What’s all this SWR Stuff, Anyway?

Phil Gaudet
K1IRK

Richard Bates
WD1O (Oh, not Zero)

Contents


NO SWR
GREATER THAN
ONE TO ONE!
I COMMAND
IT!!!

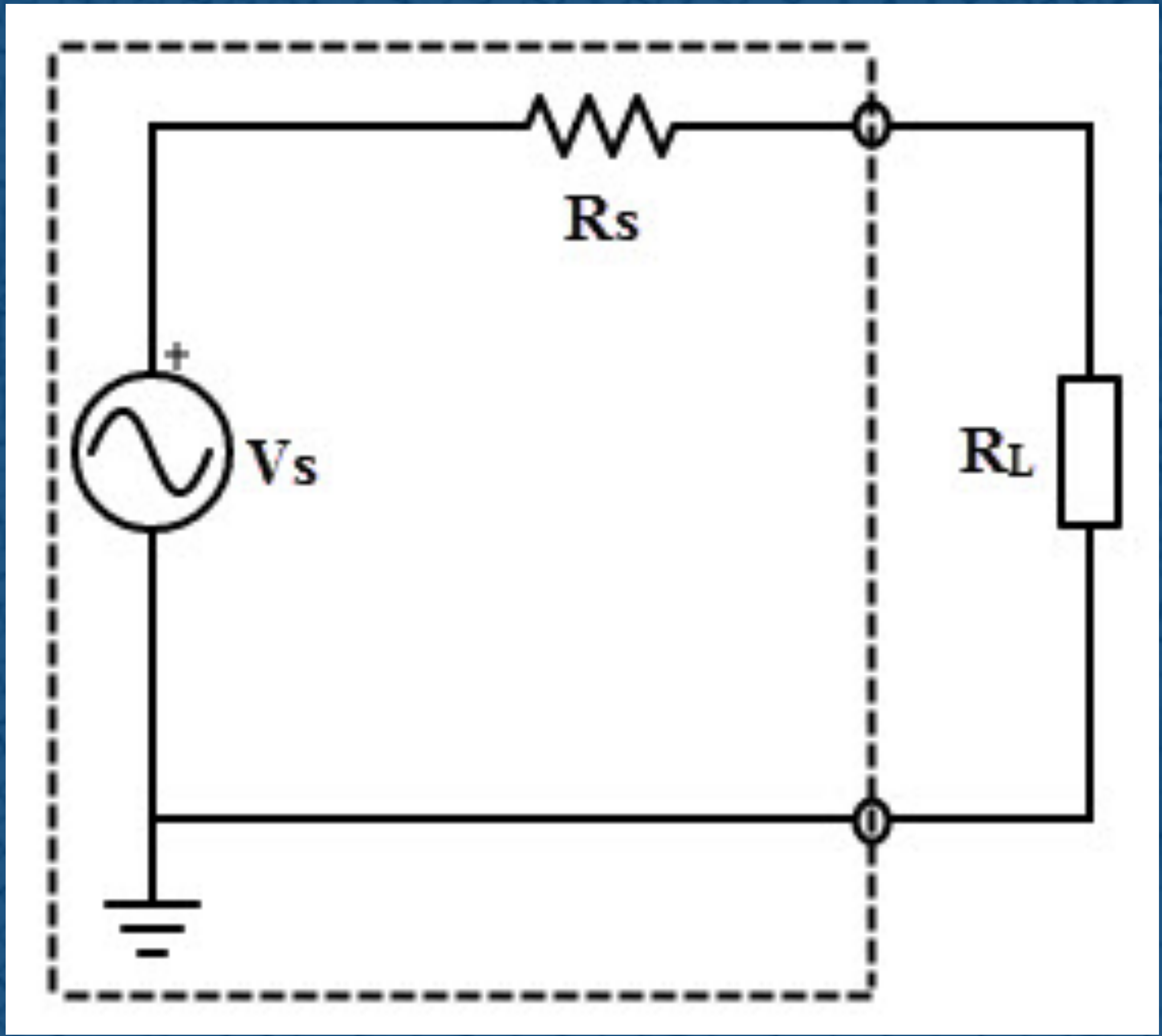
Let's Get Calibrated!

- A deciBel (dB) is the Log_{10} of a RATIO ie Voltage or Power RELATIVE to another Voltage or Power.

- 6dB is a CHANGE of One S-Unit on your receiver

- 1 dB is Minimum Detectable CHANGE in Signal by an experienced operator with the AGC

Maximum Available Power Out



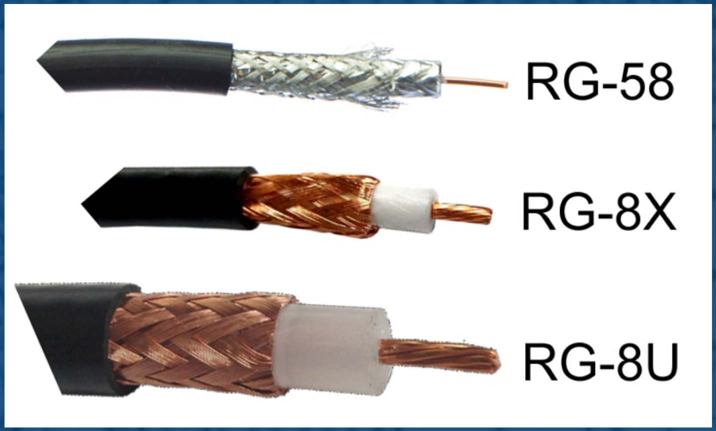
What’s a Feedline?

Feeds power from your shack to the antenna

With as little Loss as Possible

Balanced vs Unbalanced
Coax vs Ladder Line

(Ladder Line has less than 20% the loss of RG8)



What Defines a Feedline?

- Characteristic Impedance of an infinitely long line Z_0.

- Loss in dB (attenuation) per Length
- I^2R in copper and V^2/R dielectric loss
- Proportional to Length

- Loss increases with the square root of frequency
-
- (Ladder Line has less than 20% the loss of RG8)
- But lots of disadvantages

What Defines a Feedline?

- Ladder Line was used exclusively before WWII. The military found it to be non-portable and difficult to form around corners so developed coax. After the war, piles of coax were dumped on the surplus market and hams bought it up and never looked back.

- Ladder Line's advantages are:
  - It's inherently balanced.
  - It's Very Low Loss
- Ladder Line's Disadvantages are:
  - Some have Exposed wire posing Danger to Personel
  - Varies with Weather and nearby Metal.
  - May Pick up Unwanted Signals or Noise
  - Difficult to Route
  - Requires a Balun before entering the Rig.

What Defines a Feedline?

- Advantages of Coax
  - Inherently shielded so all currents flow inside the shield
  - Some Coax is very Flexible and Light.
  - Can be poked through a small hole and run around corners.
  - Lot’s of available devices accept coax.

- Disadvantages of Coax
  - Higher Loss at all frequencies than Ladder Line
  - Coax is Inherently Unbalanced so may need a Balun at the Antenna
  - Low Loss Coax may be Expensive and Bulky

