Taking the Mystery out of SWR

Bill Rinker, W6OAV

Taking the Mystery out of SWR

In the above derivation the $e^{j\omega t}$ factors have been cancelled, the numerator and denominator have been divided by V_m and the substitution $r = V'_m/V_m$ has been made. Note that r in the above expression is the reflection coefficient at $x = 0$ not the reflection coefficient at $x = -\ell$.

To gain insight into the expression note firstly that it depends upon ℓ. Therefore the input impedance is different at different places on the transmission line. Note also that Z_i is complex which means that there is a phase difference between the voltage at $x = -\ell$ and the current at $x = -\ell$.

The aim of the analysis is to derive the polar form for Z_i: as $Z_i = |Z_i| e^{j\angle Z_i}$. Then $|Z_i| = |V/I|$ and $\angle Z_i$ is the phase of V relative to I at $x = -\ell$. The analysis is set as problem Q3 on Sheet 2. It is examinable.

$$\underset{\text{at } x=-\ell}{Z_i} = Z_o \frac{e^{jk\ell} + re^{-jk\ell}}{e^{jk\ell} - re^{-jk\ell}}$$

Use Euler's identity $e^{jk\ell} = \cos k\ell + j \sin k\ell$ and $r = \frac{Z_L - Z_o}{Z_L + Z_o}$ to derive the intermediate result:

$$Z_i = Z_o \frac{Z_L \cos k\ell + jZ_o \sin k\ell}{Z_o \cos k\ell + jZ_L \sin k\ell}$$

The intermediate result is not yet in polar form. Convert the numerator to polar form also convert the denominator and hence show:

$$Z_i = Z_o \frac{\sqrt{Z_L^2 \cos^2 k\ell + Z_o^2 \sin^2 k\ell}}{\sqrt{Z_o^2 \cos^2 k\ell + Z_L^2 \sin^2 k\ell}} \exp\left(j \arctan\left(\frac{Z_o \sin k\ell}{Z_L \cos k\ell}\right) - j \arctan\left(\frac{Z_L \sin k\ell}{Z_o \cos k\ell}\right)\right)$$

Worked Examples: Two examples taken from Problem sheet 2 are given below. All the material in Problem sheet 2 is examinable. Q1, Q3, Q4 and Q9 involve calculations of input impedances at various places on a transmission line.

Example 1 (Q1a): When $Z_L = Z_o$ the result for Z_i using the intermediate result is:

$$Z_i = Z_o \frac{Z_o \cos k\ell + jZ_o \sin k\ell}{Z_o \cos k\ell + jZ_o \sin k\ell} = Z_o$$

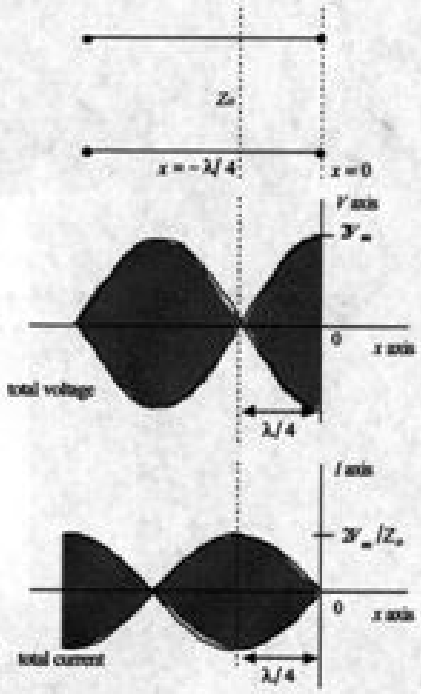
Therefore the input impedance of a line of characteristic impedance Z_o terminated in a matched impedance does not depend on ℓ and is everywhere equal to Z_o. It is a special case.

