The Principle

V(SWR)

The Result

Mirror, Mirror, Darkly, Darkly

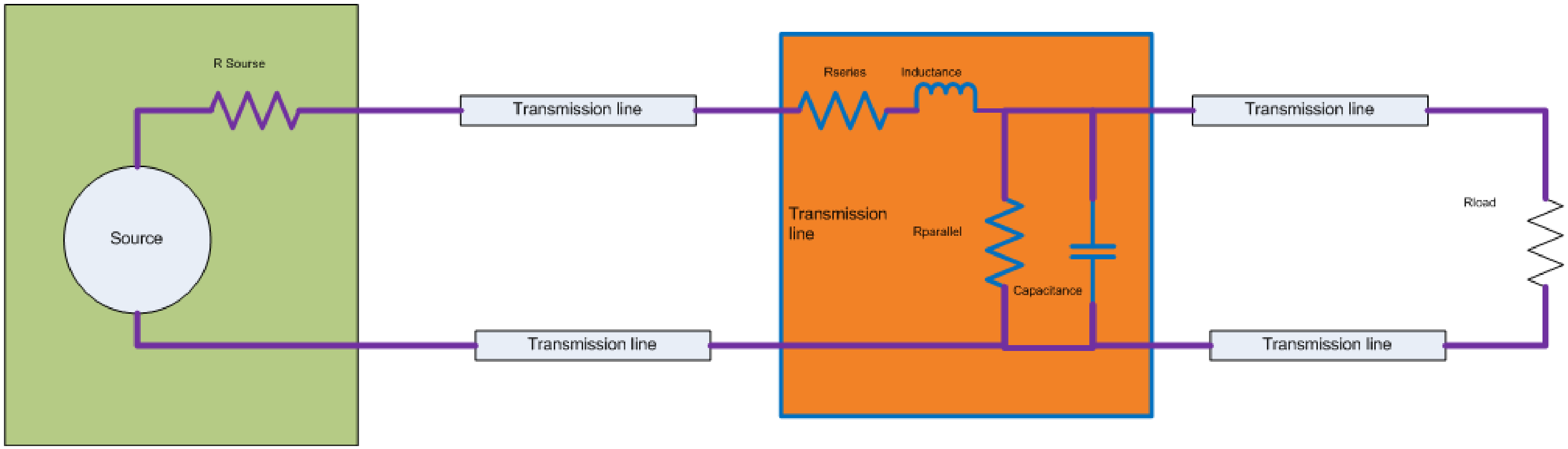
Question time!!

- What do you think VSWR (SWR) mean to you?
- What does one mean by a transmission line?
  - Coaxial line
  - Waveguide
  - Water pipe
  - Tunnel (Top Gear, The Grand Tour)
- Relative permittivity.
  - Vacuum = 1.00000
  - Air = κ_{air} = 1.0006.
- Why is the concept of an infinite transmission line of any use?

In SI units, the speed of light in vacuum, c,[14] is related to the magnetic constant and the electric constant (vacuum permittivity), ε_0, by the definition:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

VSWR Schematic



The elements in the orange box represents the equivelent circuit of a transmission line. This circuit demonstrates that the characteristics of the line are determined by mechanical effects:

Capacitance is proportional to the area divided by the gap.

Inductance is proportional to the number turns and area of the loop

Resistance is determined by the material it is made up of.