Matched Feedline Loss

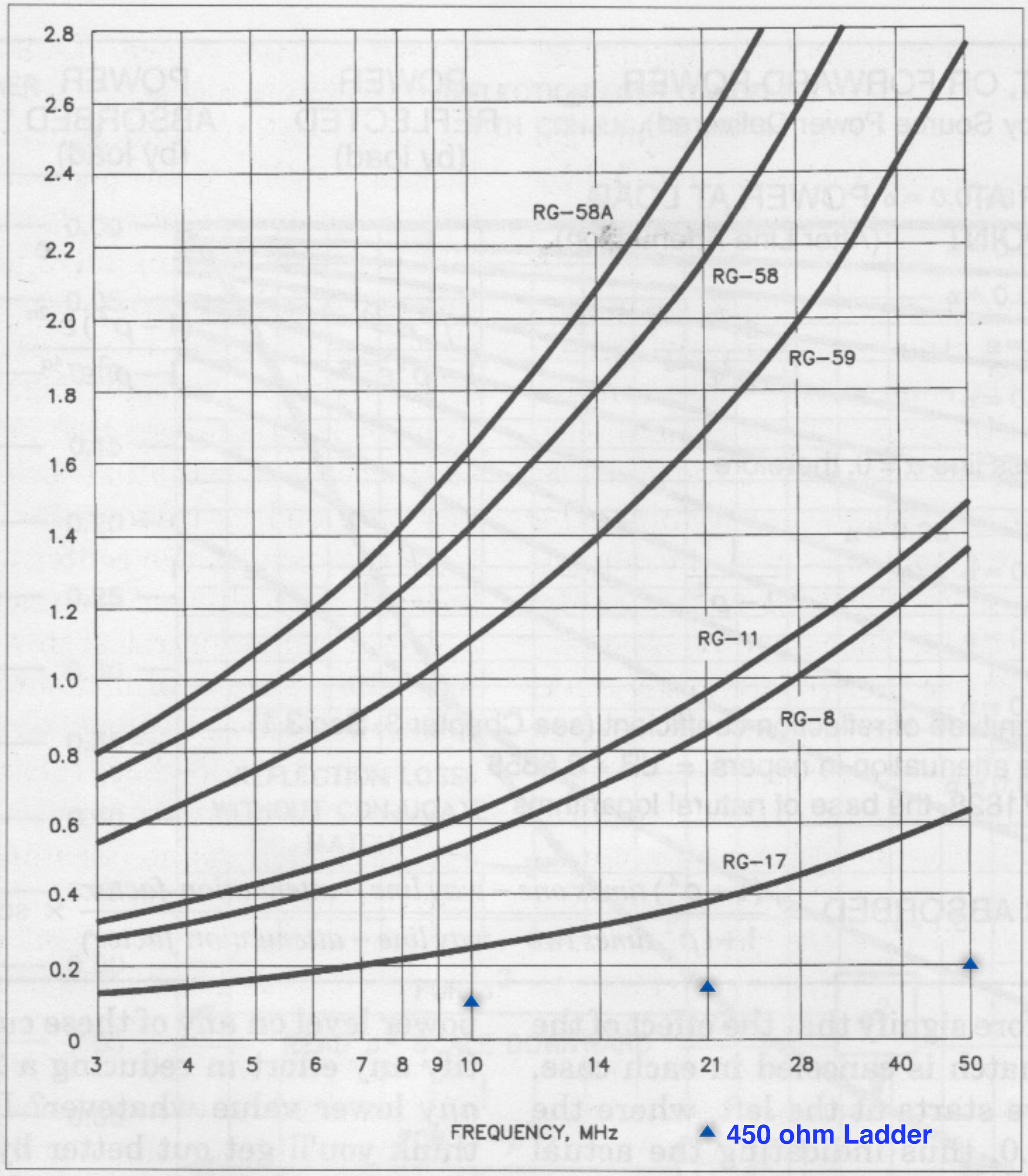


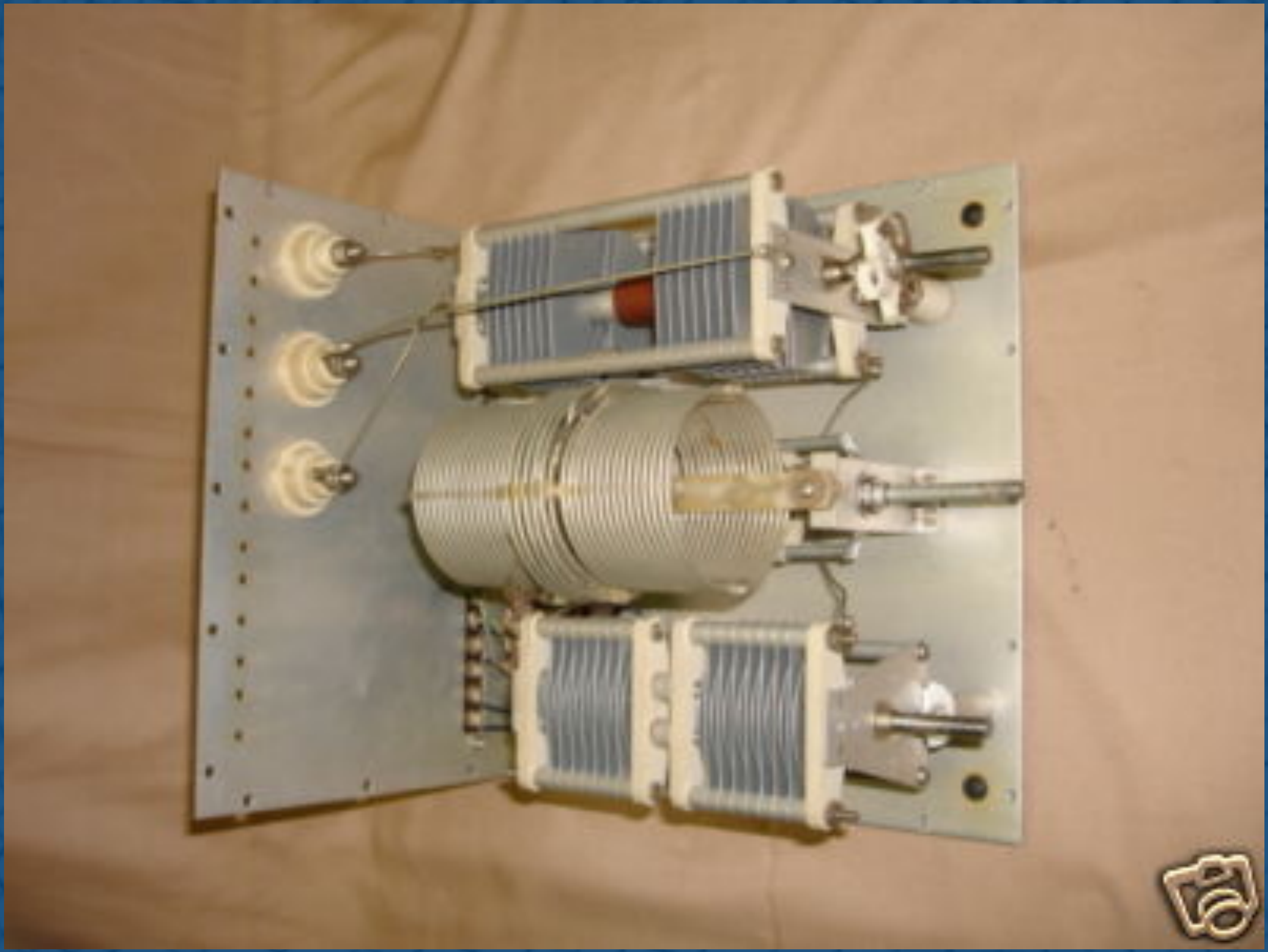
Fig 6-2 — Attenuation in decibels per hundred feet for various coaxial cables.

HF Antenna Tuners

Built-In OR
External Transmatch or Matchbox,

HF Antenna Tuners

The Magic Inside



What is SWR (VSWR)?

- A mismatch between the Charteristic Impedance of a Transmission Line and an Antenna causes a reflected wave that returns to the transmitter.
- The vector Sum of the Forward and Reflected Waves causes a Standing Wave.
- SWR (VSWR) is the ratio of Standing Wave maximum to minimum voltage (or current).

What is SWR (VSWR)?

5/13/20

- **Complex Reflection Coefficient** — ie

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \text{(complex)} \qquad 0.5\angle 30^\circ$$

- **Reflection Coefficient**

$$\rho = |\Gamma| \quad \text{(magnitude)} \qquad 0.5$$

- **VSWR**

$$VSWR = \frac{1+\rho}{1-\rho} \qquad \frac{3/2}{1/2} = 3$$

- **Power Reflection Coefficient**

$$\Gamma_{pwr} = |\Gamma|^2 = \rho^2 \qquad (0.5)^2 = 0.25$$

- **Return Loss** (positive)

$$RL = 20 \log_{10}\left(\frac{VSWR+1}{VSWR-1}\right) = +6dB$$

Waves on a String Analogy

https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

HF vs VHF/UHF Transmitters

- HF Rig
  - Usually Has a Built-In Tuner OR
  - Requires an External Tuner.
  - The Tuner Reduces the SWR at the transmitter NOT on the Transmission Line.
  - Most of the Reflected Power is Returned to the Antenna by the Tuner.