Example 2 (Q1c): A quarter wave open circuit line with $Z_L = \infty$ (open circuit) and $\ell = \lambda/4$. In this case $k\ell = \pi/2$ and from the polar expression:

$$Z_i = Z_o \frac{\sqrt{0 + Z_o^2}}{\sqrt{0 + \infty^2}} \exp\left(j \arctan\left(\frac{Z_o}{\infty \times 0}\right) - j \arctan\left(\frac{\infty}{Z_o \times 0}\right)\right) = 0$$

Even though the argument is not defined it is clear that the input impedance is 0 for the quarter wave open circuit line because the modulus is zero. That is, the input of a quarter wave line terminated with an open circuit acts like a short circuit.

The envelopes of the standing voltage and current waves on the line show why (see section 4.1). At the open circuit the voltage has an antinode and the current is zero. A quarter of a wavelength back from the open circuit termination the current has an antinode and the voltage is zero. Therefore the ratio V/I (the input impedance) at that point is zero.



4.3 Voltage standing wave ratio

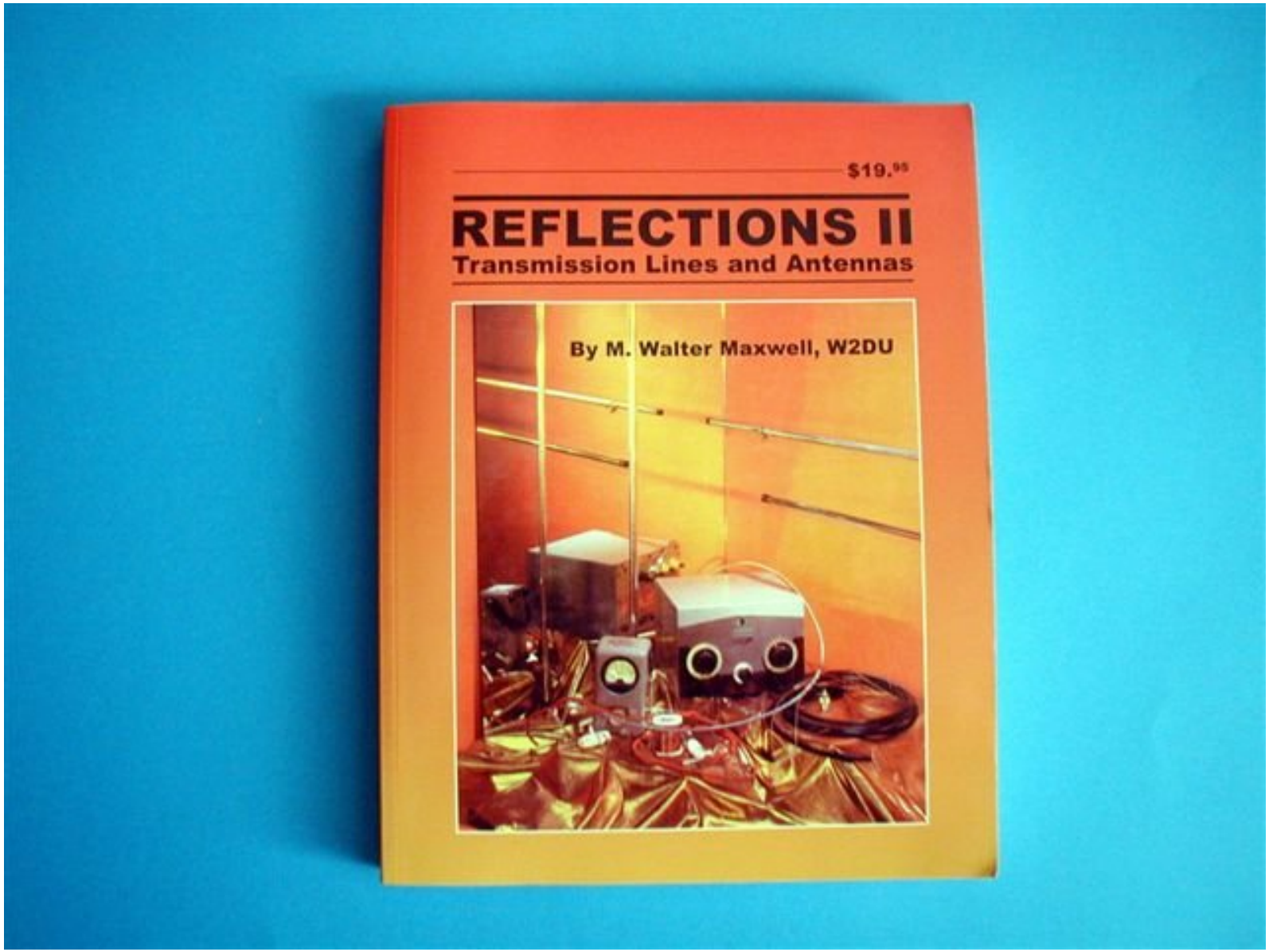
Use of VSWR as a specification: VSWR (Voltage standing wave ratio) is given by the following expression. The right hand equality is derived by dividing though by V_m and setting $r = V'_m/V_m$:

$$s = \frac{V_m + V'_m}{V_m - V'_m} = \frac{1 + r}{1 - r}$$

Manufacturers often quote VSWR rather than r. For instance, Q2 in Problem sheet 2 shows that VSWR of 1.1 is equivalent to a reflection coefficient of 0.048. For a lossless transmission line VSWR is a property of the whole line.

Standing and travelling waves: As shown in section 2.1, a voltage wave $V_m \sin(\omega t - kx)$ is a wave travelling in the $+x$ direction. Likewise $V'_m \sin(\omega t + kx)$ is a voltage wave travelling in the $-x$ direction.

Taking the Mystery out of SWR



Taking the Mystery out of SWR

SWR MYTHS

Must have a perfect match between line and antenna

The lower the SWR, the better

Must prune the antenna to exact resonance

Must make the antenna resonant in the band of interest

Subtract the % reflected from 100 to determine % radiated

Taking the Mystery out of SWR

SWR FACTS

A low SWR is not always desirable

A high SWR is sometimes desirable

It's a waste of time trying to reduce SWR below 2:1

Changing the length of feedline does not change SWR

All power fed into a feedline (minus line loss) is radiated by the antenna, no matter how high the SWR

SWR does not cause a feedline to radiate

Taking the Mystery out of SWR

WHO DOESN'T WORRY ABOUT HIGH SWR?

NASA

SPACE AGENCY

Taking the Mystery out of SWR

TIROS WEATHER SATELLITE

Beacon: 108 mHz @ 30 mw
Antenna: 150 - j100
SWR: 4:1
Reflected power: 40%
Line and match loss: 0.2 dB
SWR loss: 0.24 dB
Total loss: 0.44 dB
Efficiency: 90.4%

Taking the Mystery out of SWR

NAVSAT SATELLITE

Beacon: 150 mHz
Antenna: 10.5 - j48
SWR: 9.3:1
Reflected power: 65%
Line and match loss: 0.2d dB
SWR loss: 0.79 dB
Total loss: 1.04 dB

Taking the Mystery out of SWR

WHY NOT TUNE FOR MINIMUM SWR?

Electrical, mechanical and thermal issues prevented matching at the antenna.

Antenna served several transmitters operating at different frequencies.

If properly designed, the value of SWR does NOT matter!

