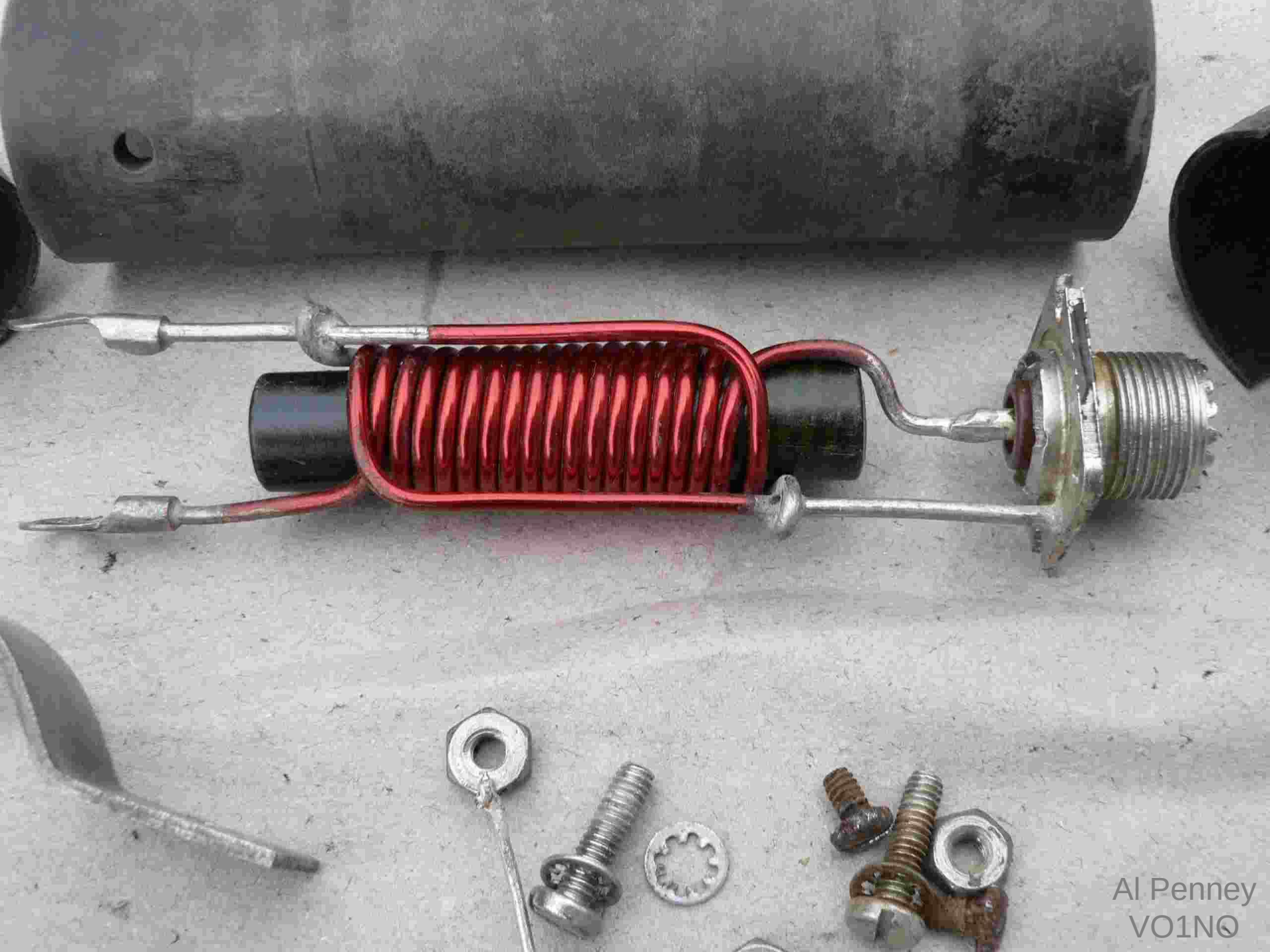
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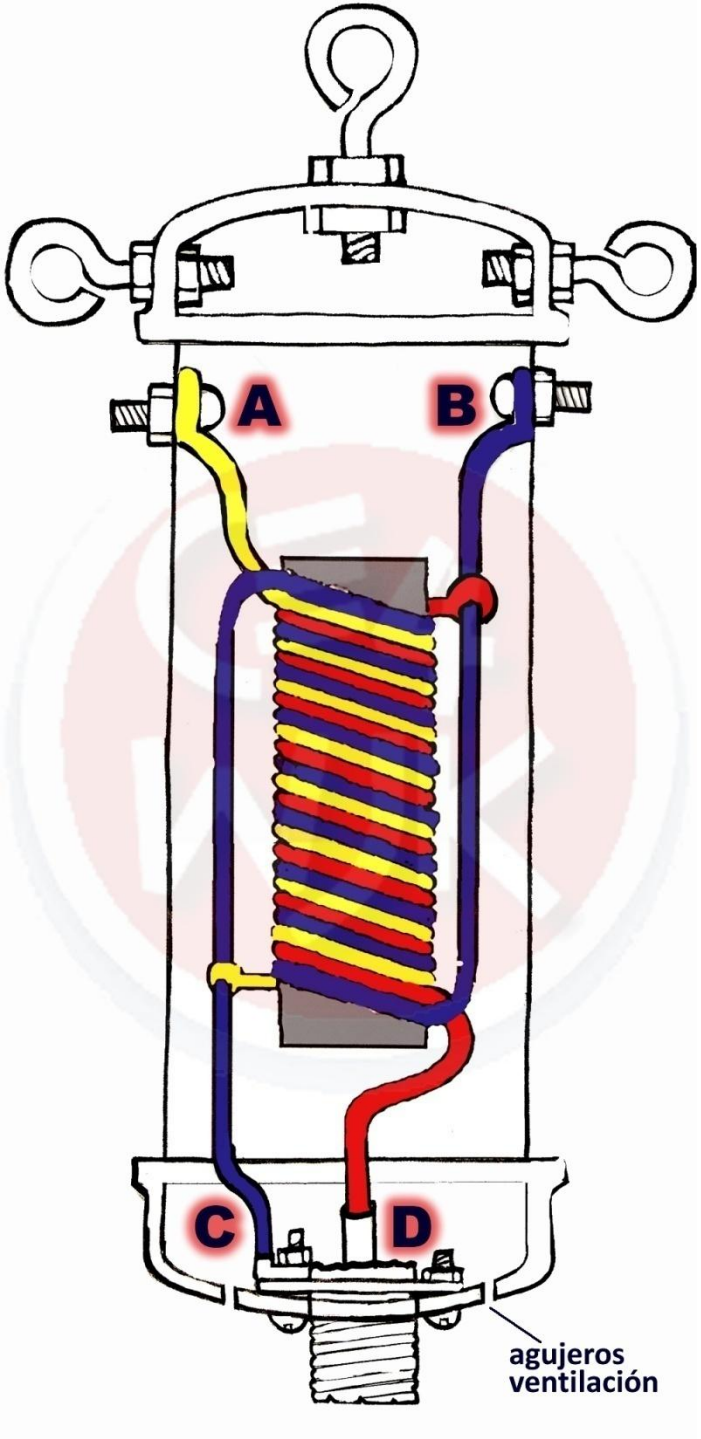