- VHF/UHF Rig
  - Usually doesn't Use a Tuner.
  - Power is Automatically Reduced as SWR increases.
  - Reflected Power may be lost.

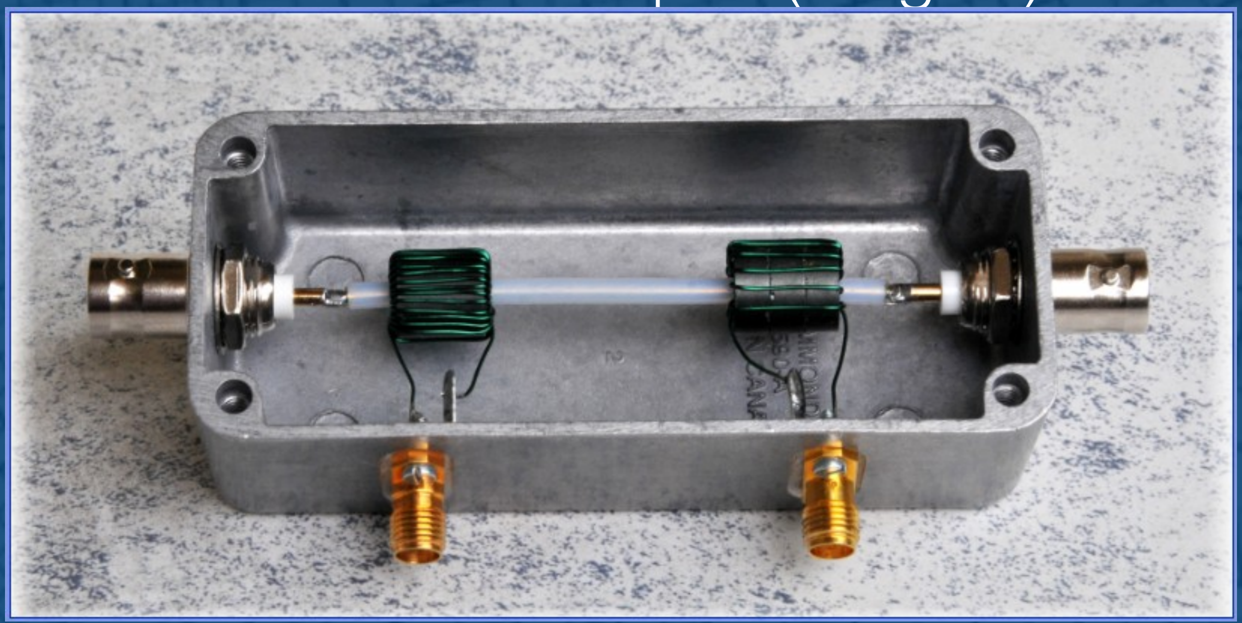
What is SWR (VSWR)?

VSWR equation

$$\mathrm{SWR} = \frac{|V_{\max}|}{|V_{\min}|} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

A Measure of the Amount of Reflected Power

Directional Coupler (Magic?)



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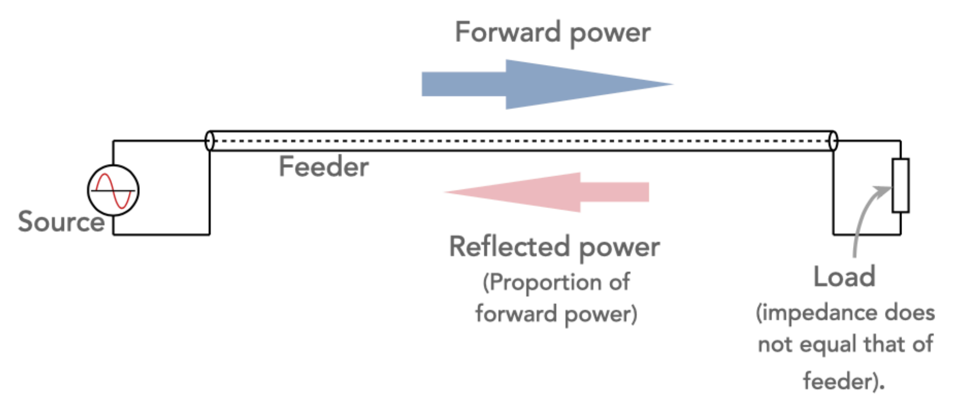
A Measure of the Amount of Reflected Power

Bird Directional Watt meter

Reflection at the Antenna (Load)

0% If Load Impedance = Feedline Characteristic Impedance

100% if Short or Open



Power is reflected when feeder and load impedances do not match

What Happens to the Reflected Power?

Where Have All My Power(s) Gone?

- Assuming Maximum Available Power transmitter transfer to the line when matched.
- TransMatch Loss is Small Potatos
- Mismatch Loss is Mostly in the Feedline
- Antenna Efficiency and Ground Loss
- A Perfect Match is not Guarantee you are “Getting Out”

SWR vs Reflected Power

Table I. VSWR, Reflected Power, and Γ (s11)

VSWR	Γ (s11)	Reflected Power (%)	Reflected Power (dB)
1.0	0.000	0.00	-Infinity
1.5	0.200	4.0	-14.0
2.0	0.333	11.1	-9.55
2.5	0.429	18.4	-7.36
3.0	0.500	25.0	-6.00
3.5	0.556	30.9	-5.10
4.0	0.600	36.0	-4.44
5.0	0.667	44.0	-3.52
6.0	0.714	51.0	-2.92
7.0	0.750	56.3	-2.50
8.0	0.778	60.5	-2.18
9.0	0.800	64.0	-1.94
10.0	0.818	66.9	-1.74
15.0	0.875	76.6	-1.16
20.0	0.905	81.9	-0.87
50.0	0.961	92.3	-0.35

Why SWR is Important

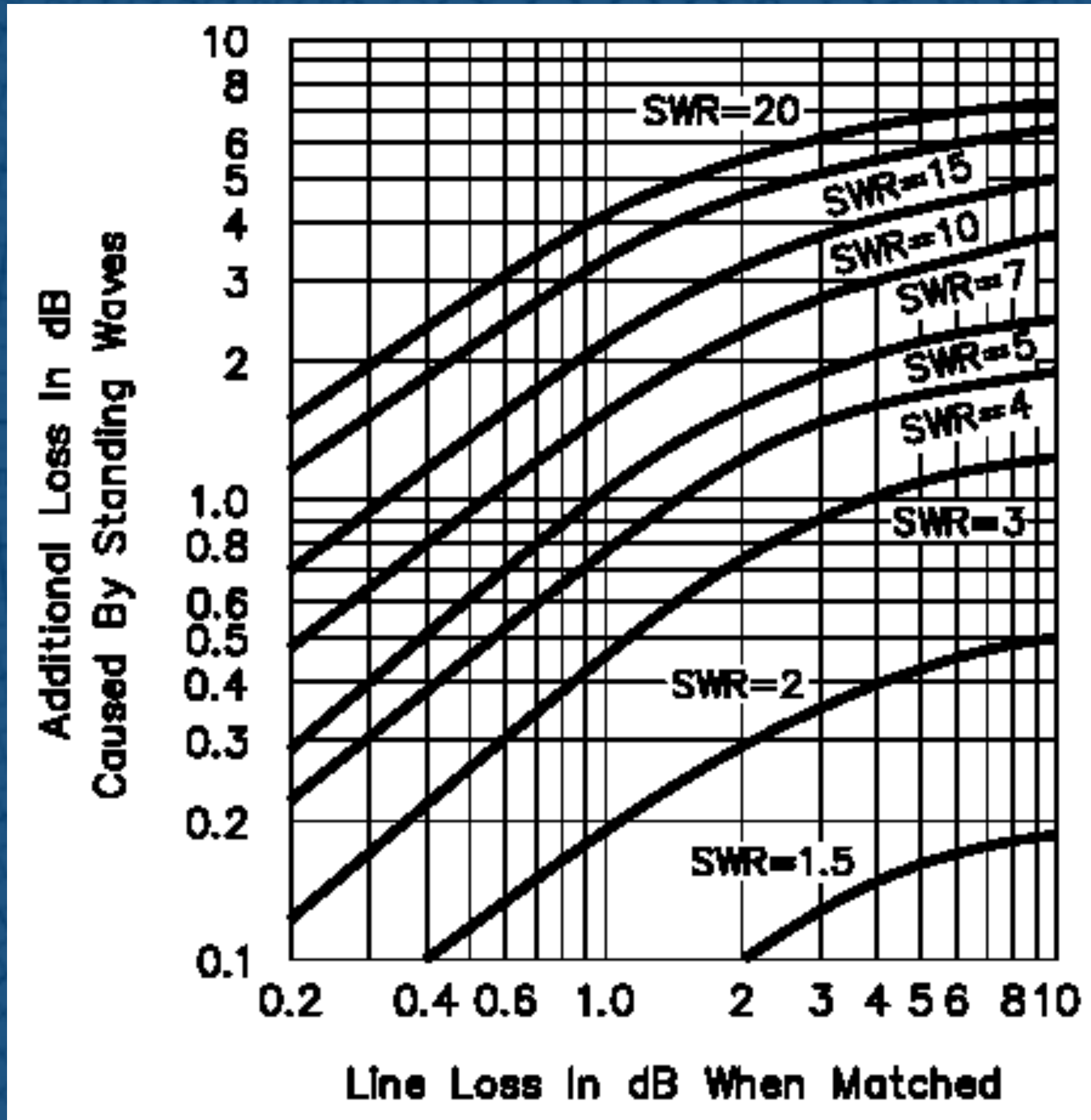
Especially for VHF/UHF rigs that have no match capability. Buy or build a good, Resonant VHF/UHF Antenna and use Low Loss Coax.