Taking the Mystery out of SWR

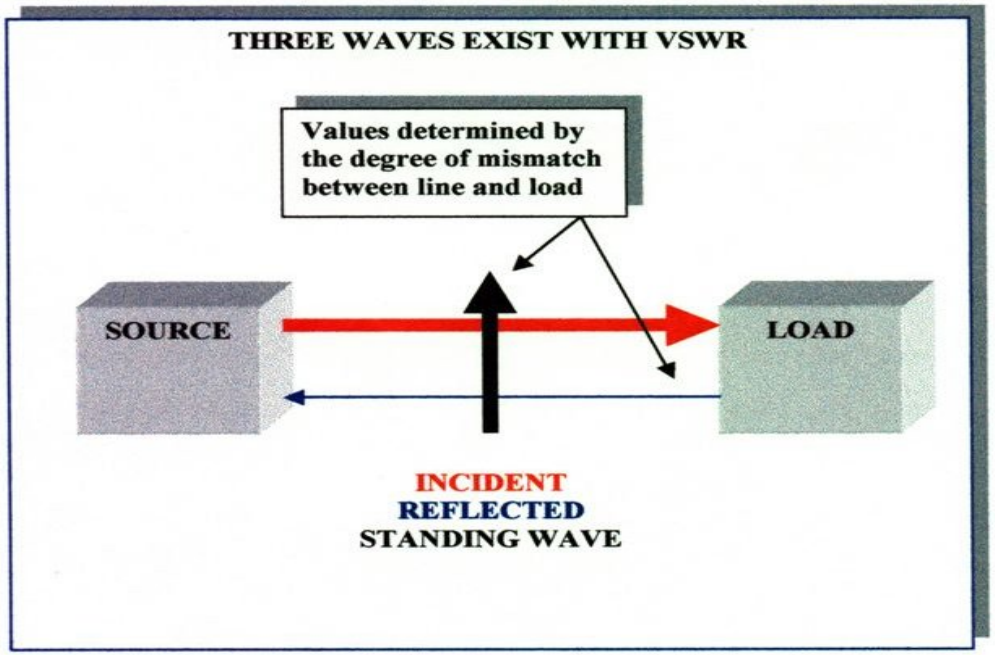
WHAT IS SWR?

The degree of the impedance mismatch between the feedline and the load

The higher the SWR the greater the mismatch

$$\text{VSWR} = \frac{\text{Efwd} + \text{Eref}}{\text{Efwd} - \text{Eref}} = \frac{1.5 + 0.5}{1.5 - 0.5} = 2{:}1$$

Taking the Mystery out of SWR



Taking the Mystery out of SWR

Lets watch SWR in action!