Transmission Line Characteristic Impedance Formula

$$Z_0 = \sqrt{L/C}$$

L – unit length inductance

C – unit length capacitance

Z_0 – *characteristic impedence in ohms*

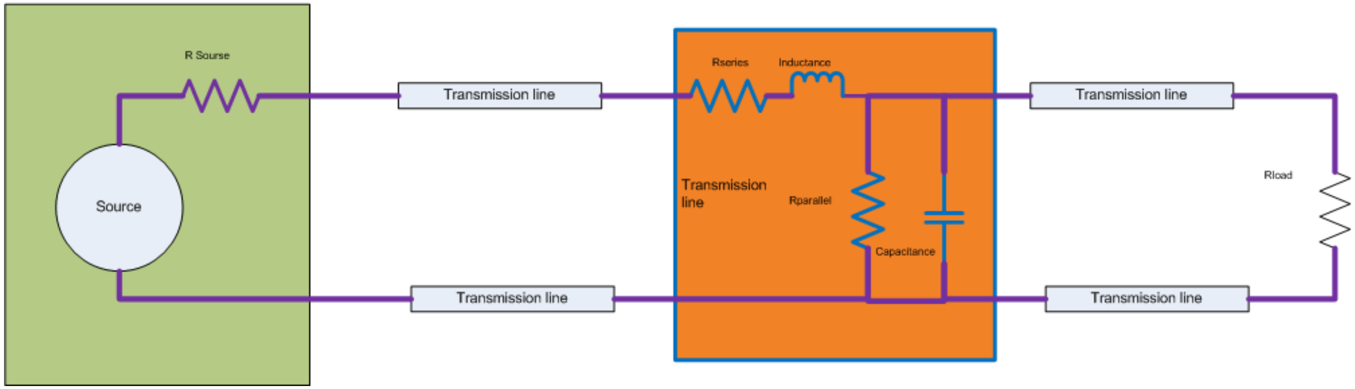
Some Definitions

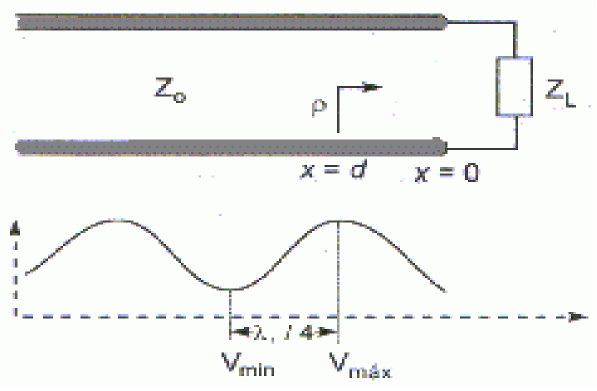
- What is meant by an infinite transmission line and what does have to matching and hence, VSWR.
  - Any line that is perfectly matched, by definition has VSWR of 1:1
  - A line which has infinite length (free space=377Ώ).
  - A large attenuator
  - A transmission line can have any impedance.

VSWR Waveform

- Circuit

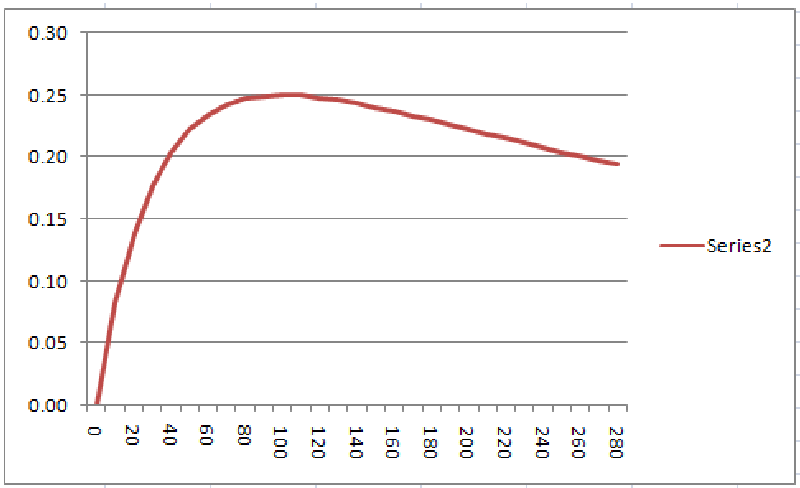
$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \ .$$



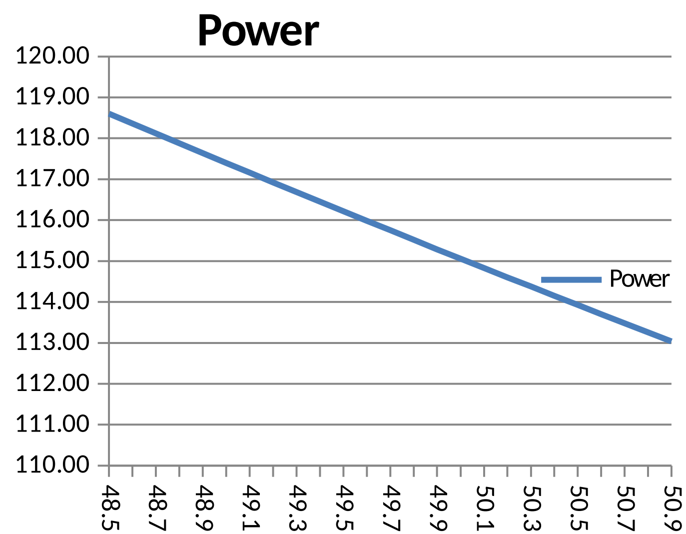


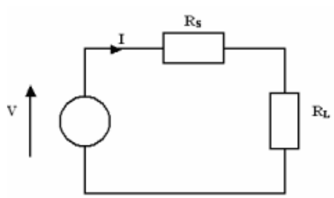
Maximum power transfer theorem

- The theorem shows the maximum power transfer with source and resistance set to 100Ω