It becomes critical as you increase operating frequency.

It becomes more important when you need to use very long (lossy) tansmission lines.

If you don’t have an HF tuner then use a resonant antenna.

Why SWR is Important



When is SWR Not Important

EXAMPLE 1

40 m dipole fed with 100’ of RG58 Zl=91 ohms
SWR is 1.8:1 at resonance

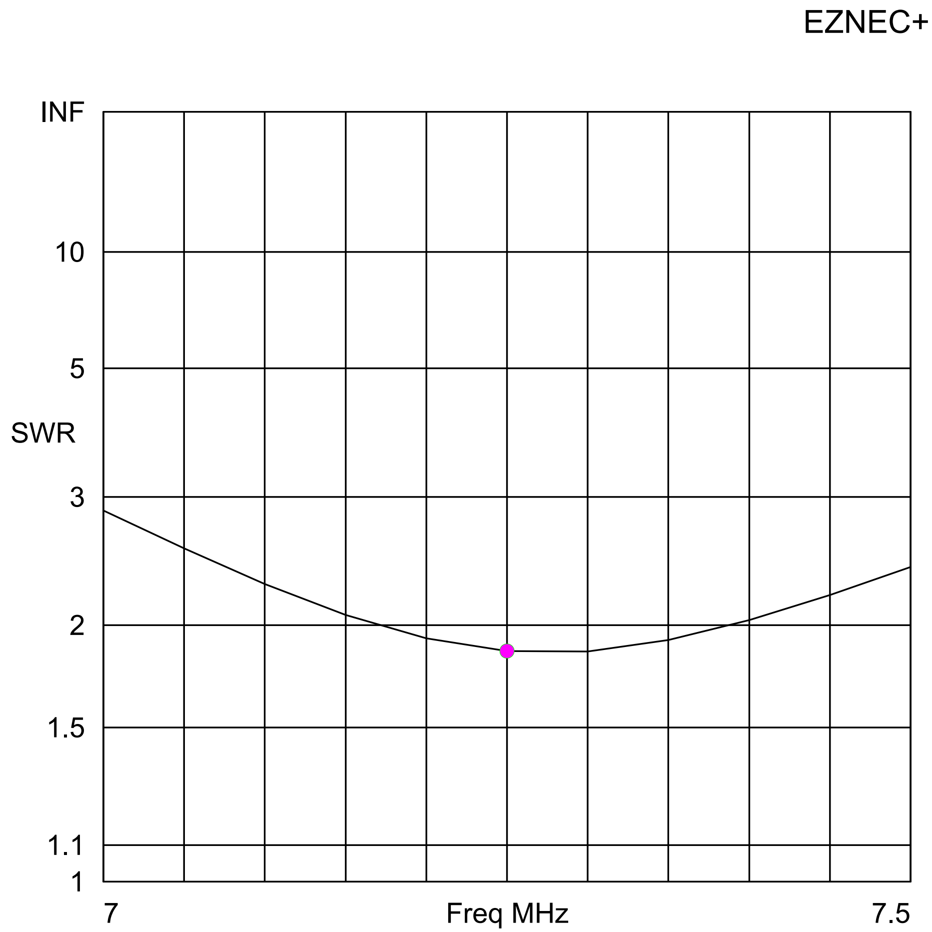
At 1:1 SWR RG58 loss would be about 1.2 dB

Additional Cable Loss due to mismatch is 0.28 dB

So Total Cable loss is about 1.5 dB

Don’t forget 1dB is just barely audible
and 6dB is 1 S-Unit

40m Dipole at 40' with No Feedline

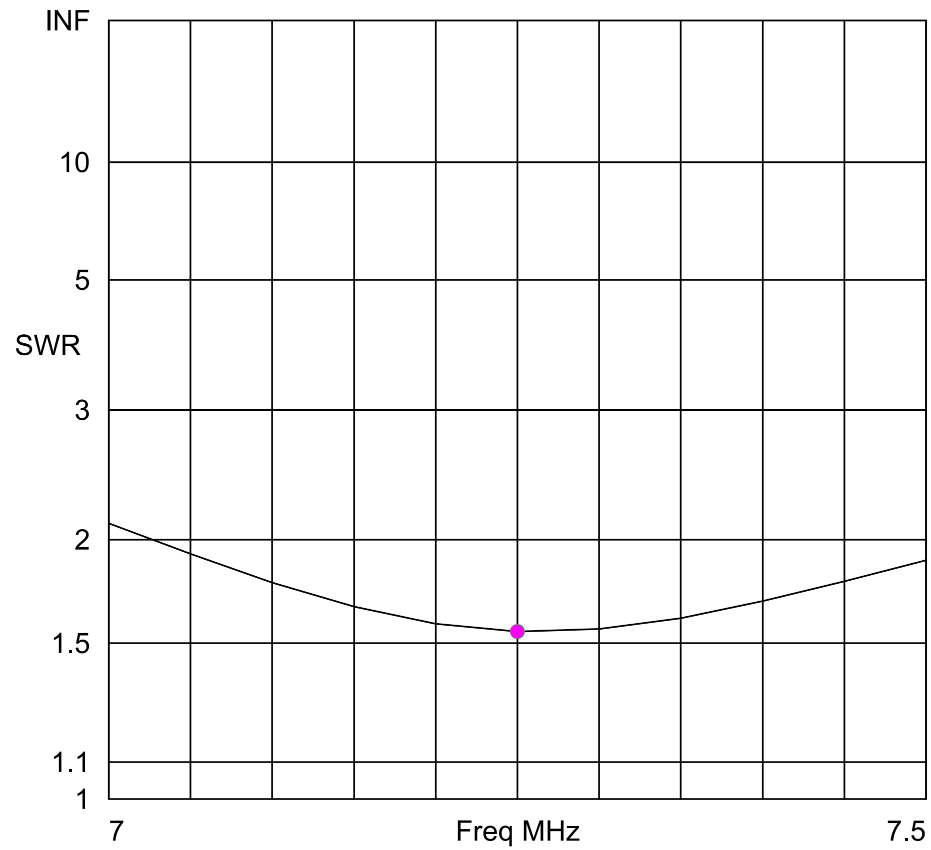


40m Dipole 40ft up

Freq	7.25 MHz	Source #	1
SWR	**1.85**	Z0	50 ohms
Z	90.56 at -9.19 deg.		
	= 89.4 - j 14.46 ohms		
Refl Coeff	0.2995 at -14.23 deg.		
	= 0.2903 - j 0.07363		
Ret Loss	10.5 dB		

40m Dipole at 40’ with 100’ RG58 Feedline

EZNEC+



40m Dipole 40ft up

Freq	7.25 MHz	Source #	1
SWR	**1.55**	Z0	50 ohms
Z	56.04 at -23.46 deg.		
	= 51.41 - j 22.31 ohms		
Refl Coeff	0.2152 at -73.98 deg.		
	= 0.05939 - j 0.2069		
Ret Loss	13.3 dB		

When SWR is Not Important

EXAMPLE 2

40 m dipole fed with 100’ of 450 ohm Ladder Line
SWR is 10.2:1 on 20m

At 1:1 SWR Ladder Line loss would be about 0.1 dB

Additional Feedline Loss due to mismatch is 0.5 dB

So Total Feedline loss is about 0.6 dB!