Taking the Mystery out of SWR

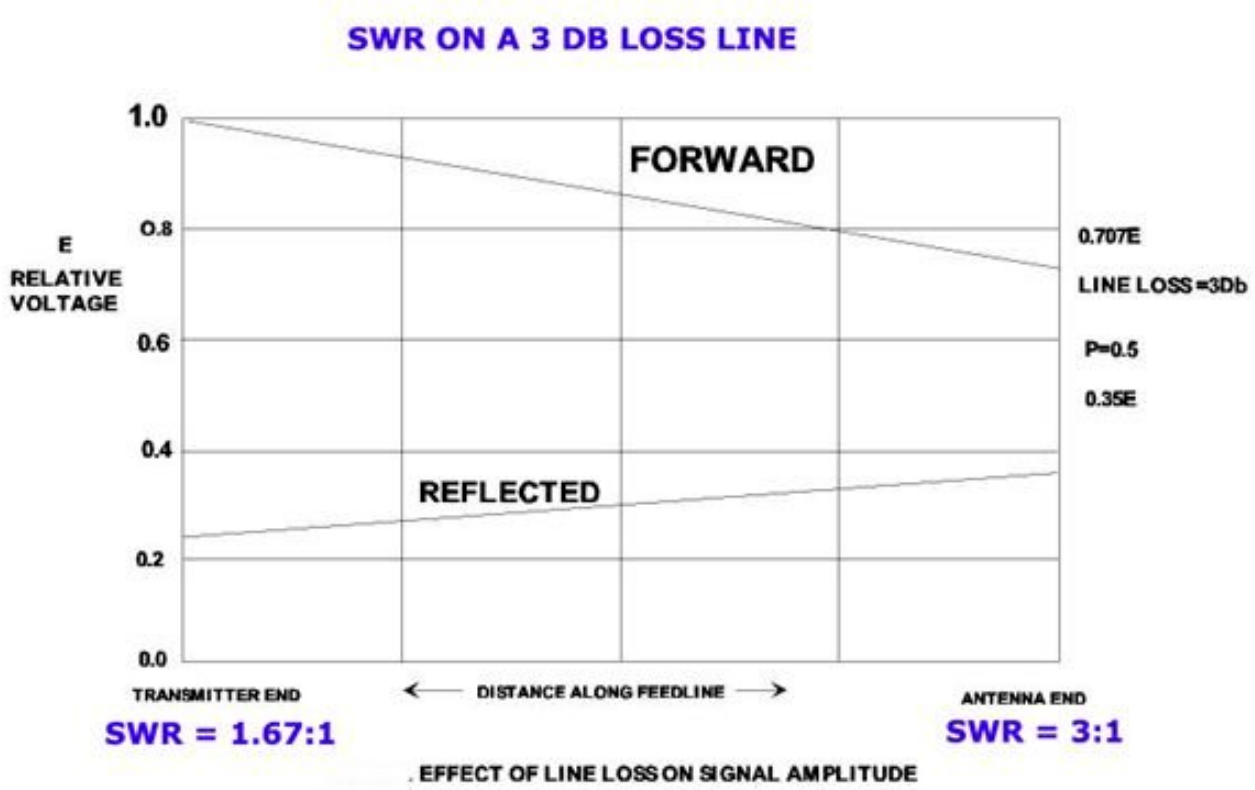
SWR FACT

SWR remains the same along a lossless feedline

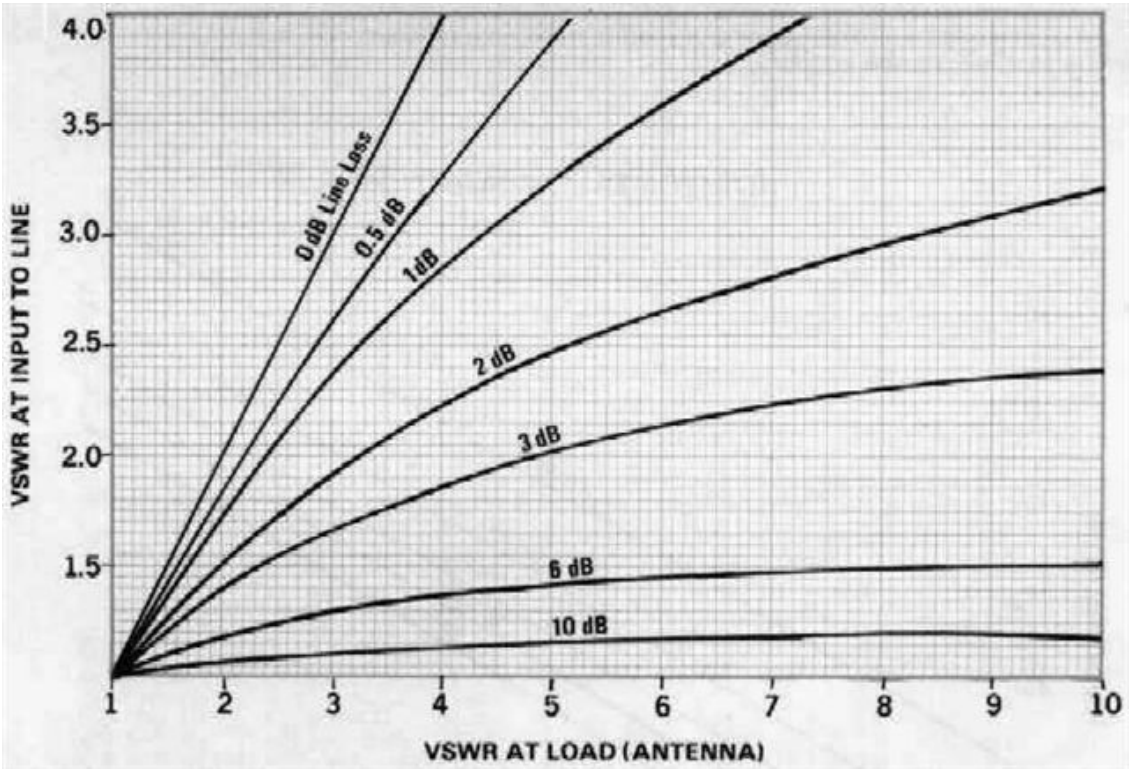
SWR decreases along a lossy feedline

WHY IS THIS IMPORTANT?

