Feedlines for Amateur Radio

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Disclaimer

- Feedlines are a complex topic in many ways. Entire books are devoted to the topic. *(ie Joel Hallas W1ZR(sk) "The care and feeding of transmission lines", ARRL Press, 2012)*
- This presentation is not intended to cover all possible topics dealing with Feedlines.
- To fully understand it requires advanced mathematics beyond the scope of the presentation and most people.
- Understanding of the basics is very beneficial to all amateurs and worth knowing.

Feedlines – What will you learn

What is considered to be the feedline?

What are the possible choices for feedlines and how do they differ?

What precautions do I need to take with feedlines?

What the tradeoffs between different types?

What are sources of the losses in a typical feedline system?

What is the basic construction of coaxial cable and why is it 50 Ohms?

Why is an impedance match important?

What is SWR and how is it used as an indicator of the feedline health?

What are some best practices for Feedlines?

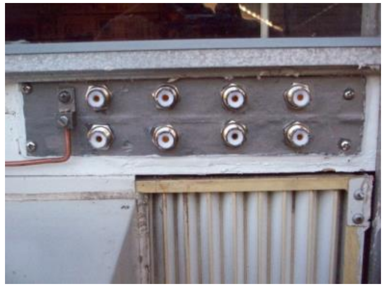
What’s a feedline?

<u>Anything</u> between your actual antenna and your radio is part of the feedline system and contributes to the gains or losses.

- Coax or window-line(ladder-line)
  - Hardline is just rigid coax
- Antenna “tuner” (really an impedance match box)
- Baluns
- Antenna switches
- Lighting arrestors
- SWR/Power meters
- Feed-thru (for wall or window ingress)



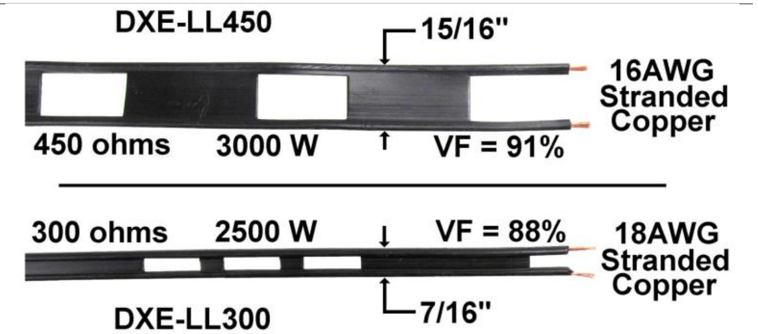


Types of Feedlines

Open Wire Line

Window Line



Coaxial cable

50 and 75 Ohms

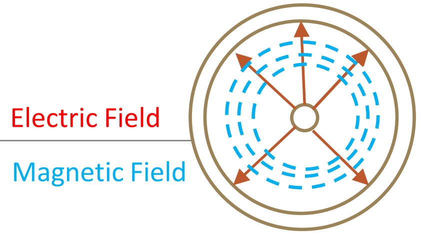
Hardline

- Sometimes called Heliax
- Air or foam insulated

50 Ohms or custom impedance

Above 2 GHz

Coax as a feedline solution



PROS

- Most flexible solution, as the routing of the cable is not important to the integrity of the signal.
- Can be buried (as long as rated for it) and can be in close contact with metal objects like towers, roofs, windows, etc , without compromising the signal.
- Easily switched (or patched) for flexibility with multiple antennas, meters, and radios.
- Less sensitive to EMI or RFI
- Readily available in various sizes and lengths.

CONS

- There can be significant losses depending on length, frequency, and composition of the cable.
- For maximum power transfer, the impedance of the source, load, and cable must match. (typ 50Ω)
- It uses the TEM (transverse electromagnetic mode)
  - which is what leads to the losses. Ie. The coax is a **waveguide** and high SWR can lead to heating.
- Low loss = more $$$'s (RG8x vs LMR400)
- Connectors tend to be the weakest point of the system
- Tight bends can comprise the cable structure

Reference: https://www.youtube.com/watch?v=HD5ODAdl1Ow

Coax Loss By Type

Table 20.1
Length in Feet for 1 dB of Matched Loss

MHz	*1.8*	*3.6*	*7.1*	*14.2*	*21.2*	*28.4*	*50.1*	*144*	*440*	*1296*
RG-58	179	122	83	59	50	42	30	18	9	5
RG-8X	257	181	128	90	74	63	47	27	14	8
RG-213	397	279	197	137	111	95	69	38	19	9
LMR-400	613	436	310	219	179	154	115	67	38	21
9913	625	435	320	220	190	155	110	62	37	20
EC4-50				290		202		87		26
EC5-50				787		548		239		75
450 Ω OWL*	1065	758	547	391	322	279	213			
600 Ω OWL**	4550	3030	2130	1430	1150	980	715			

HF

VHF/UHF

*Wireman #551, 400 Ω characteristic impedance
**Conductors #12 AWG

Source: ARRL Handbook, Table 20.1 – 98th Edition (2021)

Window line as a feedline solution

PROS

- Low cost
- Very Low loss
- Light weight (compared to coax)
- Handles high SWR
- Can feed a non-resonant multi-band antenna better than coax