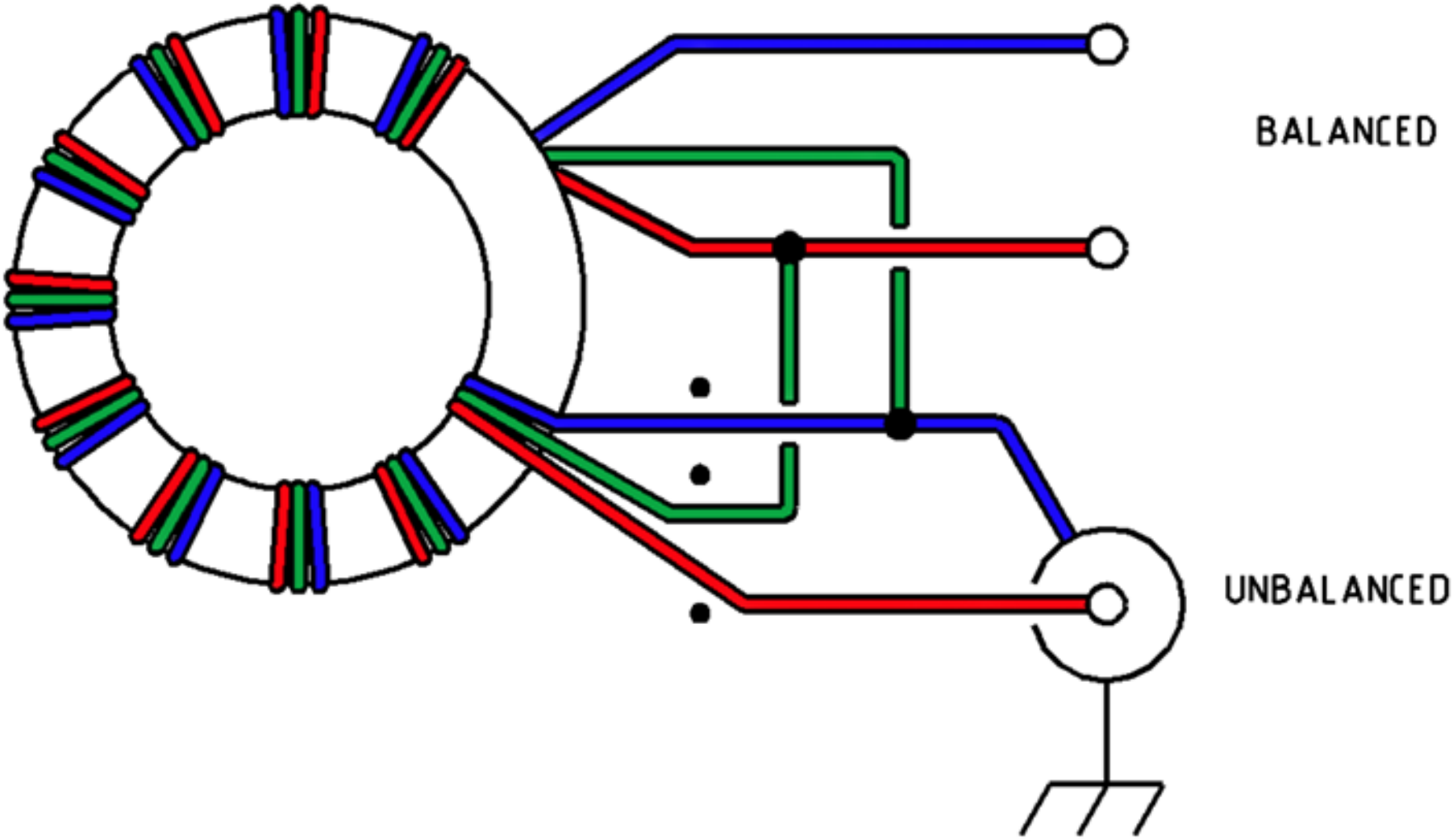

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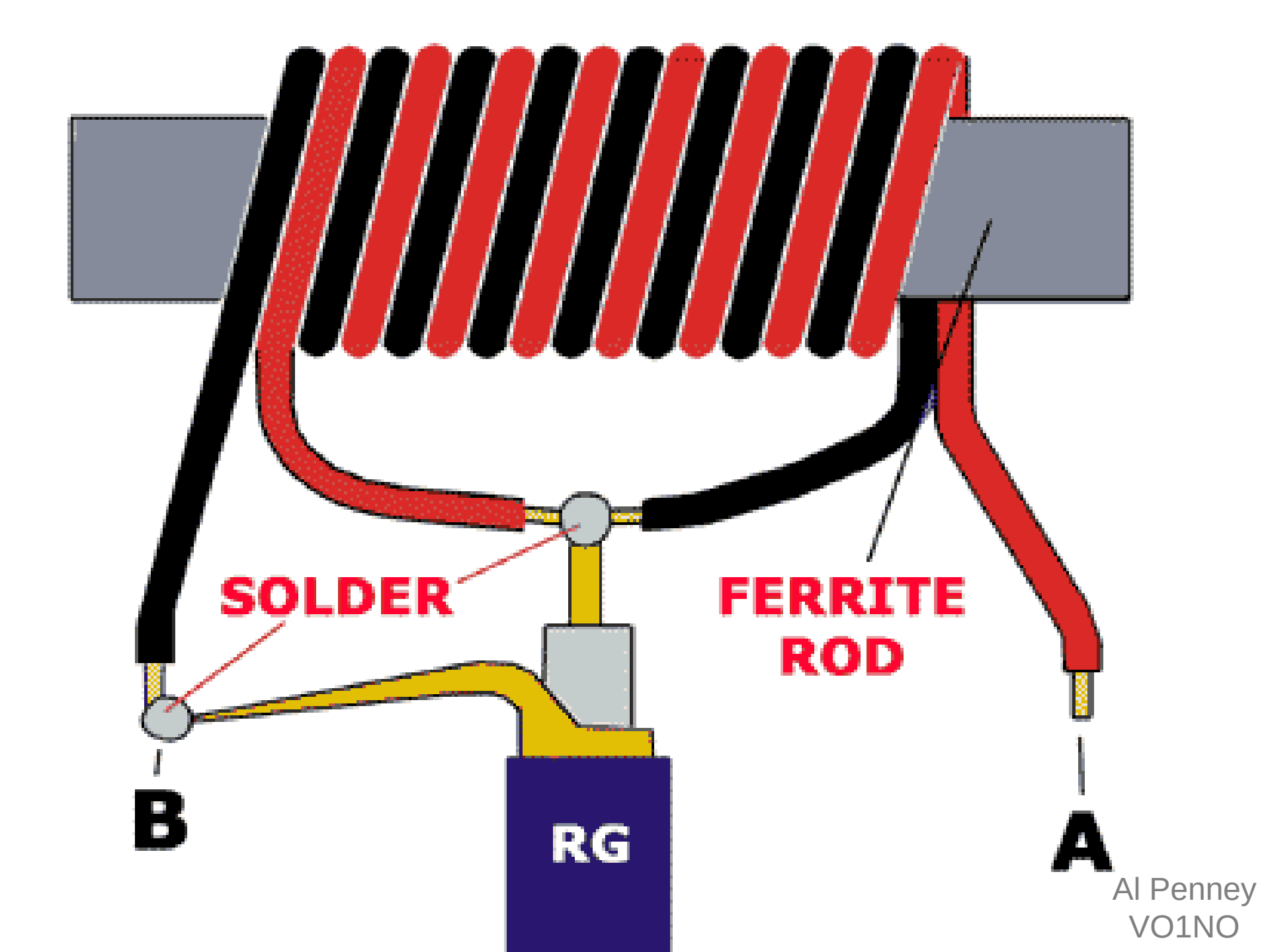