Taking the Mystery out of SWR



Taking the Mystery out of SWR



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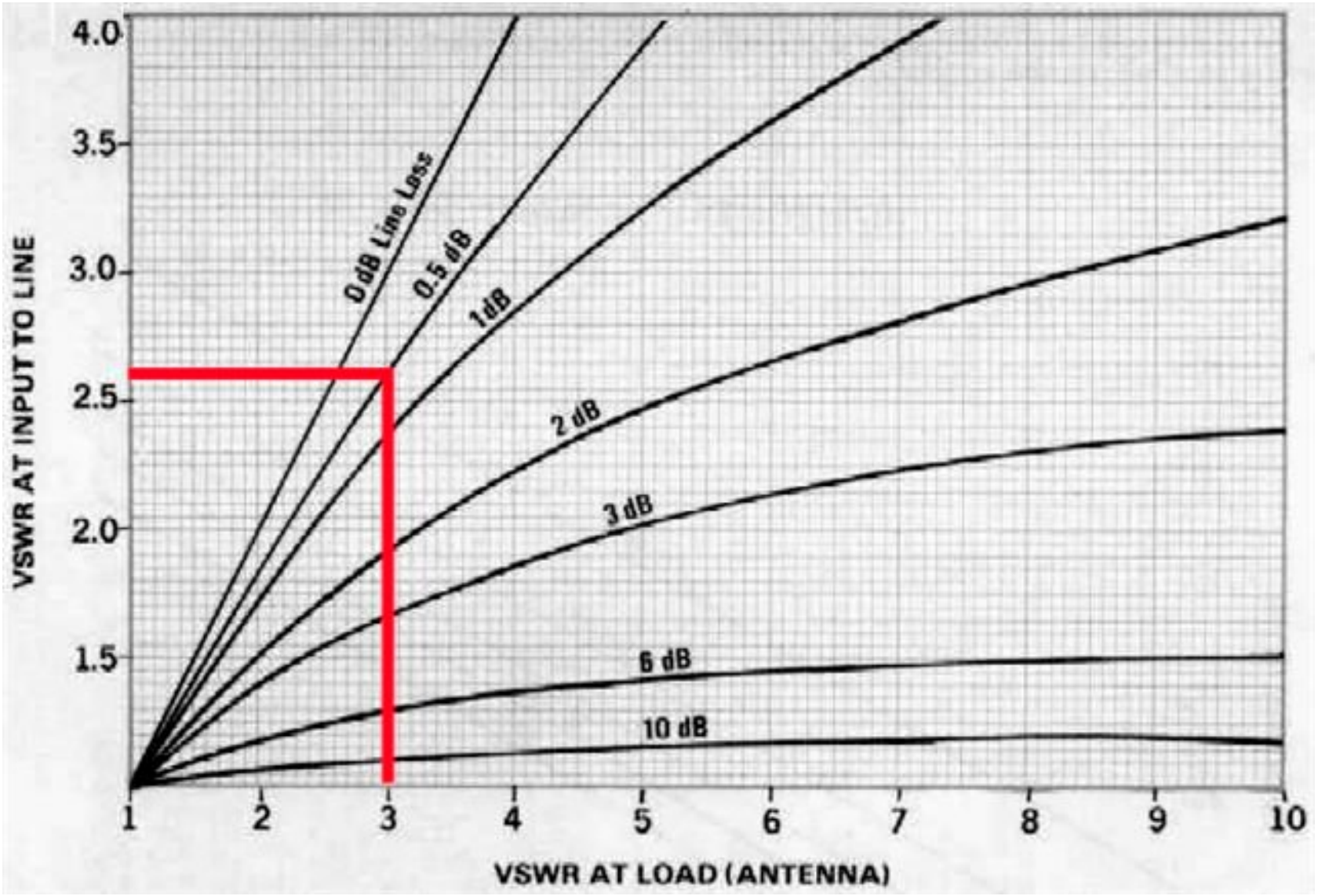