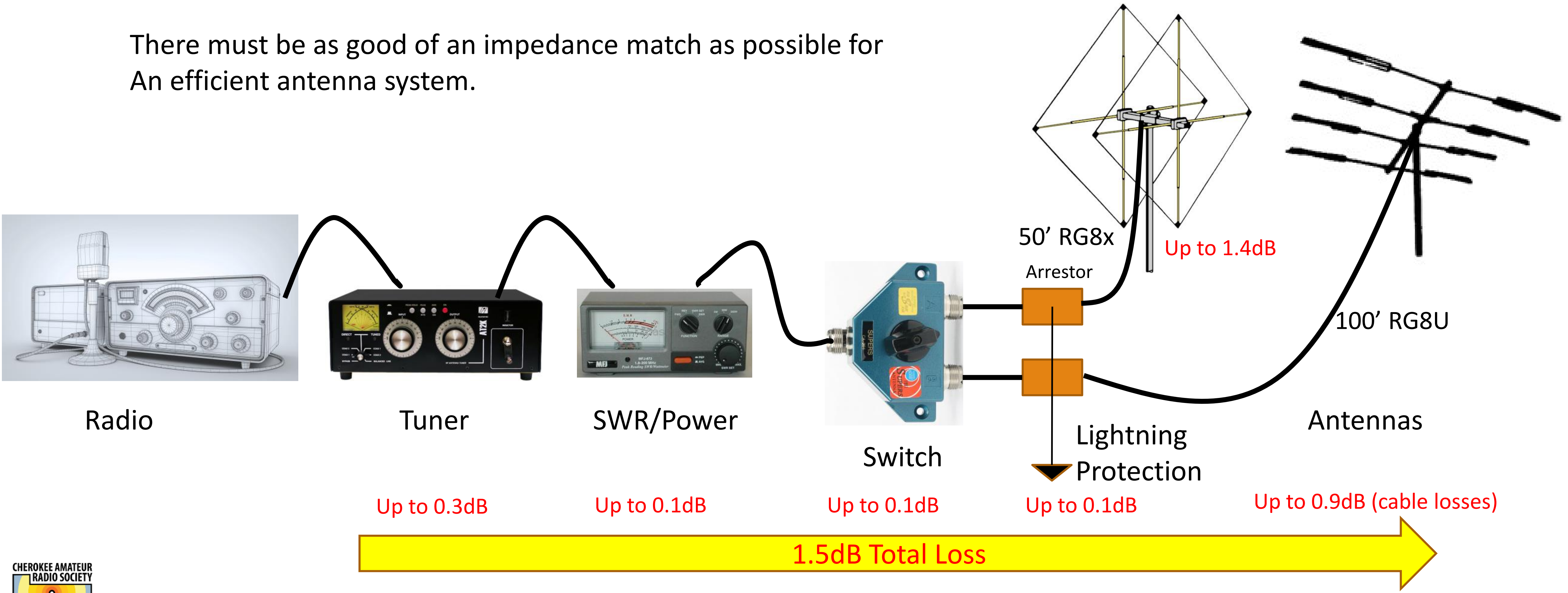
CONS

- Very sensitive to it's path to transmitter
- Requires a balun to convert balanced to unbalanced if you use any coax.
- Would need a balun in the Tuner if directly connected (6:1 or 9:1)
- Dangerous to people and pets if touched when transmitting

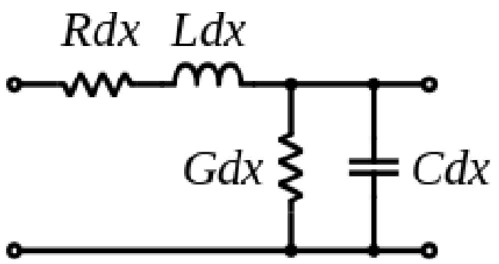
Reference: https://kv5r.com/ham-radio/ladder-line/

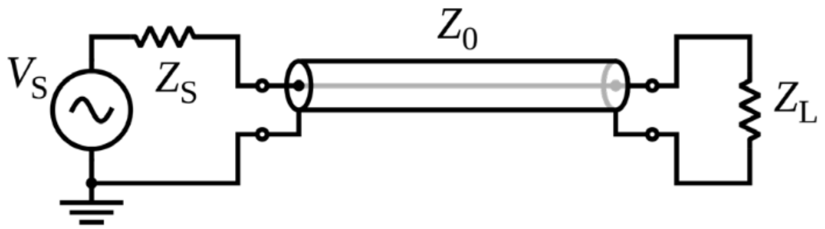
Sources of Losses

There must be as good of an impedance match as possible for
An efficient antenna system.



Feedline losses
– ie attenuation of the cable





- Higher the frequency the more the "skin effect" and series resistance and reactance. (Rdx & Ldx)
  - Only a thin layer of the wire carries the signal
- The dielectric (eg foam insulator) defines the conductance of the inner conductor. (Gdx & Cdx)
- Deformity, holes, or gaps in the outer shield allow signal leakage measured as loss.
- The TOTAL attenuation is a result of resistive losses, loss resulting from the dielectric material, and losses do to the integrity of the cable itself.

Efficient Antenna Systems

- As long as the length of the antenna is at least a half-wavelength at its lowest intended frequency, its efficiency is well over 90%, just like a resonant dipole. (*why random long wires work*)

- The **problem** is getting power to it— ie **the feedlines**
  - **Coax** is very lossy (due to dielectric heating) unless terminated into its characteristic impedance, and this effect is what leads many hams to erroneously believe that non-resonant antennas are inefficient. **But the problem isn't non-resonance, it's high SWR on coax resulting in RF heating.**

Window-line does not suffer from high losses at high SWR.

- It may be effectively used to feed an antenna that may, at various HF frequencies, present the feed-line with any SWR from 1:1 to ~12:1.
- With window-line you don't have to worry about resonance and SWR, until you get to the radio, where you use a **tuner** to make the match to 50Ω.