If matched at the transmitter almost all the available power is radiated by the antenna.

Don’t forget 1dB is just barely audible
and 6dB is 1 S-Unit

When SWR Is Important

EXAMPLE 3

Marine band antenna fed with 100’ of RG58
Let’s say the SWR is 4:1 using at 146.5 MHz

At 1:1 RG58 loss would be about 5.6 dB.
Additional Feedline Loss due to mismatch is 1.8 dB

So Total Feedline loss is about 7.4 dB!
(25W Out but only 4W Delivered)

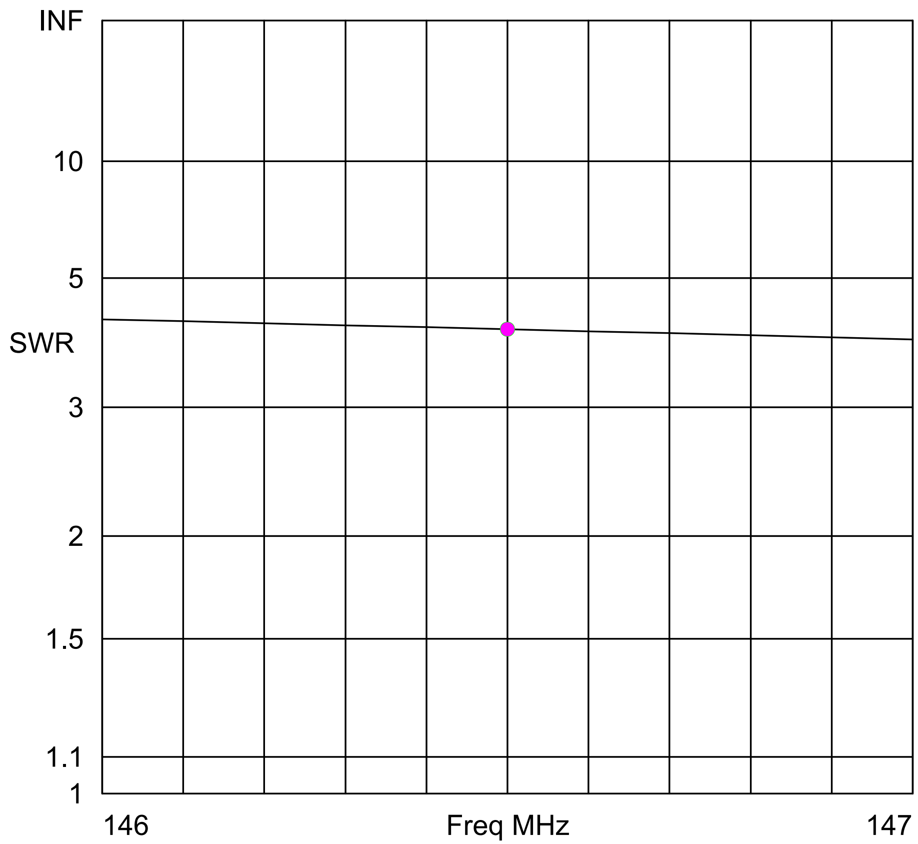
However your SWR Meter May Read 1.3:1 Due to Cable Loss

Don’t forget 1dB is just barely audible
and 6dB is 1 S-Unit

Marine 162 MHz Dipole at 40’ at Antenna

Average Far Field Gain = -3.3 dB

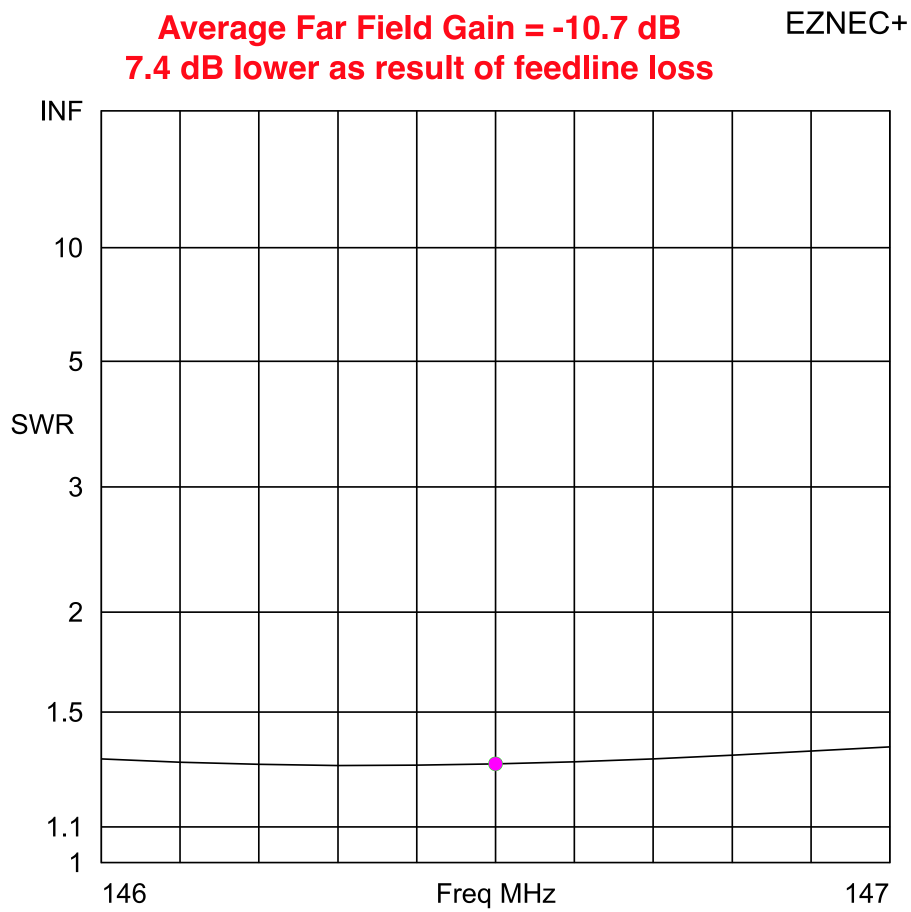
EZNEC+



Marine dipole 40ft up

Freq	146.5 MHz	Source #	1
SWR	**4.01**	Z0	50 ohms
Z	86.51 at -57.17 deg.		
	= 46.9 - j 72.69 ohms		
Refl Coeff	0.6006 at -55.57 deg.		
	= 0.3396 - j 0.4954		
Ret Loss	4.4 dB		

Marine 162 MHz Dipole at 40' with 100' RG58



Marine dipole 40ft up

Freq	146.5 MHz	Source #	1
SWR	**1.3**	Z0	50 ohms
Z	40.14 at 8.24 deg.		
	= 39.72 + j 5.755 ohms		
Refl Coeff	0.131 at 147.09 deg.		
	= -0.11 + j 0.0712		
Ret Loss	17.7 dB		

Field Strength Meter

The only good way to compare antennas or modifications to your antenna is by measuring field strength in far field (1 wavelength).

It should be mounted on a fixed tripod with an antenna that is much smaller than a wavelength and out in the open with no buildings or trees nearby.

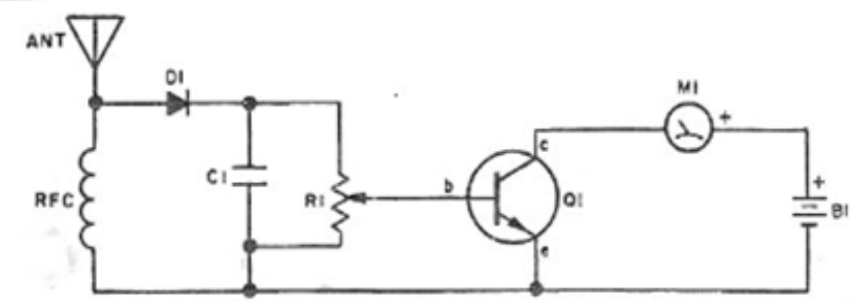
Work with a ham who lives nearby and has a decent S-meter.