Vd =	10.00	Volts
Resistance	100.00	Ω





In the diagram opposite, power is being transferred from the source, with voltage V and fixed source resistance R_S, to a load with resistance R_L, resulting in a current I. By Ohm's law, I is simply the source voltage divided by the total circuit resistance:

$$I = \frac{V}{R_S + R_L}.$$

The power P_L dissipated in the load is the square of the current multiplied by the resistance:

$$P_L = I^2 R_L = \left(\frac{V}{R_S + R_L}\right)^2 R_L = \frac{V^2}{R_S^2/R_L + 2R_S + R_L}.$$

Some more Definitions

- What is VSWR?
  - VSWR is the acronym for **V**oltage (**S**tanding **W**ave **R**atio).
  - VSWR has no units, its a ratio of the max and min values of the standing wave.
  - VSVR value can be between 1 to ∞ or 1 to 0.
- Some features of VSWR
  - The max and min occur every ¼λ
  - Repeats every ½λ (Smith chart repeats likewise)
  - Short circuit would give 0 volts and 2*I amps; zero power
    - Where I and V are the matched currents and voltages
  - Open circuit would give 2*V and 0 amps; zero power
- SWR meters measure incident and reflected **power**

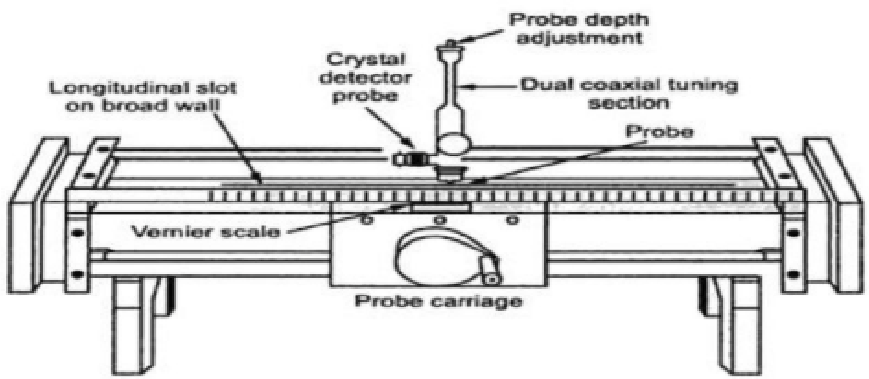
This is based on the Reflection Coefficient (Γ)

- What is the value of VSWR:
  - VSWR = (1-Γ)/(1+Γ)
- VSWR:
  - This is based on the derivation of the reflection coefficient (Γ).
  - The reflection coefficient is the ratio of the max reflected voltage to the min reflected voltage.
  - The max and min occur at every quarter wavelength.

Simple way of measuring VSWR

Slotted Line Carriages

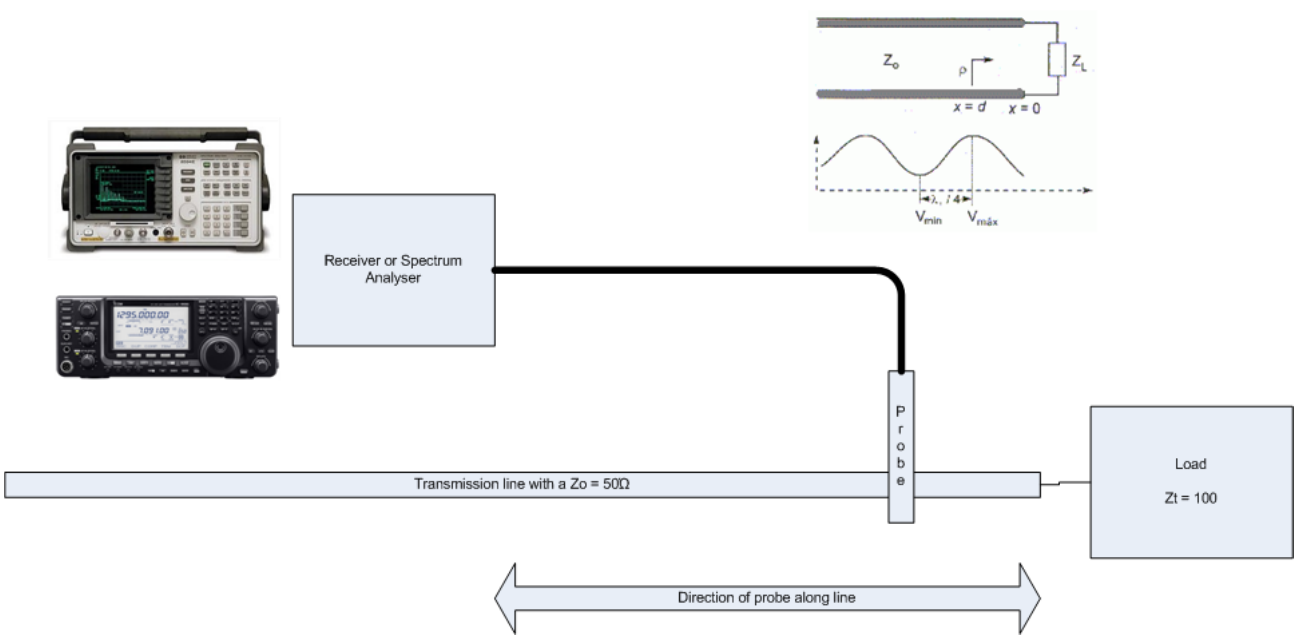
- A slotted line carriage is a microwave instrument which is used to measure:
  - Wavelength
  - Voltage Standing Wave Ratio (VSWR) and standing wave pattern
  - Impedance, reflection coefficient and return loss measurement
- It has a coaxial E-field probe which penetrates inside a rectangular waveguides slotted in sections from the outer wall.
- The probe is able to transverse a longitudinal narrow slot and locate the standing waves maxima(V_{max}) and minima(V_{min}) along the line giving VSWR.