Knowing about feedlines will help you determine and decide the best solutions for you

Look at some examples of Feedlines

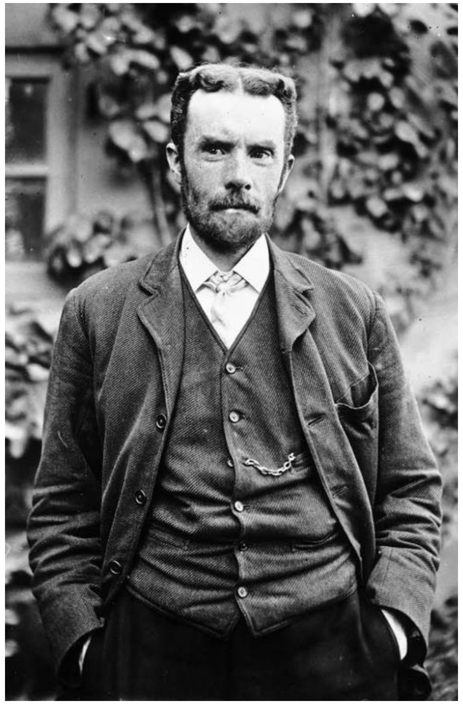
Passing about the room various examples of feedlines used by amateurs

These are courtesy of Stan Ham (WB9GFA). Thanks Stan!

Why is coaxial cable 50 Ohms?
Why do we even have such a cable?

Why do even have coaxial cable?

- Early days of telephony posed problems with cross-talk.
  - Wires run for lengths near each other will induce voltages and currents, which is foretold by Ampere's Laws.
- Problem was studied by engineers who considered that a "shielded" cable may work, and it did, but was not understood why.
- English physicist and mathematician Oliver Heaviside(1880) proved mathematically that a wire inside another wire would eliminate crosstalk. Some thought he was crazy for this idea.



Oliver Heaviside ~ 1900

- Heaviside also invented differential calculus as well as theorized the conducting ionosphere.
- It was originally called the Kennelly-Heaviside Layer in 1902

Why 50 Ohms ?

Best Impedance based on application?

- Lloyd Espenscheid and Herman Eiffel, working for Bell Labs in 1929. They were going to send RF signals (4 MHz) for hundred of miles carrying a thousand telephone calls.
- Evaluated coaxial wires for optimization of three things:
  - Power handling capability => 30 Ohms
  - High voltages => 60 Ohms
  - Lowest loss (ie attenuation) => 75 Ohms
- From the data, they landed on 60 ohms but finally at **50 ohms** because 50 is closer to 60 than to 30 and still offered reasonable capability for power.
- Note that 75 ohm is common for cable TV for it's lowest losses/ft.

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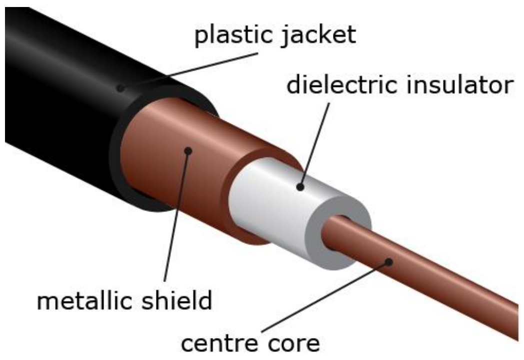
Construction and costs

- Construction of a wire inside a wire is where we get the modern coaxial cable.
- Widespread use and application keeps the price affordable for amateurs.
  - Coax is average of $1/ ft to about $4/ft for the good stuff.
  - Heliax can range from $3 to $10 per foot
- Original coax was rigid and often a copper pipe inside anther pipe. (*we still do this with Heliax, but it is a little flexible*)
- The 50 Ohms comes from compromise of power handling versus losses.
  - However, special cases, like commercial stations may use closer to the 30 ohms for high power.
  - Most amateur uses are 50 Ohms