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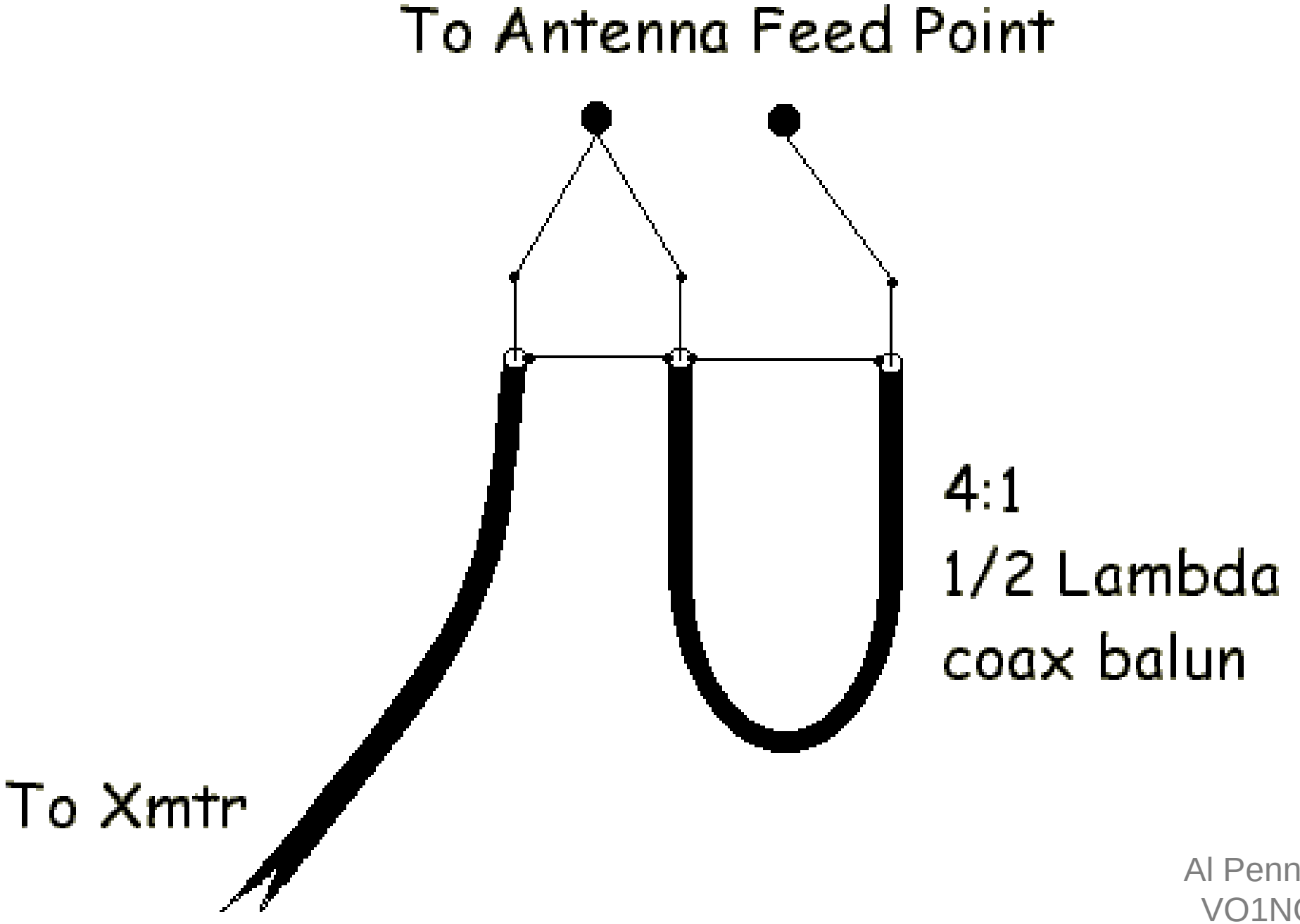

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