A remote reading FS meter would be ideal.

Field Strength Meter

FS Meters are usually quite simple and easy to build.

42 Field Strength Meter



A kilowatt transmitter may pin the needle of regular FSMs (field strength meters), but you need high sensitivity to get readings from low-power oscillators, flea power transmitters and CB walkie-talkies. This simple, amplified FSM has a sensitivity of 150 to 300 times that of ordinary models. It indicates full scale when other meters can't budge off the pin.

Dependable frequency range is approximately 3 to 30 MHz. A metal enclosure is recommended, with a stiff wire antenna about 6 in. long. For compactness, RFC should be a miniature 2.5-mH choke.

To operate the unit, sensitivity control R1 is adjusted for ⅓ to ¾-scale reading. Avoid working too close to the top of the scale, since it can saturate transistor Q1, producing full-scale readings at all times. Back off on R1 as you make transmitter adjustments to keep the needle at approximately half scale. Any high-gain npn small-signal transistor can be substituted for Q1.

PARTS LIST FOR FIELD STRENGTH METER

- B1—1.5-V AA battery
- C1—0.001-µF, 100-VDC capacitor
- D1—1N60 diode
- M1—0-1 mA DC meter
- Q1—npn transistor—HEP-726
- R1—50,000-ohm potentiometer
- RFC—2.5-mH choke—J. W. Miller 6302

Antenna Radiation Resistance

The Radiation Resistance of an antenna is that portion of the power that you send to it that is converted into EM waves leaving the antenna.

The power sent down the transmission line is divided between the Antenna's Radiation Resistance, I^2R metal resistance and resistance of the ground under it

Low SWR is Not Necessarily Good

Ground Losses

Vertical 1/4 wave Antenna
with 100 or more Radials and a Matchbox

Say the Antenna Feedpoint Impedance is 30 ohms.
If it’s being fed by 50 ohm cable, the SWR is 1.7

Remove 4 radials at a time until
the SWR drops to 1:1 due to 20 ohms of ground loss.

Transmission Line Radiation

Caused by Imbalance

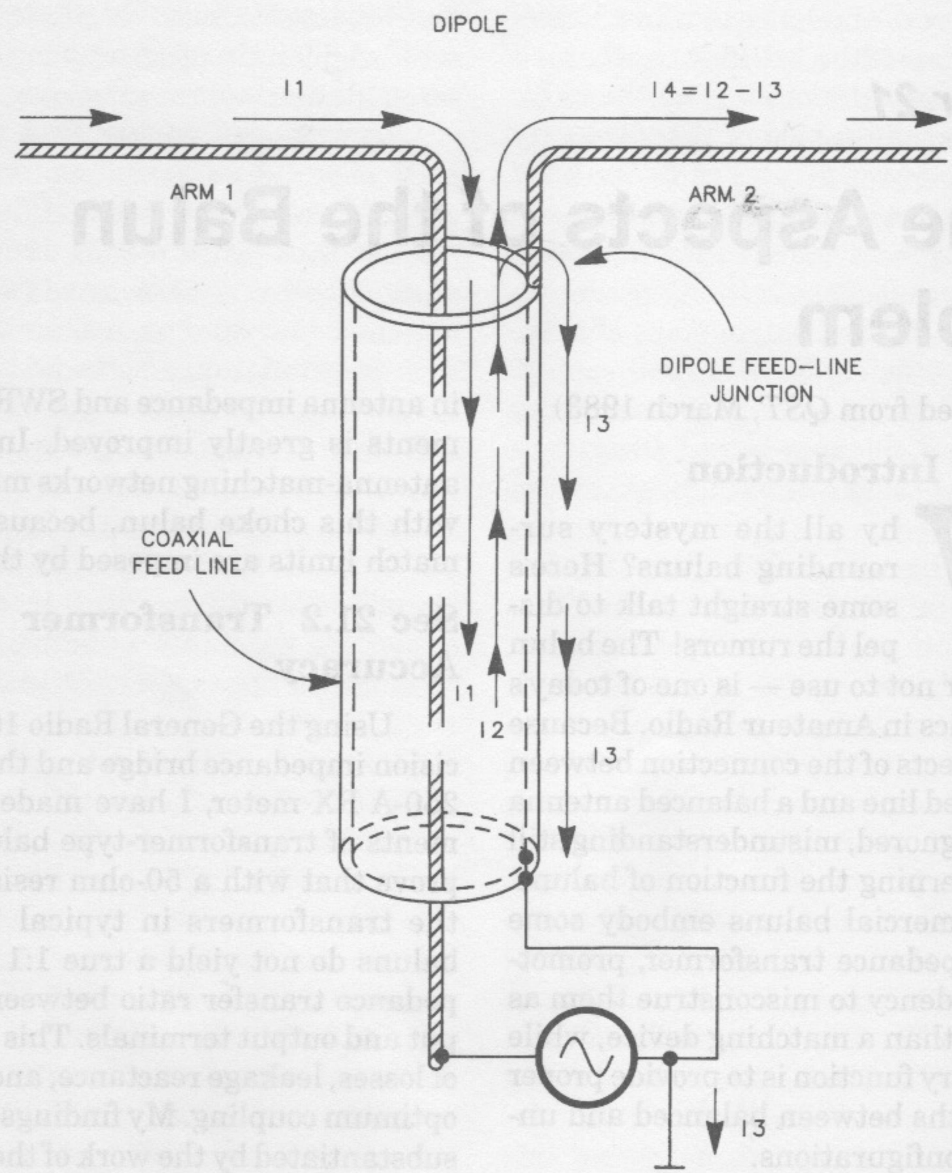
OR

By Coupling Antenna Current into Feedline

Not by high SWR

For Instance: A Coax Fed Dipole

Transmission Line Radiation



21-1—Illustration of the various current paths at a dipole feed point.