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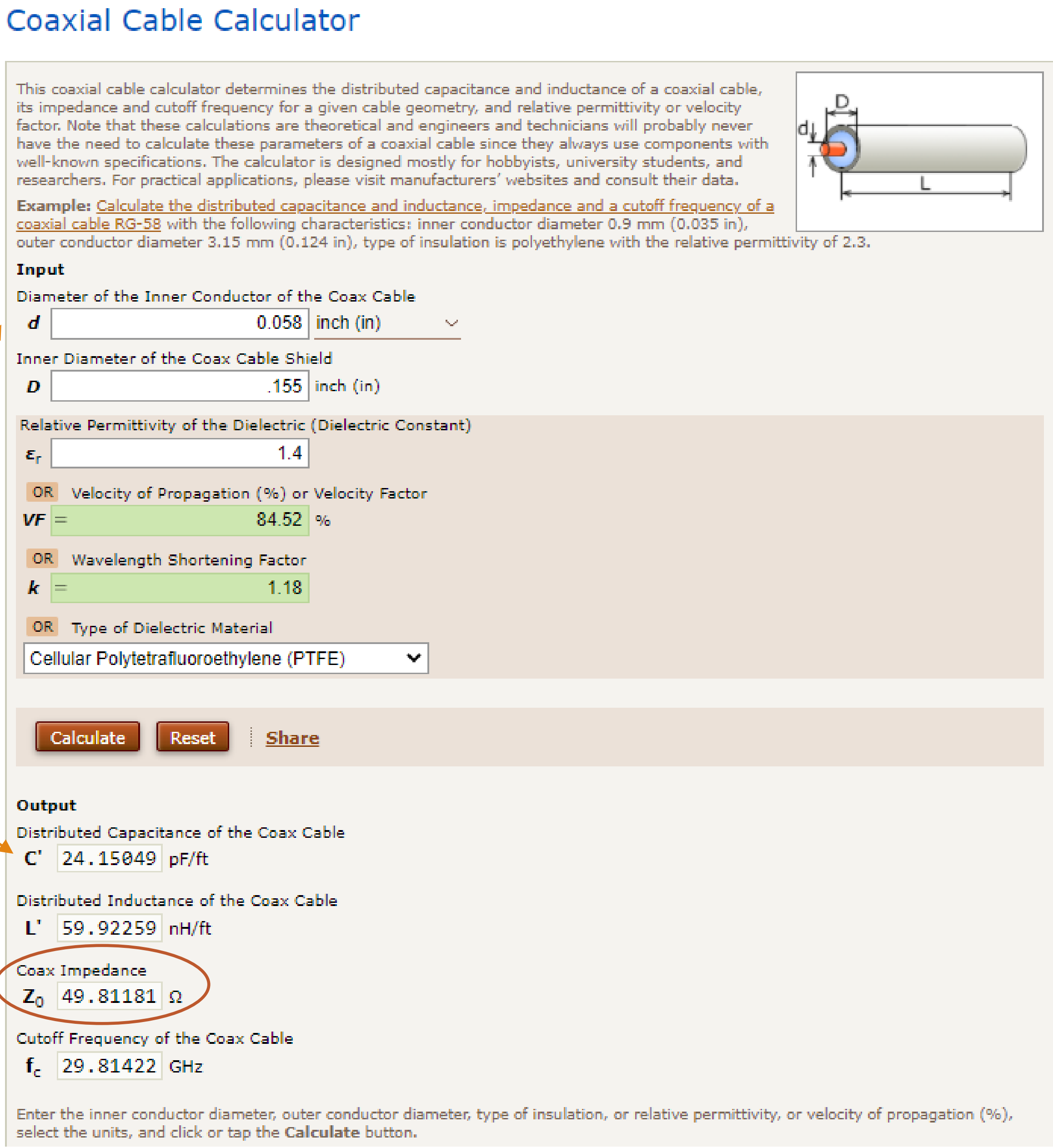
Coax Impedance

- The impedance of coaxial cable is largely determined by the ratio of the diameter of the inner conductor to the outer conductor.
- You can find a calculator online that uses the formula and takes into account the dielectric material.
- Note also that there both a distributed capacitance and inductance per foot of cable.
- Most commercial cables are 50 or 75 ohms.



Reference:
https://www.translatorscafe.com/unit-converter/uz-Latn-UZ/calculator/coaxial-cable/

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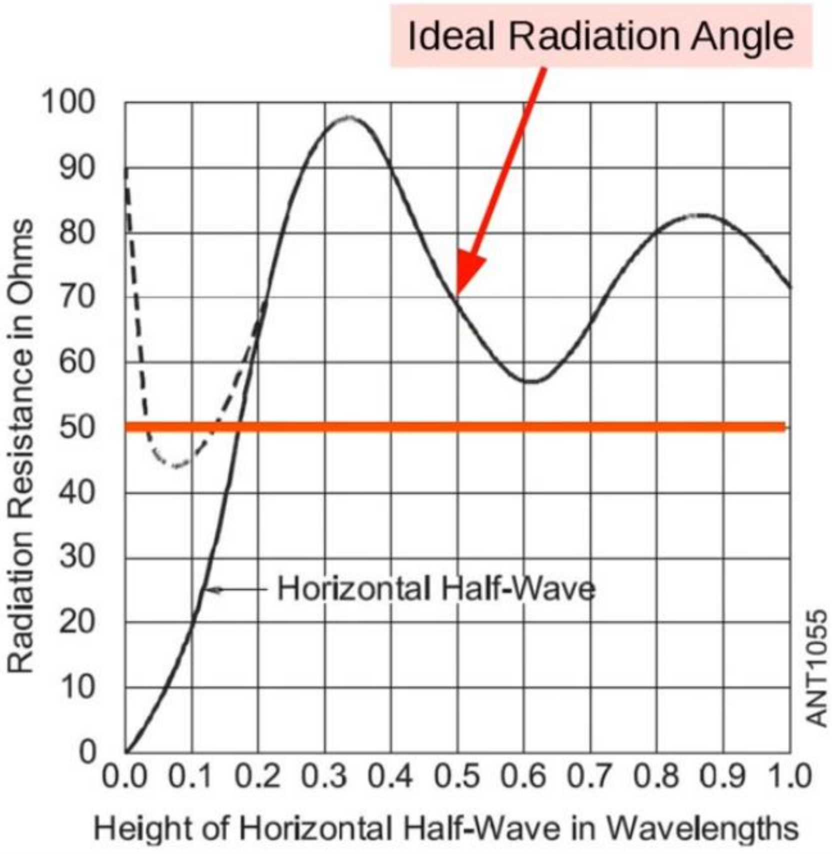
Is 50 Ohms okay for Ham Radio?