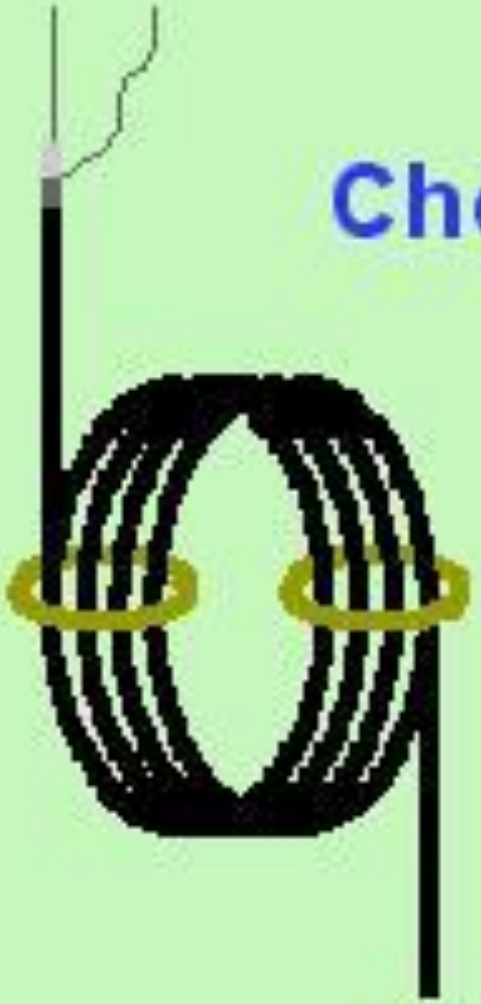
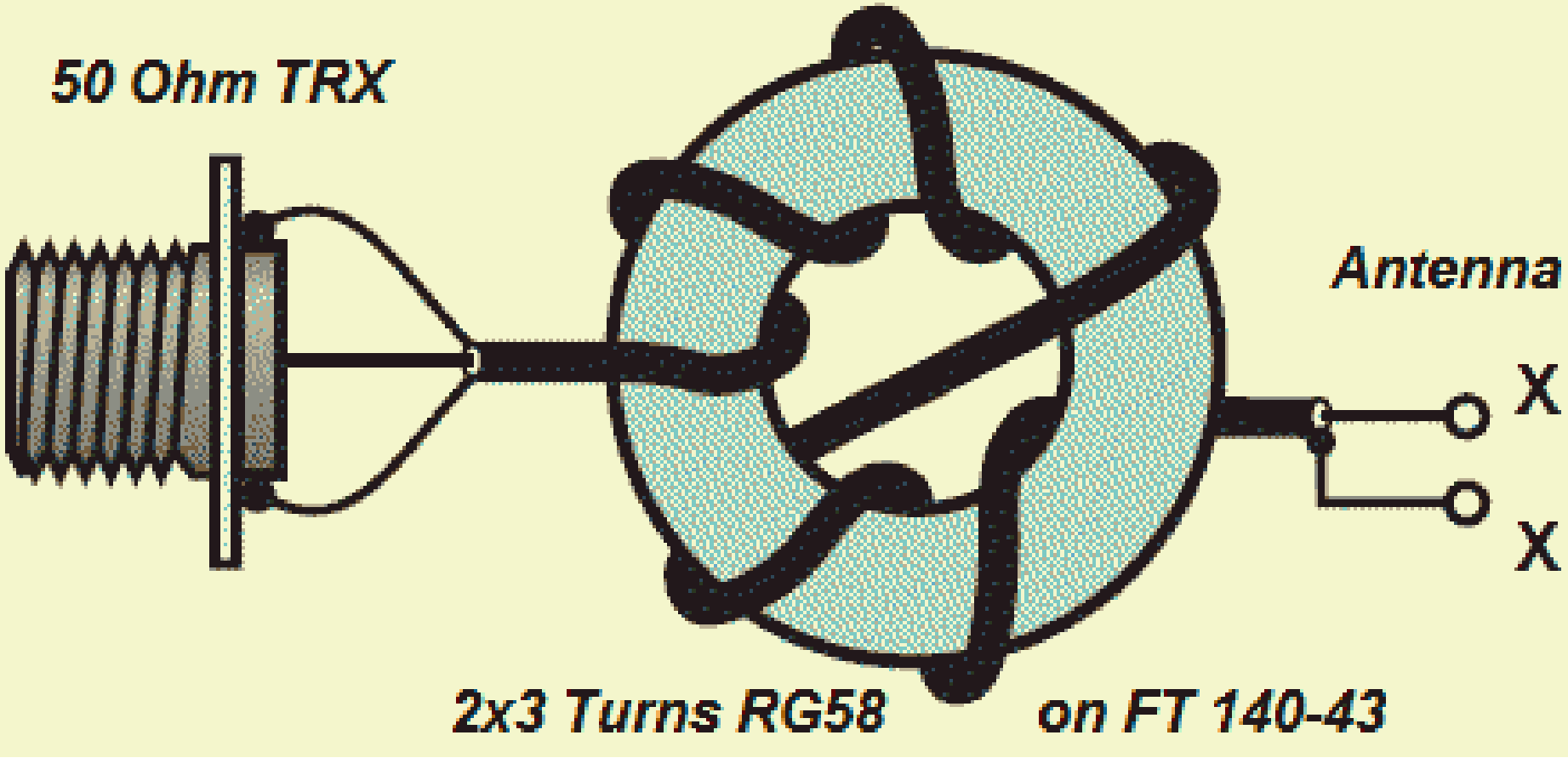
Shield and Center
Conductor to Antenna
Horizontal Elements