Transmission Line Radiation

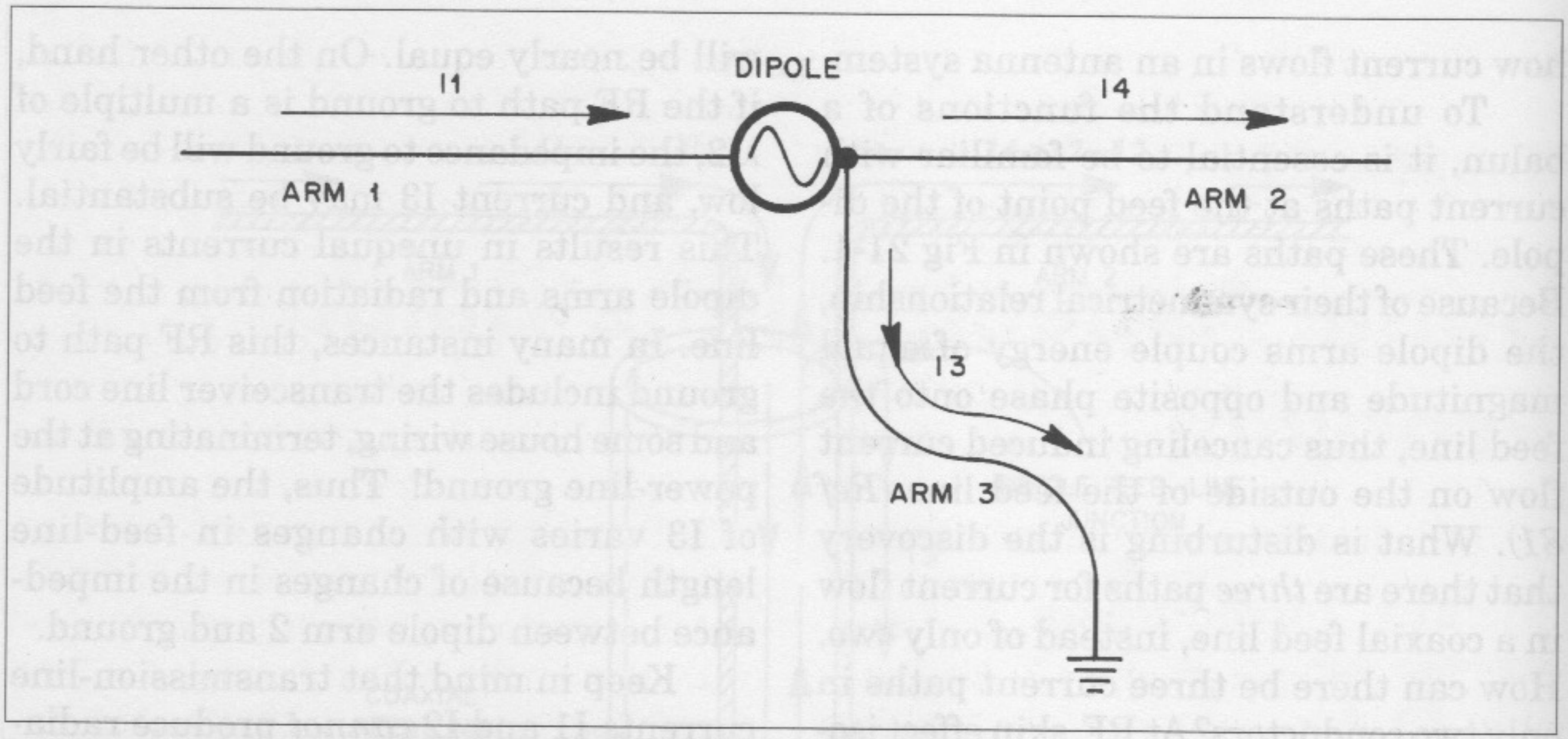


Fig 21-2—Simplified electrical representation of Fig 21-1.

Current flowing in Arm 3 depends on its Length

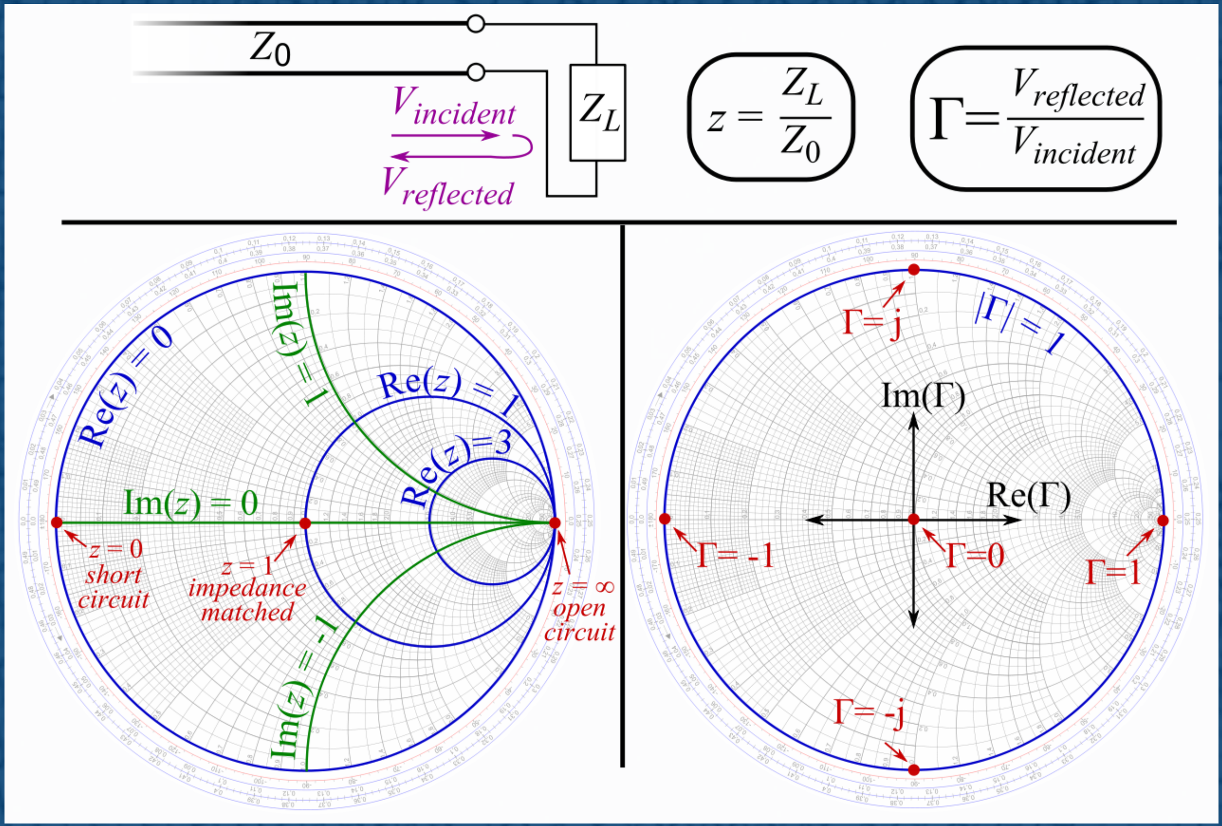
Transmission Line Radiation

How do you prevent Radiation?

Voltage and Current Baluns

Common Mode Chokes
Coiled Coax or
Multiple Ferrite Cores (W2DU)

SWR, Return Loss, Smith Charts and Time Domain Reflectometry



These concepts are all related with a bit of math – for example https://ecee.colorado.edu/~ecen4634/4634-Lectures-Labs.pdf

Vector Network Antenna Analyzers

Examples

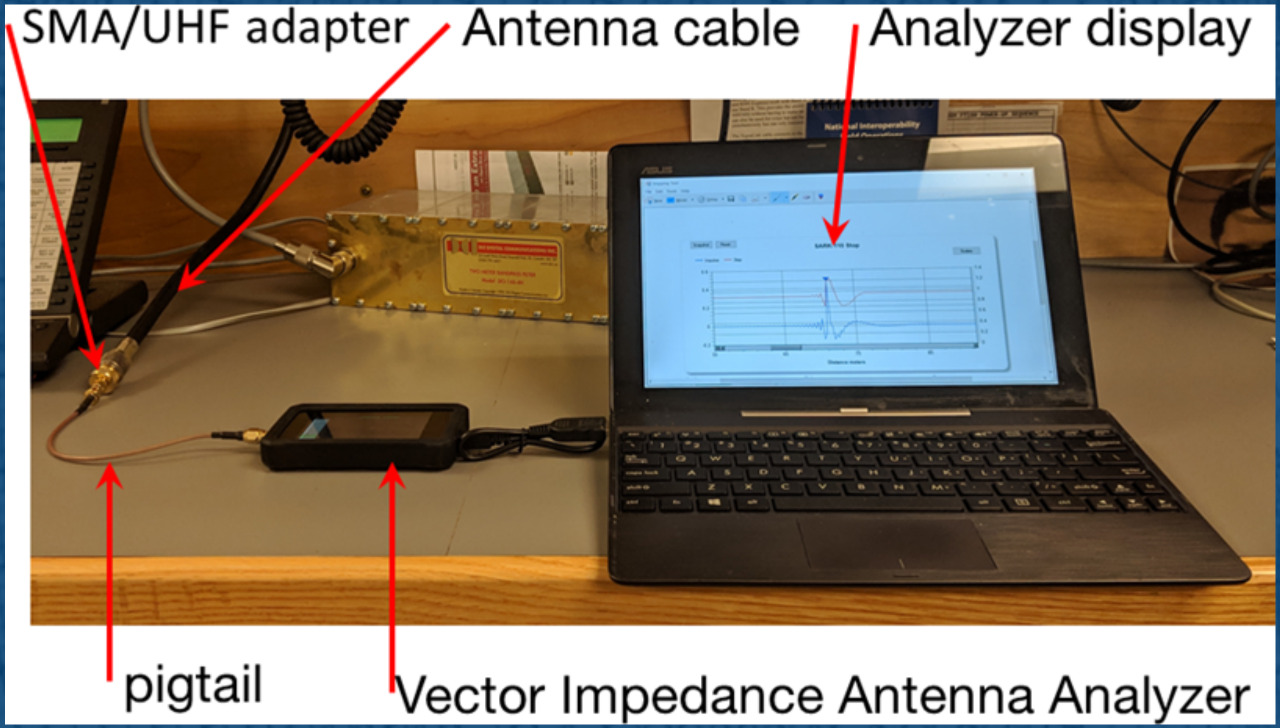
- NanoVNA-H Vector Network Antenna Analyzer
  ~$80 with measurement range: 10 kHz – 1.5 GHz