- It works fine for most cases.
  - Ideal radiation angle for the dipole is at $\frac{1}{2}\lambda$
  - That may be too high for bands > 20m
- If your antenna impedance = 70 Ohms
  - SWR = 70/50 = 1.4: 1   - a good value
  - Even if it went to 100 Ohms that is SWR= 2:1
- Often metal objects near your antenna will de-tune the impedance and it may be closer to 50
- 50 Ohms is also the best compromise for equipment that must transmit and receive.
- 75 Ohms is great for receive-only antennas.
  - See info on a Beverage Antenna, usually 75 Ohms



$\frac{1}{2}\lambda$

For:
10m 16’
20m 33’
40m 66’
80m 131’

Source: ARRL Antenna Book, Figure 2.15 – 22nd Edition

More on Antennas NEXT MEETING

Impedance Matching

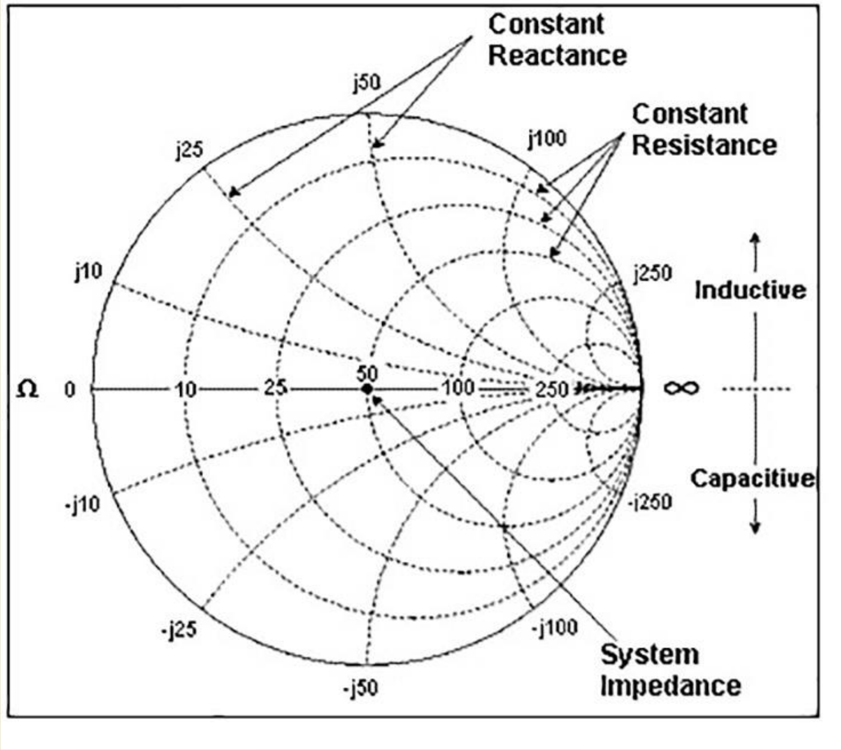
What is impedance?

Has 2 parts:

- Real part – which is standard ohmic resistance
- Imaginary part – which is inductive or capacitive reactance (resistance to AC voltages and currents)

Represented by a complex number with two parts, or a vector with a phase angle.

- Example: 55 + j32 or you could say 63.6 at θ=30.2°
- You will typically see these numbers on your antenna analyzer to show the impedance it "sees" at the place you measure the feedline + antenna
- The Smith Chart simply folds the axis in a circle with the center being the system characteristic impedance.



Reference : https://byjus.com/rectangular-to-polar-calculator/

How do measure the impedance?

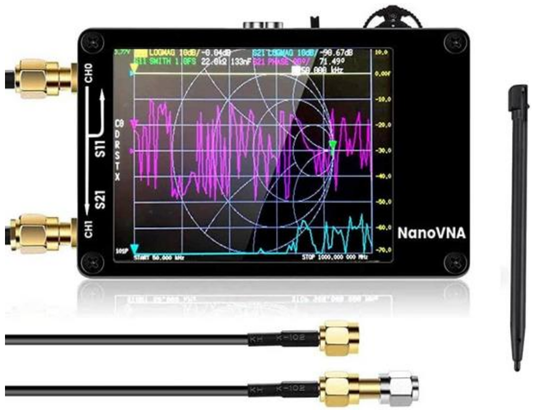
Measuring can be accomplished with two different instruments:

Antenna Analyzer – measures S11 parameter and electrical cable length

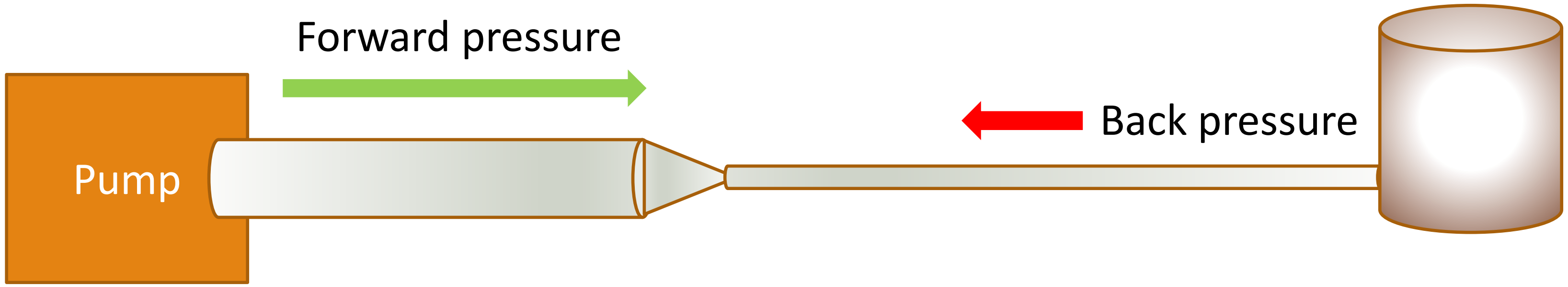
- $200- $600 range

NanoVNA – Can measure S11 and S21 parameters and electrical cable length

- $60- $250 range



Impedance Matching Concept



- RF systems work in a similar manner.
- The transmitter (source) is like a pump and the tank (sink) is the antenna
- Any **mismatch** in the delivery system (ie the pipes in this case) causes **back pressure** and limits the flow to the tank.
- In feedlines, this is the S21 (Forward Transfer Loss/Insertion Loss) parameter and S11 (Reflection/Return Loss) parameter.