Choke Balun

8 to 10 Turns of
Coax, 8 to 10
Inches in Diameter

Coax to
Transmitter



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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.
- Expressed as a ratio… 1:1 is perfect, 2:1 acceptable, 5:1 generally too high.

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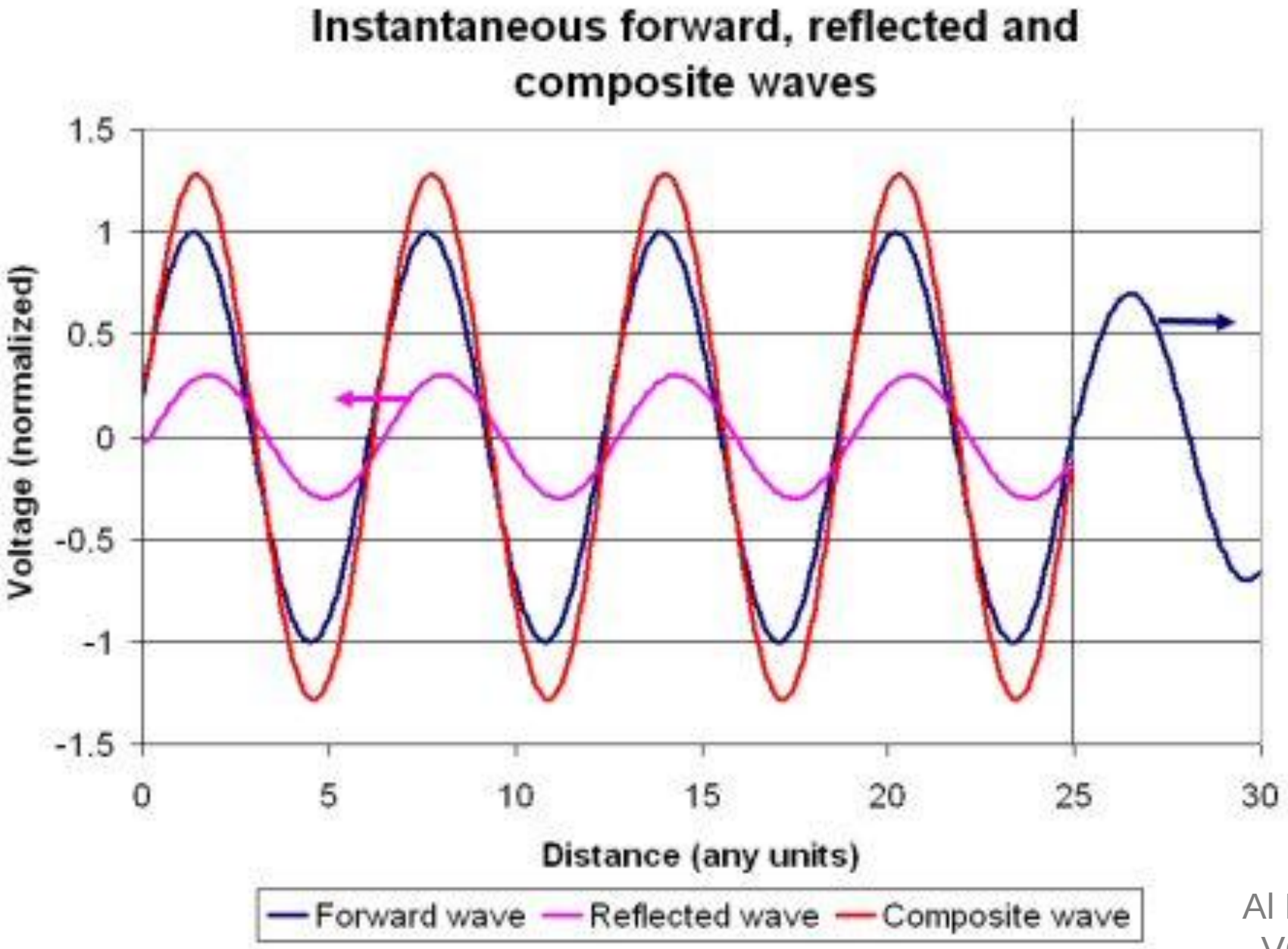