22

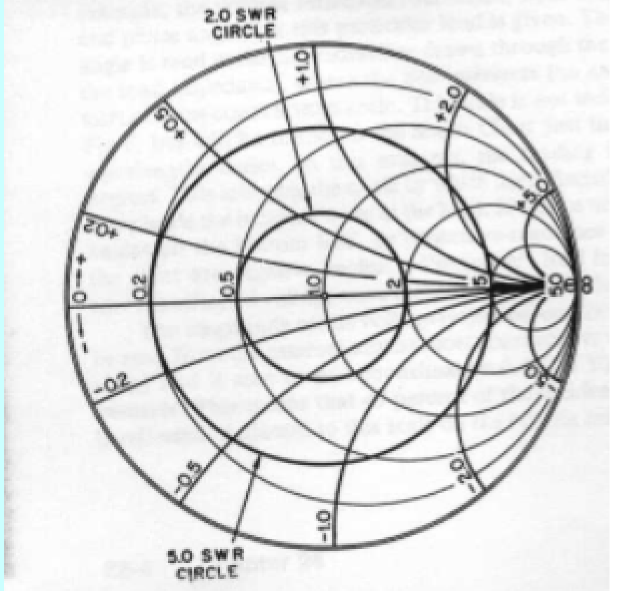
VSWR Measurement.

- Receiver approach.
  - It is useful if you know the velocity of propagation of the cable. (A number between 0 and 1)



Using a network analyser (Mini MVNA tiny)

- Frequency range 50MHz to 3GHz
- Cal kit: Short Circuit, Open Circuit and Load.
- Display: Cartesians (XY plot) or Smith chart.
- VSWR requires one port.



Useful Formulas

VSWR to Return loss

3:1 =	6 dB
2:1 =	9.5 dB
1.5:1 =	14 dB
1.2:1 =	20.8 dB
1.1:1 =	26.4 dB

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \qquad RL = -20\log\left[\frac{VSWR - 1}{VSWR + 1}\right] \qquad ML = -10\log\left\{1 - \left[\frac{VSWR - 1}{VSWR + 1}\right]^2\right\}$$

$$VSWR = \frac{1+\Gamma}{1-\Gamma} \qquad RL = -20\log(\Gamma) \qquad ML = -10\log\left(1 - \Gamma^2\right)$$

$$\Gamma = 10^{\frac{-RL}{20}} \qquad VSWR = \frac{1 + 10^{\frac{-RL}{20}}}{1 - 10^{\frac{-RL}{20}}} \qquad ML = -10\log\left[1 - \left(10^{\frac{-RL}{20}}\right)^2\right]$$

Definitions:
Γ = Reflection coefficient
RL = Return loss
ML = Mis-Match loss

Mis-Match Test Cases

Test case 1						Test case 2						Test case 3				
100	watts		20.00	dBW		100	watts		20.00	dBW		100	watts		20.00	dBW
			50.00	dBm					50.00	dBm					50.00	dBm
Return loss			**3.00**	dB		Return loss			**9.50**	dB		Return loss			**20.80**	dB
Power			50.12	Watts		Power			11.22	Watts		Power			0.83	Watts
			17.00	dBW					10.50	dBW					-0.80	dBW
Power transmitted to load			49.88	Watts		Power transmitted to load			88.78	Watts		Power transmitted to load			99.17	Watts
		VSWR =	5.85					VSWR =	2.01					VSWR =	1.20	

VSWR meters

The picture depicts a typical VSWR meter
The important point is that the two scales indicate power. (Incident and reflective)
From these two readings the return loss is calculated.
From the return loss the VSWR is calculated

This calculation is shown in the excel computation below and this is calculated by the meter in the VSWR curves in red and the indicated VSWR is where the two needles cross.