The 'S' here refers to something called scattering parameters and is a measurement usually in dB

Smn where m is the output port and n is the input port

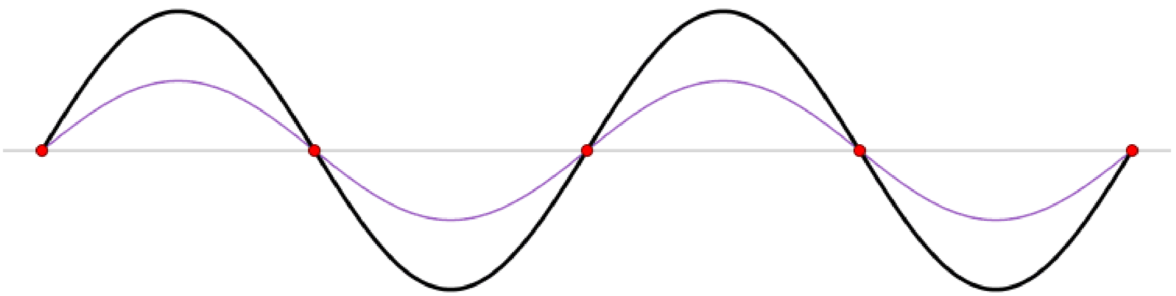
Why is a match important?

- Maximum Power Transfer Theorem (Jacobi’s Law) says so
  - MPT happens when source and load impedance are equal.
- Reduces reflections in the feedline (which raises SWR)
- Baluns are our main means of providing a matches for antenna where impedance is > or < 50 Ohms
- The type of antenna determines the match needed, so you must know this for it to work right.
  - eg. EFHW needs a 49:1 balun
- Antenna “Tuner” is a misnomer.
  - It is really a matching network that keeps the transmitter happy so it sees something close to 50 Ohms.
  - It tunes the combination of the Feedline and the antenna

What is SWR? (Really VSWR)

- Voltage Standing Wave Ratio or VSWR, commonly called just SWR
- It occurs when reflected power reacts with forward power along a transmission line.
- It is expressed as a ratio of Vmax to Vmin of the standing wave. (*Also S11 if using a nanoVNA to measure it*)
- The measurement we may take depends on the location along the transmission line.

Infinite SWR



Blue = Forward wave
Red = Reflected wave
Black = Standing wave

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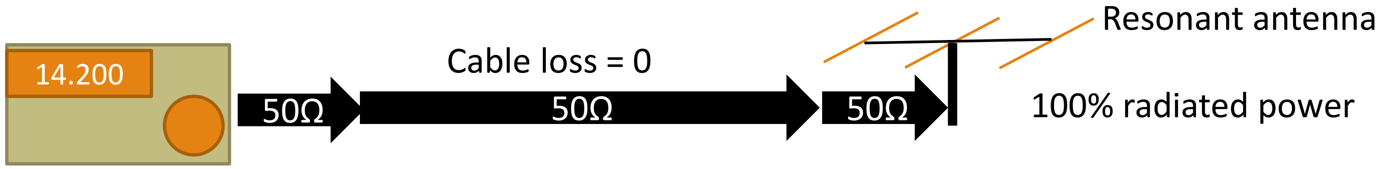
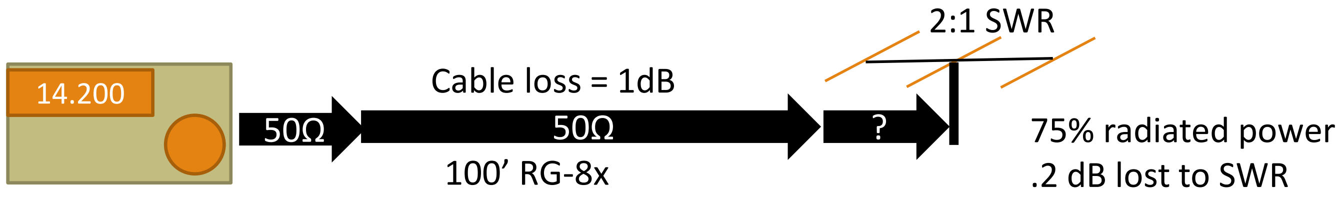
SWR example – where losses come from

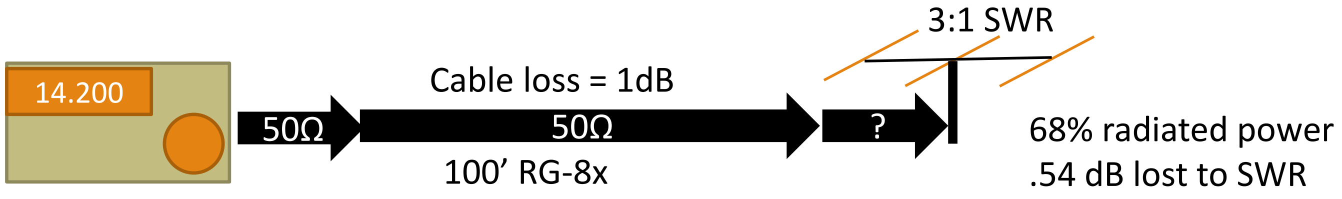
SWR = 1: 1 Perfect case with no losses
(would only be true at one frequency)