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Impact of SWR

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

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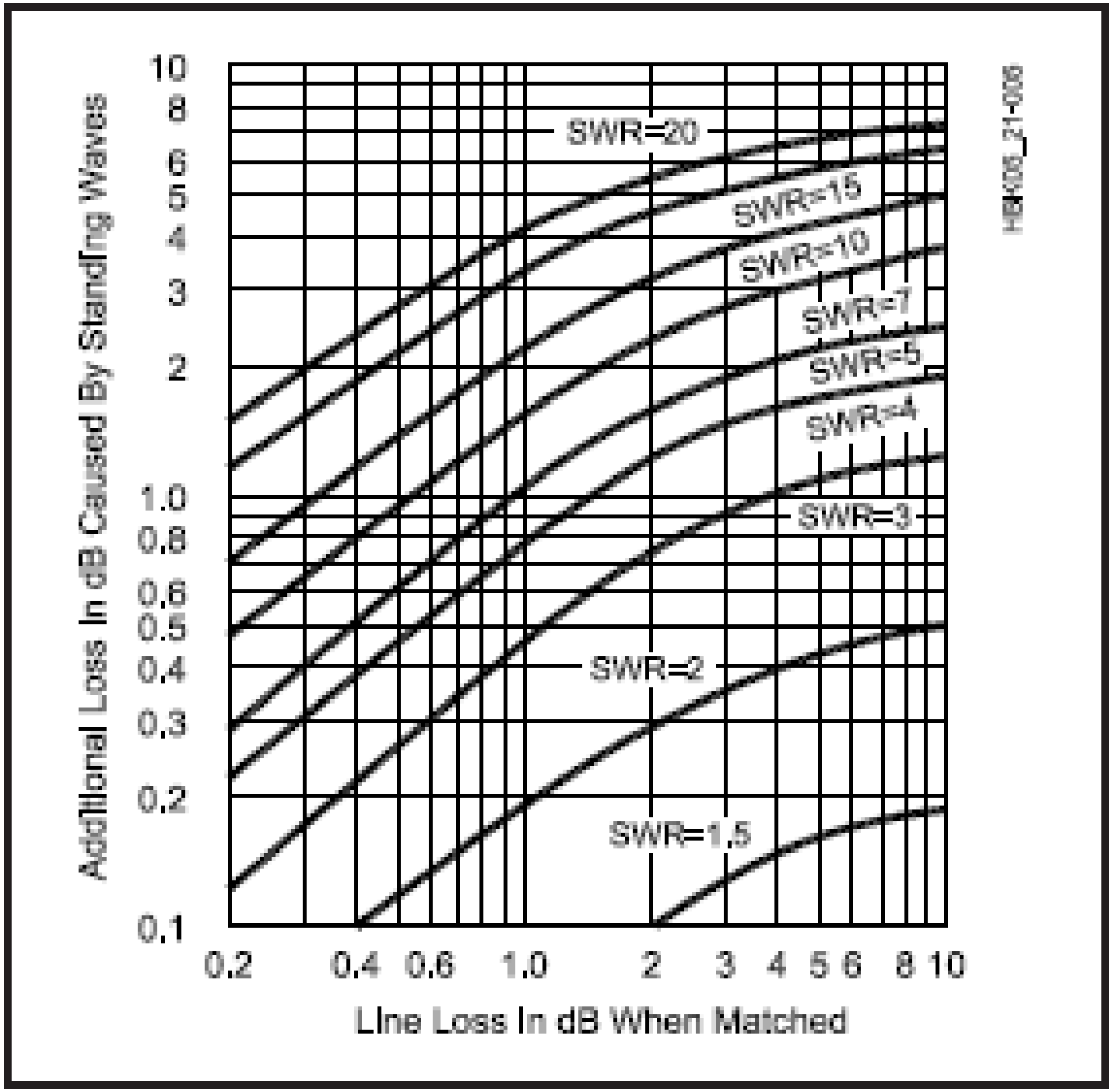
Impact of SWR

- Antenna tuner can hide improper matches, but will dissipate power as heat.
- High SWR also causes additional losses in the transmission line.



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Calculating SWR

- SWR meter compares forward voltage V_f and reverse voltage V_r
- SWR = $V_f + V_r / V_f - V_r$

- Can also be calculated by comparing impedances of the load Z_O and the line Z_L
- SWR = Z_O / Z_L