From Return loss to VSWR					
incedent power	100.00	mw		20.00	dBm
Reflected power	10.00	mw		10.00	dBm
Transmitted power	90.00	mw		19.54	dBm
Return loss =	10.00	dB		10.00	dB
Mis-Match loss =	0.46	dB			
VSWR =	1.92	:1			

Common transmission lines

- If the transmission line is coaxial in construction, the characteristic impedance follows a different equation:

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

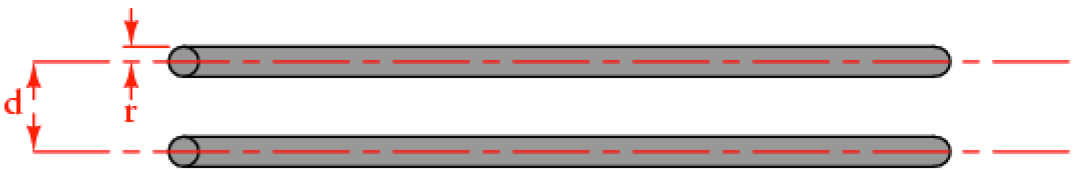
Where,

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

Calculation of the line impeadance				
	d1 =	3.00	mm	
	d2=	2.00	mm	
	k =	1.00	permitivity	
	Z_0 =	24.30		

Common transmission lines

- For a parallel-wire line with air insulation, the characteristic impedance may be calculated as such:



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

Where,

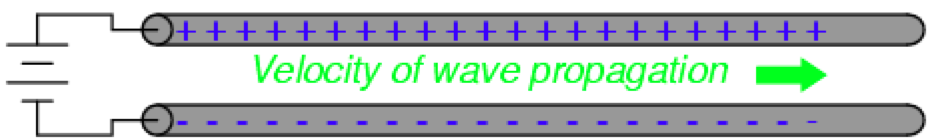
Z_0 = Characteristic impedance of line
d = Distance between conductor centers
r = Conductor radius
k = Relative permittivity of insulation between conductors

Calculation of the line impedance				
	d =	3.00	mm	
	r =	2.00	mm	
	k =	1.00	permitivity	
	Z_0 =	48.60		

Calculation of the line impeadance				
	d =	23.40	mm	
	r =	1.00	mm	
	k =	1.00	permitivity	
	Z_0 =	377.90		

Velocity factor

- Velocity factor is purely a factor of the insulating material's relative permittivity (otherwise known as its *dielectric constant*), defined as the ratio of a material's electric field permittivity to that of a pure vacuum. The velocity factor of any cable type—coaxial or otherwise—may be calculated quite simply by the following formula:



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

Where,

v = Velocity of wave propagation

c = Velocity of light in a vacuum

k = Relative permittivity of insulation between conductors

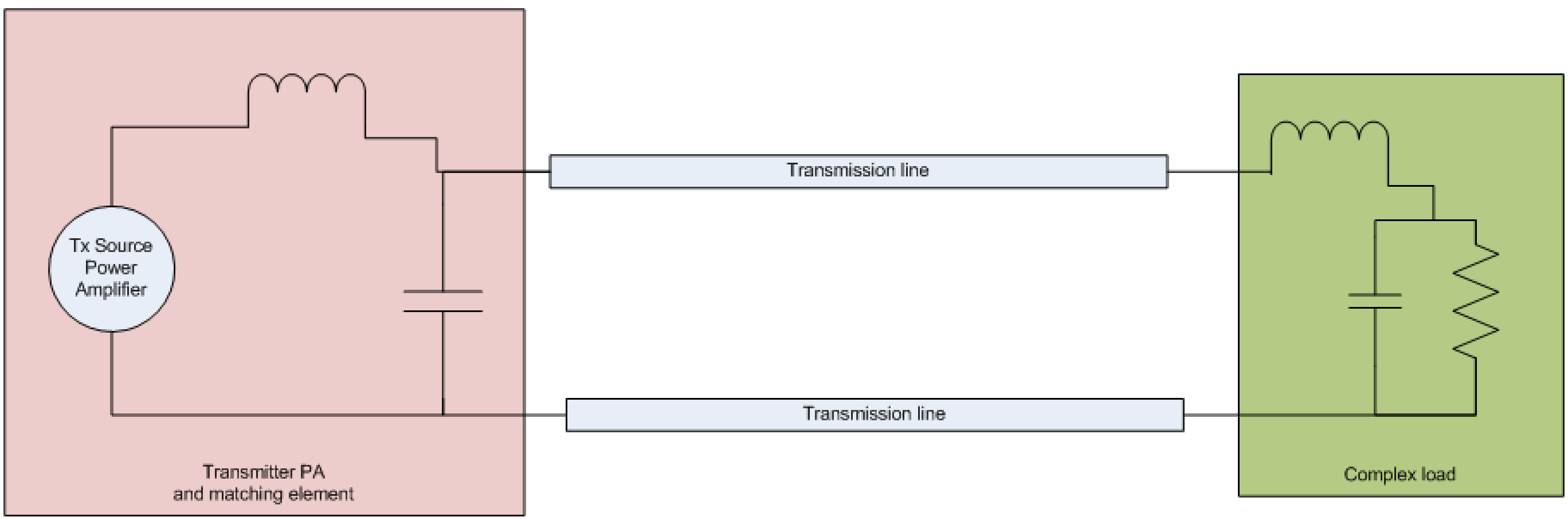
Velocity of propogation				
	k =	1.00	permitivity	