SWR = 2: 1 Acceptable cable losses



SWR = 3: 1 Acceptable antenna losses



SWR > 3:1 at the transmitter will cause power to “fold back”

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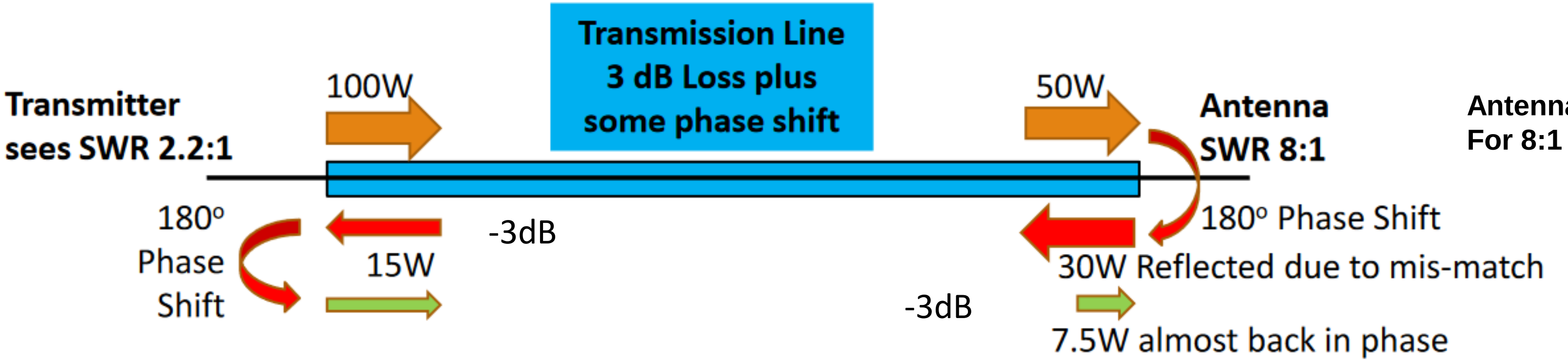
Lossy Coax can fool you



Antenna loss is 60%
For 8:1 SWR so 30W is reflected

KEY TAKE AWAY: The reflected power has been attenuated by 2X 3dB, ie., 6 dB and this means a SWR at the transmitter is 2.2:1 with the SWR at the antenna is actually 8:1.

SWR must be measured at the antenna and feedlines measured separately

SWR vs Power

* ERP = Percentage of Effective Radiated Power

SWR READING	% OF LOSS	ERP*	WATTS AVAILABLE
1.0:1	0.0%	100.0%	4.00
1.1:1	0.2%	99.8%	3.99
1.2:1	0.8%	99.2%	3.97
1.3:1	1.7%	98.3%	3.93
1.4:1	2.8%	97.2%	3.89
1.5:1	4.0%	96.0%	3.84
1.6:1	5.3%	94.7%	3.79
1.7:1	6.7%	93.3%	3.73
1.8:1	8.2%	91.8%	3.67
1.9:1	9.6%	90.4%	3.61
2.0:1	11.1%	88.9%	3.56
2.1:1	112.6%	87.4%	3.50
2.2:1	14.1%	85.9%	3.44
2.3:1	15.5%	84.5%	3.38
2.4:1	17.0%	83.0%	3.32
2.5:1	18.4%	81.6%	3.27
2.6:1	19.8%	80.2%	3.21
2.7:1	21.1%	78.9%	3.16
2.8:1	22.4%	77.6%	3.10
2.9:1	23.7%	76.3%	3.05
3.0:1	25.0%	75.0%	3.00
4.0:1	36.0%	64.0%	2.56
5.0:1	44.4%	55.6%	2.22
6.0:1	51.0%	49.0%	1.96
7.0:1	56.3%	43.8%	1.75
8.0:1	60.5%	39.5%	1.58
9.0:1	64.0%	36.0%	1.44
10.0:1	66.9%	33.1%	1.32

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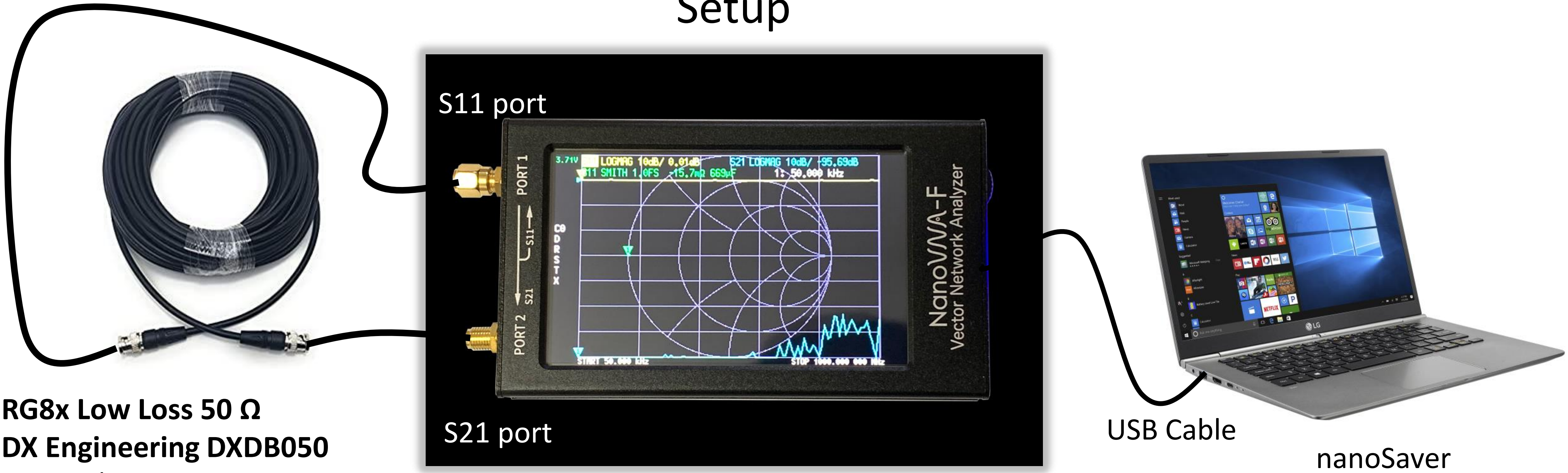
Summary of Best Practices