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

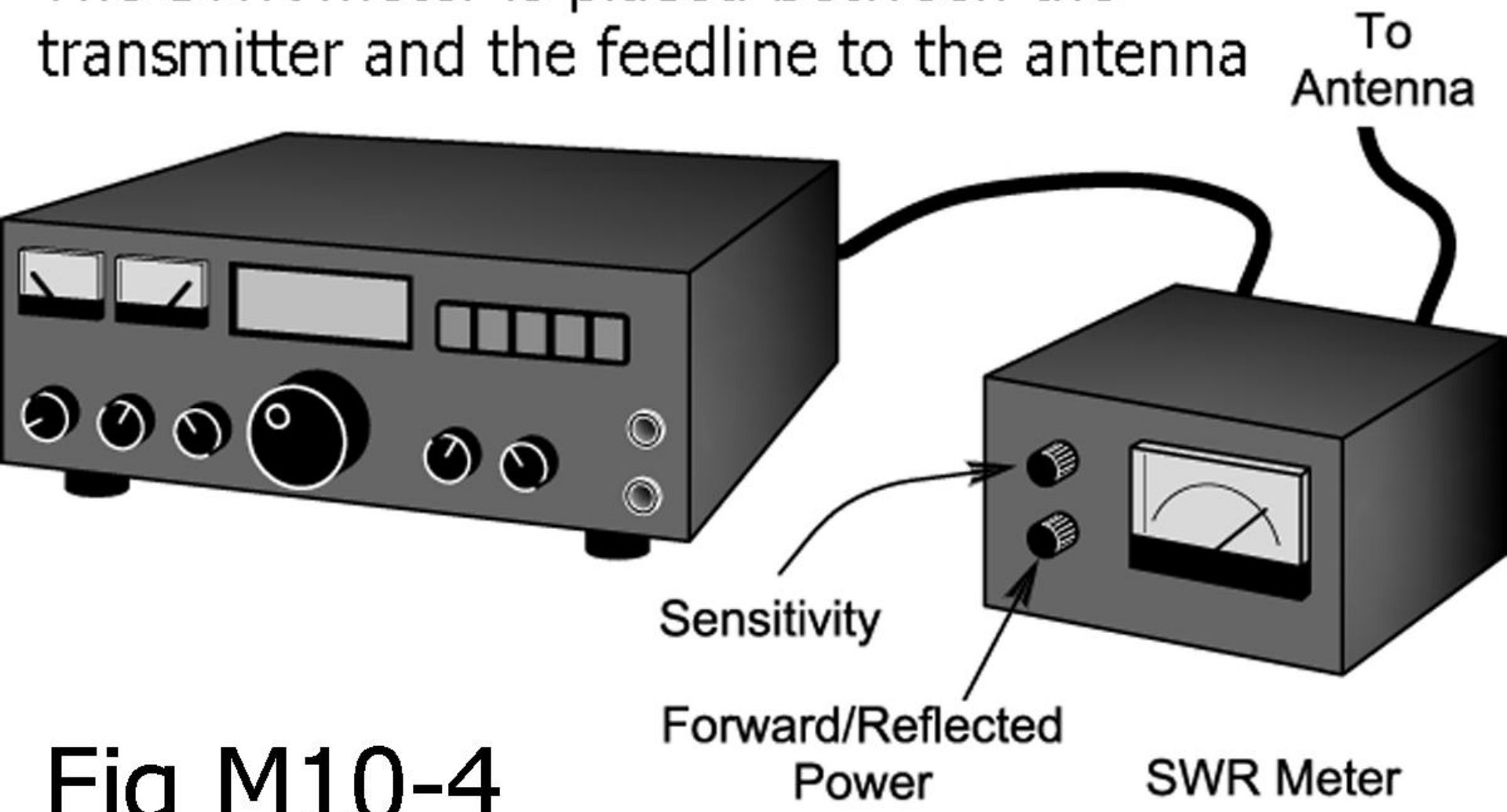

Fig M10-4

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Questions?

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● Among other radio experts, "hams" now welcome the return of the Amphenol line from honorable service on far-flung battlefronts around the world. Amphenol components—greatly improved by wartime experience and augmented in number, style and type—are currently available for civilian applications. Simplifying buying, this wider selection of high-quality, tested items can be procured from one manufacturer.

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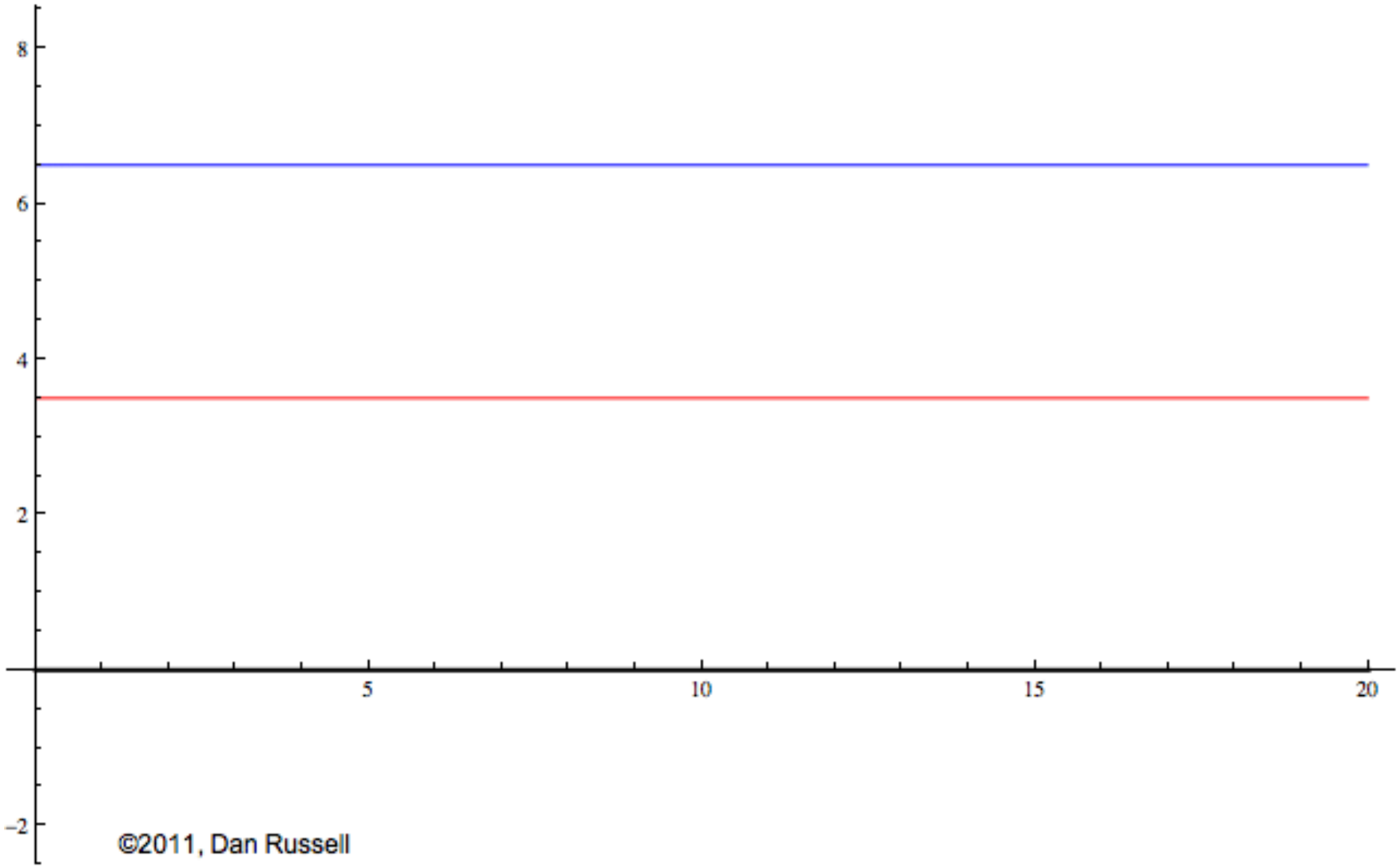