VSWR and its relationship to Transmitter amplifier

- The transmitter has to get all the power to the antenna structure. (Transmission line and antenna).
- The power amplifier must be matched to the transmission system.
- It must be able withstand full reflected power.
- It must be efficient in the use of input power.

Transmitter Equivalent Circuit

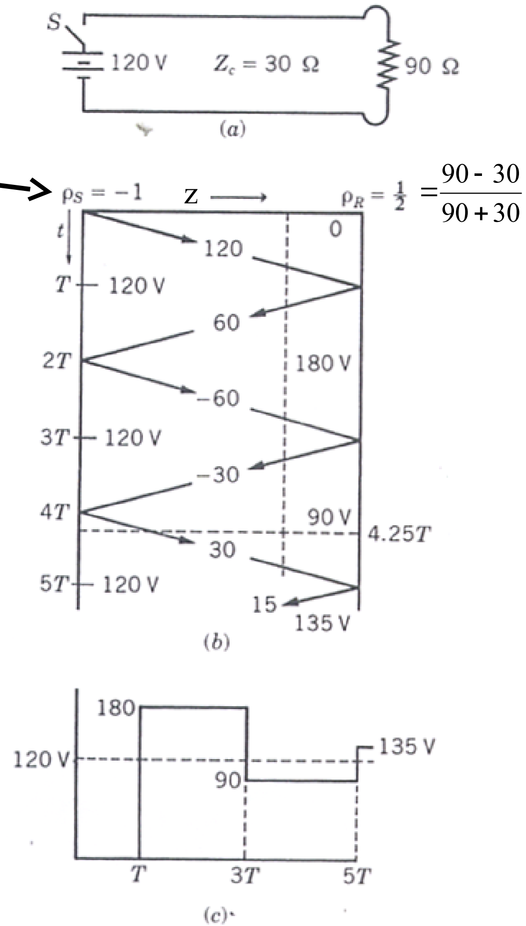
- The circuit below depicts a typical circuit for a transmitter PA delivering power to a complex load via a transmission line



Lattice (bounce) diagram

This is a space/time diagram which is used to keep track of multiple reflections.

Ideal voltage source



Voltage at the receiving end

$$T = \frac{l}{U}$$

Figure 5.14 Circuit diagram, lattice diagram, and plot of voltage versus time for Example 5.6 where the receiving-end resistance is 90 Ω.