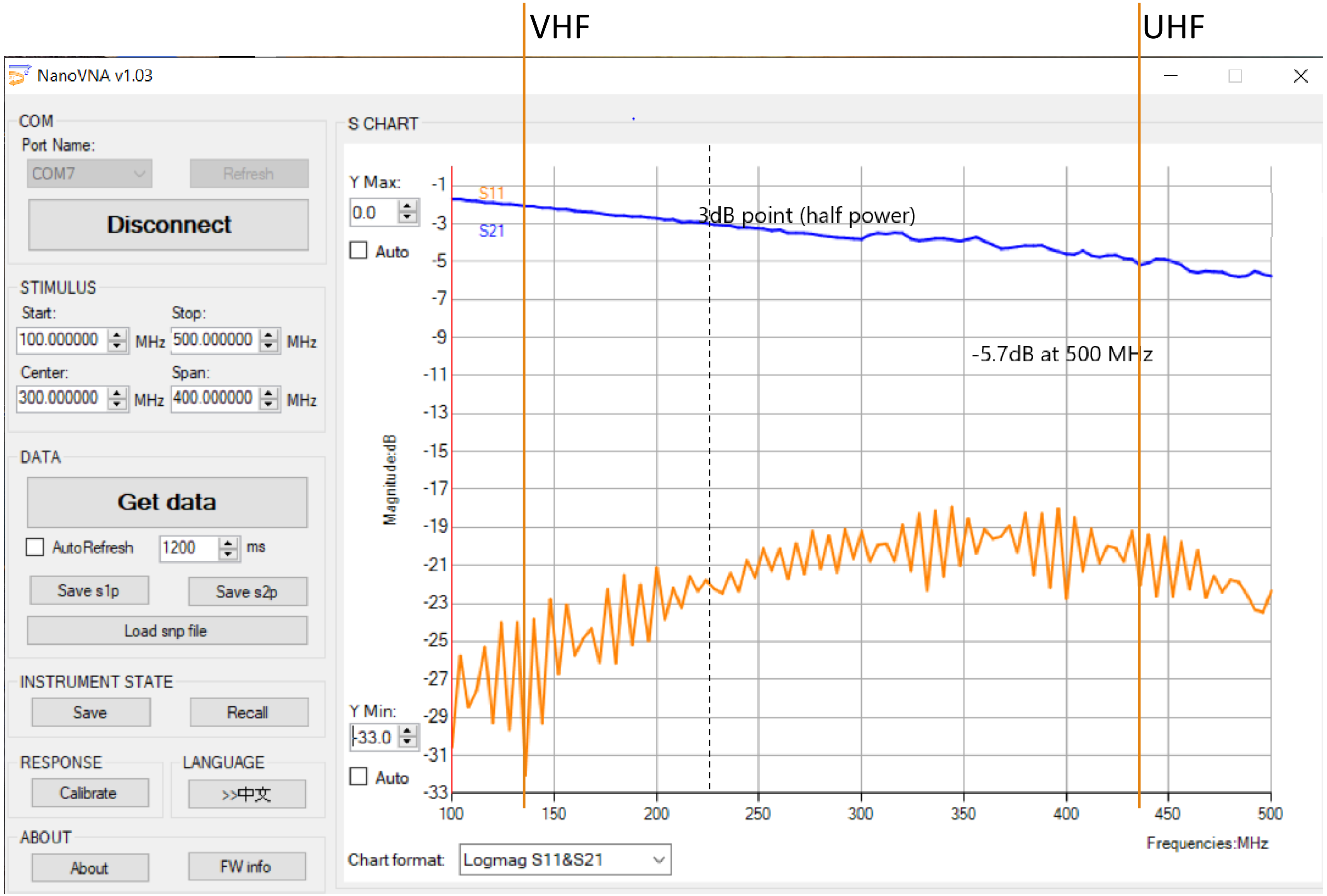
- SWR will not tell you how your antenna is performing.
  - Even a dummy load has low SWR (usually 1:1)
  - It only tells you about the impedance match of the thing you are measuring, antenna or combinations
- Measure antennas and feedlines separately to look for any serious issues.
- If you use parallel feedline (ladder line), then observe these rules of thumb:
  - Support it away from conducting surfaces by a distance three times the spacing of the feedline.
  - If you have to cross a conductor, run the feedline at right angles to that surface or straight through it.
  - If we must make turns, keep them gentle, like a radius of 10 times the conductor spacing.
- The weak link in most antenna systems is the connectors, and water is the biggest issue.
- Use the right feedline for the right circumstances and your physical restrictions for routing it.

Demonstration – Coax Loss

Setup



RG8x Low Loss 50 Ω
DX Engineering DXDB050
<1.4dB/100’ loss @ 30MHz
Vf = 82%



Is this coax any good for VHF?

Is this coax any good for UHF?

Why or why not?

Thanks for your participation! Questions?