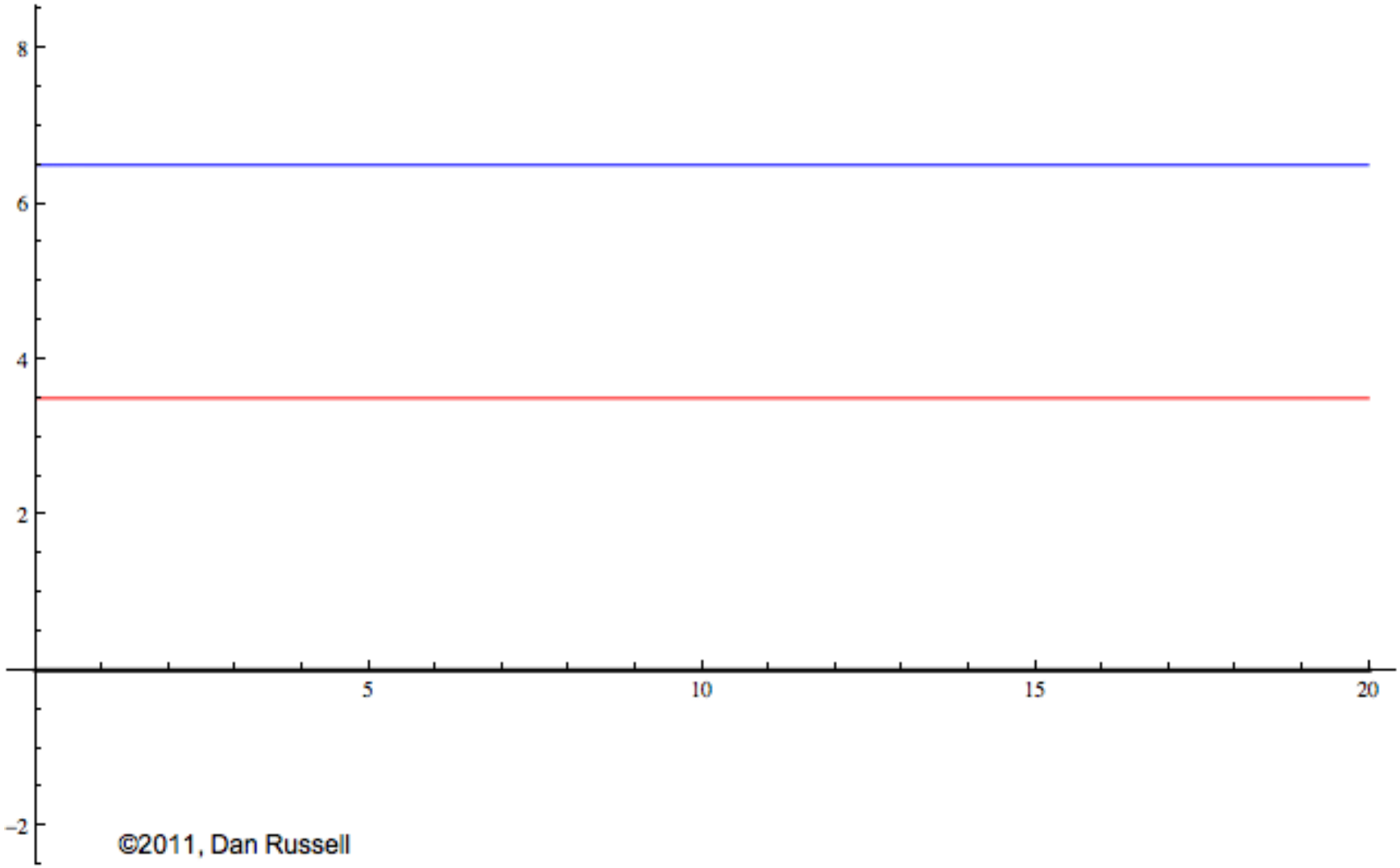

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