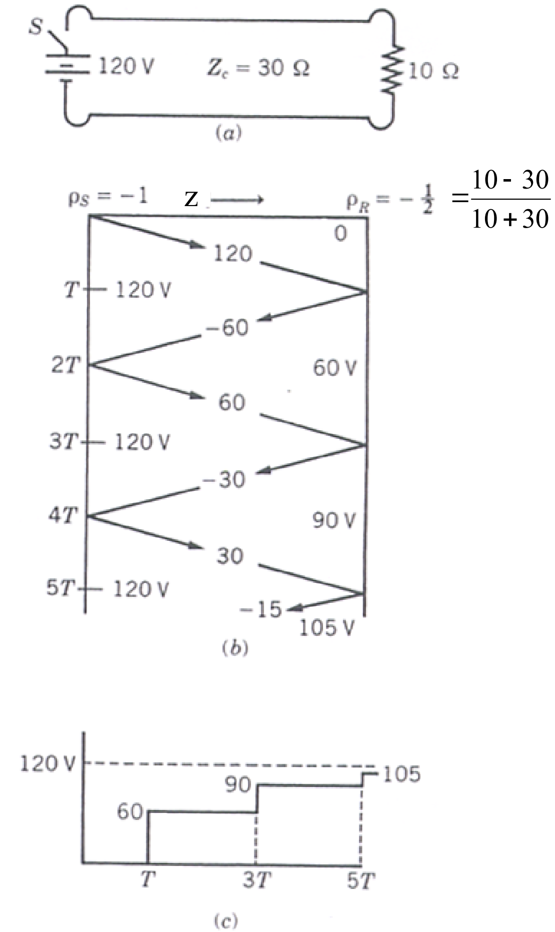


Figure 5.15 Circuit diagram, lattice diagram, and plot of voltage versus time when the receiving-end resistance for Example 5.6 is changed to 10 Ω.

Ladder diagram showing the reflection in a cable driven by an impulse function

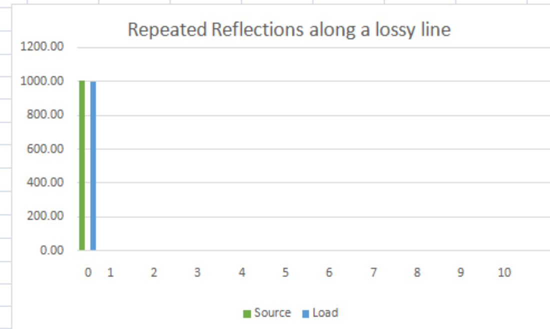
VSWR Ladder

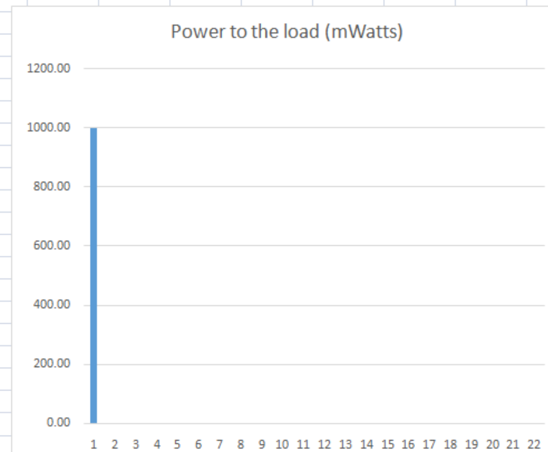
Unit Impulse (Dirac) of δt of amplitude of 1	VSWR Source		Cable	VSWR Load	
	4.00E+00 :1			1.00 :1	
	0.25			1.00	
Γ =	0.60		Γ =	0.00	
Signal = 1	Watt				

Time int	mWatts	dbm	Atten Loss (db)	dbm	Reflect mWatts	Load mWatts	Power lost in cbl
0	1000.00	30.00		30.00	0.00	1000.00	0.00
1	0.00	-33.01 -35.23		-33.01 -35.23	0.00	0.00	0.00
2	0.00	-98.24 -100.46		-98.24 -100.46	0.00	0.00	0.00
3	0.00	-163.47 -165.69		-163.47 -165.69	0.00	0.00	0.00
4	0.00	-228.70 -230.92		-228.70 -230.92	0.00	0.00	0.00
5	0.00	-293.93 -296.14	0.00	-293.93 -296.14	0.00	0.00	0.00
6	0.00	-359.15 -361.37		-359.15 -361.37	0.00	0.00	0.00
7	0.00	-424.38 -426.60		-424.38 -426.60	0.00	0.00	0.00
8	0.00	-489.61 -491.83		-489.61 -491.83	0.00	0.00	0.00
9	0.00	-554.84 -557.06		-554.84 -557.06	0.00	0.00	0.00
10	0.00	-620.07 -622.29		-620.07 -622.29	0.00	0.00	0.00

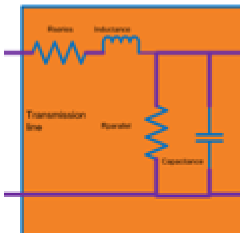
Reflection

	0	dBW	Total Power Transmitted =	1000.00	0.00		
Transmitter Zo	30	dBm					
Z =	50		Total power =		1000.00	mWatts	
		Milli-Watts					
VSWR =	0.019607843	0.00	0.00	0.00			
			0.00	1000.00	1000.00	mWatts	



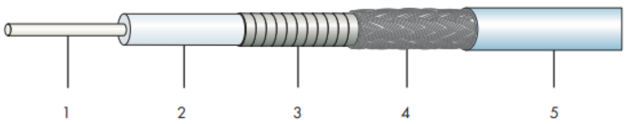


Confirming the cable constants of a Sucoflex 104E coax cable



SUCOFLEX_104

Cable design



	Description	Diameter
1. Centre conductor	Solid silver-plated copper wire	
2. Dielectric	Low density PTFE	
3. 1st outer conductor	Silver-plated copper tape, wrapped	
4. 2nd outer conductor	Silver-plated copper braid	
5. Jacket	Fluoroethylenepropylene, blue	5.50 mm