- SARK-110 Antenna Analyzer
  ~$390 with measurement range: 100 kHz – 230 MHz with TDR

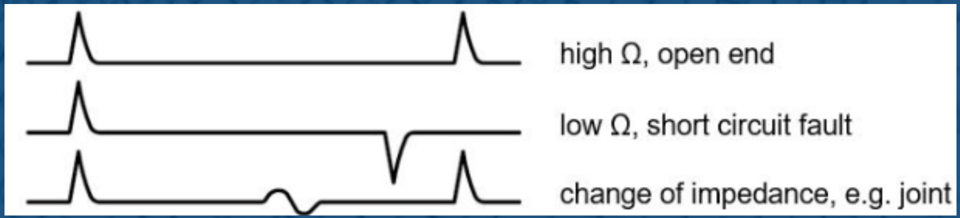
- Banggood N1201SA Vector Impedance Analyzer
  ~$200 with measurement range: 140 MHz – 2.7 GHz with TDR

Using Time Domain Reflectometry to Identify Impedance Discontinuities

Measuring Equipment with the SARK-110 Analyzer



Schematic Examples of TDR traces



Notes on Interpreting TDR & RL Measurements

SWR and Return Loss

$$SWR = \frac{|V_{max}|}{|V_{min}|} = \frac{|V_f| + |V_r|}{|V_f| - |V_r|} = \frac{\left|\frac{V_f}{V_r}\right| + 1}{\left|\frac{V_f}{V_r}\right| - 1}$$

Rearranging to express the Return Loss V_r / V_f *in terms of the SWR*

$$Return\ Loss, dB = -20\ \log_{10} \frac{SWR + 1}{SWR - 1}$$

Return Loss, dB	*SWR*
-5	3.57
-10	1.93
-20	1.22

Distance to Fault

$$Distance, m = \frac{\alpha \times c}{2 \times \Delta f}$$

where $\alpha = cable\ velocity\ f$

$e.g. \sim 0.81\ for\ hard\ line$

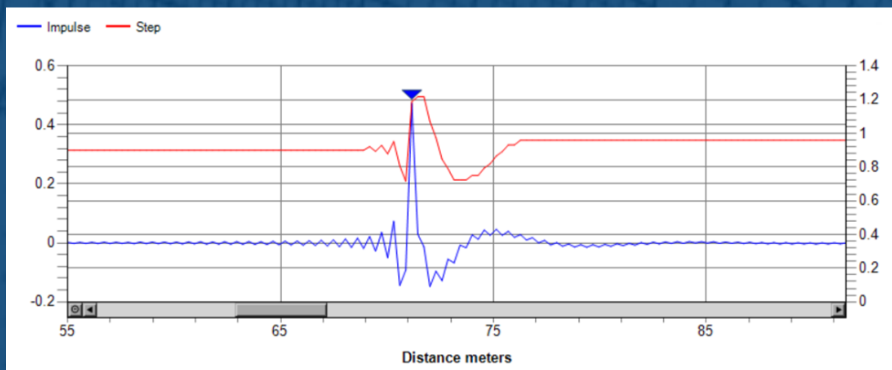
$\& \sim 0.66\ for\ RG8$

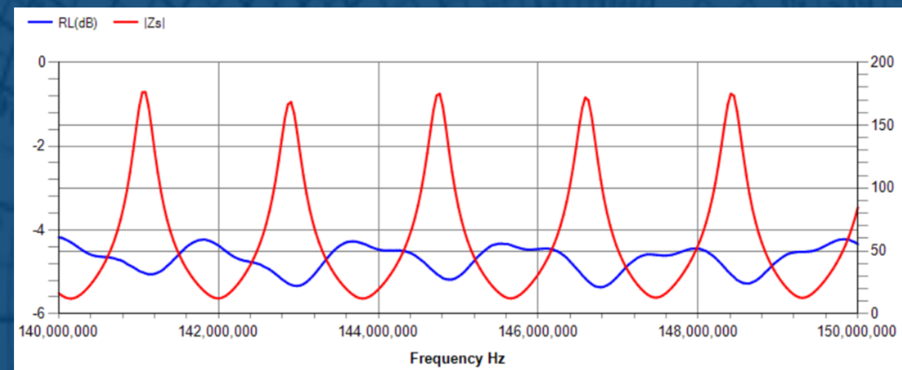
$c = 3 \times 10^8$

$\Delta f = ripple\ frequency$

Antenna System Measurements at EOC

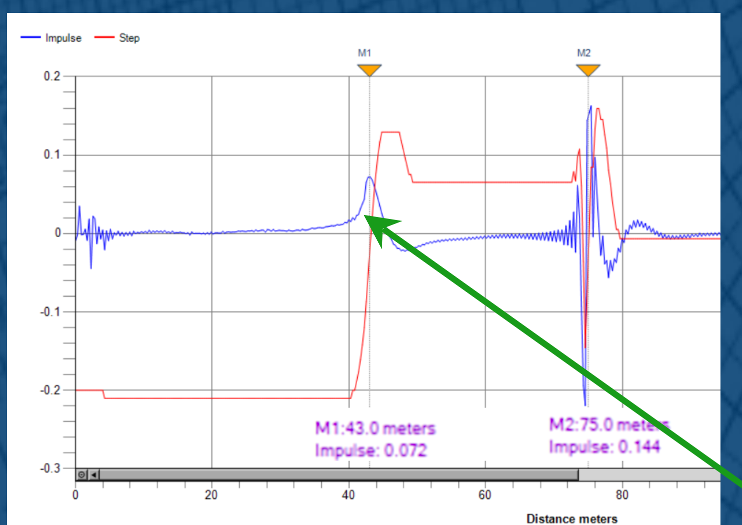
The faulty system in April 2019 with an open-circuit at antenna

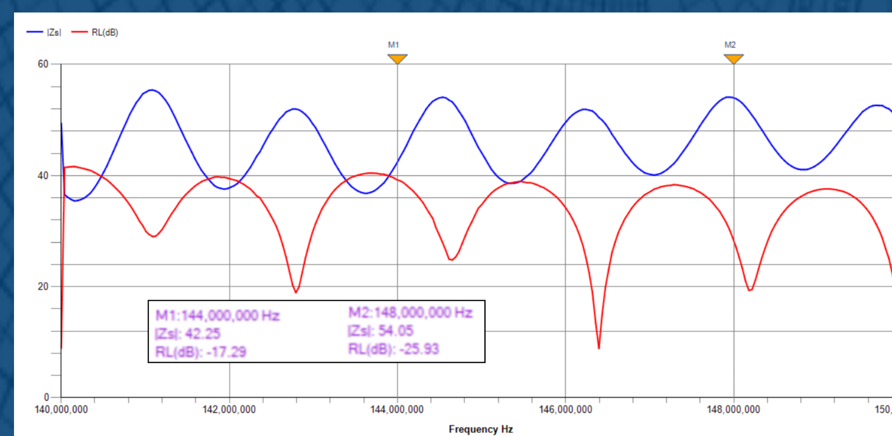




Impedance Zs shows 1.84 MHz periodicity related to the 71m distance to the fault

The repaired system in August 2019 with replacement feed line





Note impedance discontinuity at 43m due to polyphase at building exit

Takeaways

- Don't waste a nice Sunday afternoon trying to lower your HF antenna's SWR if it's 2:1 or less.
- Low SWR does not necessarily mean you are "Getting Out" Be wary of an antenna system that exhibits low SWR over a large frequency range.
- An HF antenna tuner will maximize your power to the antenna.
- Don't be afraid of SWR of 2 or even 3:1 on HF as long as your tuner can match it and your feedline is low loss. This will give you access to other portions of the band you might be wary of using.
- For VHF/UHF be sure to use a well tuned antenna and a short, low loss feedline to maximize power. Check the antenna's SWR with a short coax with it mounted a wavelength above ground before putting it on a tower.

Questions?

Richard will demonstrate transmission line and antenna measurements
using his nifty hand held antenna analyzer.

References

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