Electrical cable data

Impedance					50 Ohm
Operating frequency					26.5 GHz
Capacitance					87 pF/m
Velocity of propagation					77 %
Time delay					4.3 ns/m
Nom. attenuation*	coefficient a	**0.2291**	coefficient b	**0.0071**	
Max. attenuation*	coefficient a	**0.2520**	coefficient b	**0.0078**	
Max. operating voltage					2.6 kVrms
Min. screening effectiveness up to 18 GHz					90 dB

**Attenuation calculation* $\alpha_{25} = a \cdot \sqrt{f(\mathrm{GHz})} + b \cdot f(\mathrm{GHz})$ *(dB/m)*

Practical implications of SWR

- The most common case for measuring and examining SWR is when installing and tuning transmitting antennas. When a transmitter is connected to an antenna by a feed line, the driving point impedance of the antenna must be resistive and matching the characteristic impedance of the feed line in order for the transmitter to see the impedance it was designed for (the impedance of the feed line, usually 50 or 75 ohms).
- The impedance of a particular antenna design can vary due to a number of factors that cannot always be clearly identified. This includes the transmitter frequency (as compared to the antenna's design or resonant frequency), the antenna's height above the ground and proximity to large metal structures, and variations in the exact size of the conductors used to construct the antenna.[4]
- When an antenna and feed line do not have matching impedances, the transmitter sees an unexpected impedance, where it might not be able to produce its full power, and can even damage the transmitter in some cases.[5] The reflected power in the transmission line increases the average current and therefore losses in the transmission line compared to power actually delivered to the load.[6] It is the interaction of these reflected waves with forward waves which causes standing wave patterns,[5] with the negative repercussions we have noted.[7]
- Matching the impedance of the antenna to the impedance of the feed line can sometimes be accomplished through adjusting the antenna itself, but otherwise is possible using an antenna tuner, an impedance matching device. Installing the tuner between the feed line and the antenna allows for the feed line to see a load close to its characteristic impedance, while sending most of the transmitter's power (a small amount may be dissipated within the tuner) to be radiated by the antenna despite its otherwise unacceptable feed point impedance. Installing a tuner in between the transmitter and the feed line can also transform the impedance seen at the transmitter end of the feed line to one preferred by the transmitter. However, in the latter case, the feed line still has a high SWR present, with the resulting increased feed line losses unmitigated.
- The magnitude of those losses are dependent on the type of transmission line, and its length. They always increase with frequency. For example, a certain antenna used well away from its resonant frequency may have an SWR of 6:1. For a frequency of 3.5 MHz, with that antenna fed through 75 meters of RG-8A coax, the loss due to standing waves would be 2.2 dB. However the same 6:1 mismatch through 75 meters of RG-8A coax would incur 10.8 dB of loss at 146 MHz.[5] Thus, a better match of the antenna to the feed line, that is, a lower SWR, becomes increasingly important with increasing frequency, even if the transmitter is able to accommodate the impedance seen (or an antenna tuner is used between the transmitter and feed line).
- Certain types of transmissions can suffer other negative effects from reflected waves on a transmission line. Analogue TV can experience "ghosts" from delayed signals bouncing back and forth on a long line. FM stereo can also be affected and digital signals can experience delayed pulses leading to bit errors. Whenever the delay times for a signal going back down and then again up the line are comparable to the modulation time constants, effects occur. For this reason, these types of transmissions require a low SWR on the feed line, even if SWR induced loss might be acceptable and matching is done at the transmitter.

Review

- *Standing waves* are waves of voltage and current which do not propagate (i.e. they are stationary), but are the result of interference between incident and reflected waves along a transmission line.
- A ***node*** is a point on a standing wave of *minimum* amplitude.
- An ***antinode*** is a point on a standing wave of *maximum* amplitude.
- Standing waves can only exist in a transmission line when the terminating impedance does not match the line's characteristic impedance. In a perfectly terminated line, there are no reflected waves, and therefore no standing waves at all.
- At certain frequencies, the nodes and antinodes of standing waves will correlate with the ends of a transmission line, resulting in ***resonance***.
- The lowest-frequency resonant point on a transmission line is where the line is one quarter-wavelength long. Resonant points exist at every harmonic (integer-multiple) frequency of the fundamental (quarter-wavelength).

Any questions

No!!!

then Time for Tea

The End