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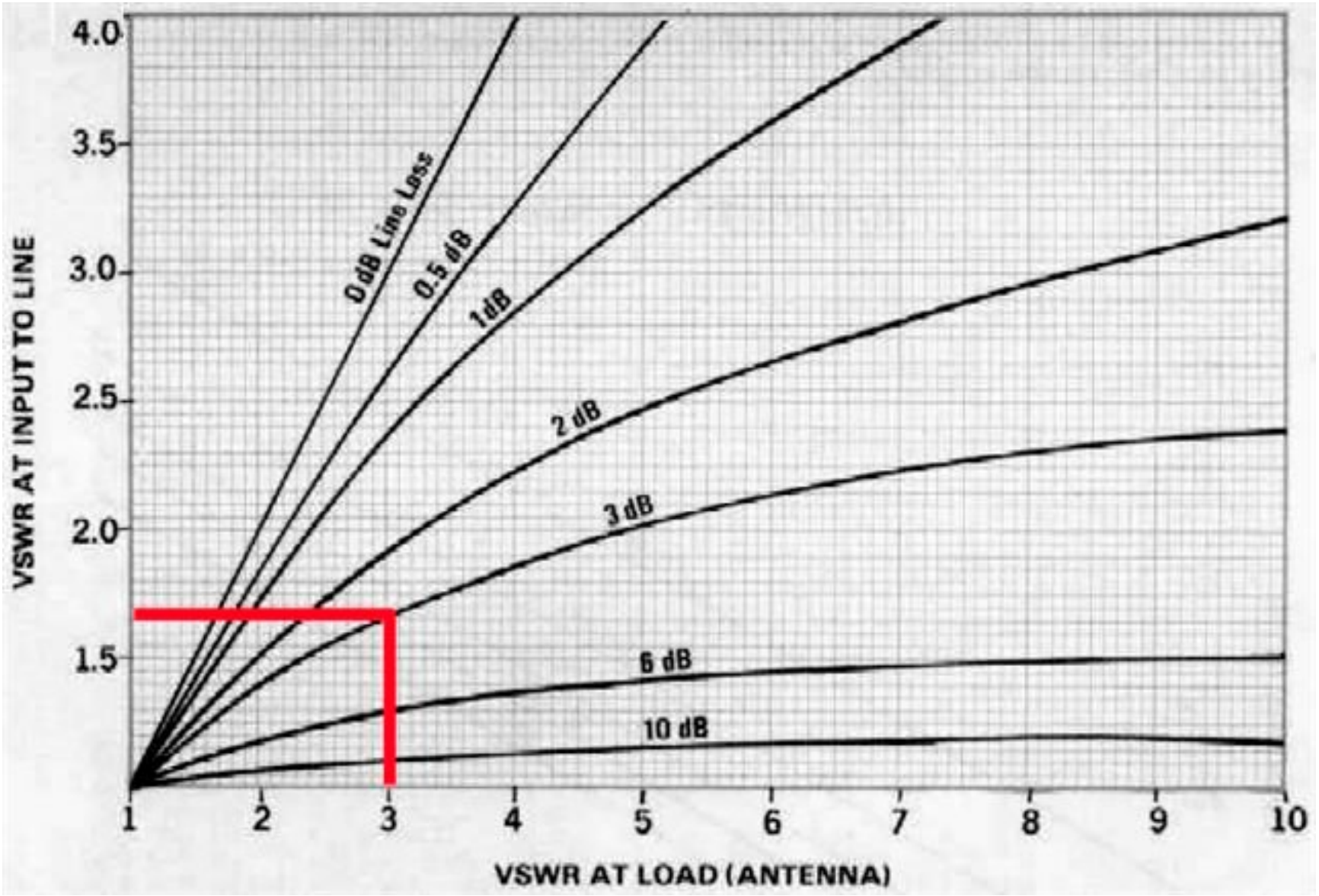


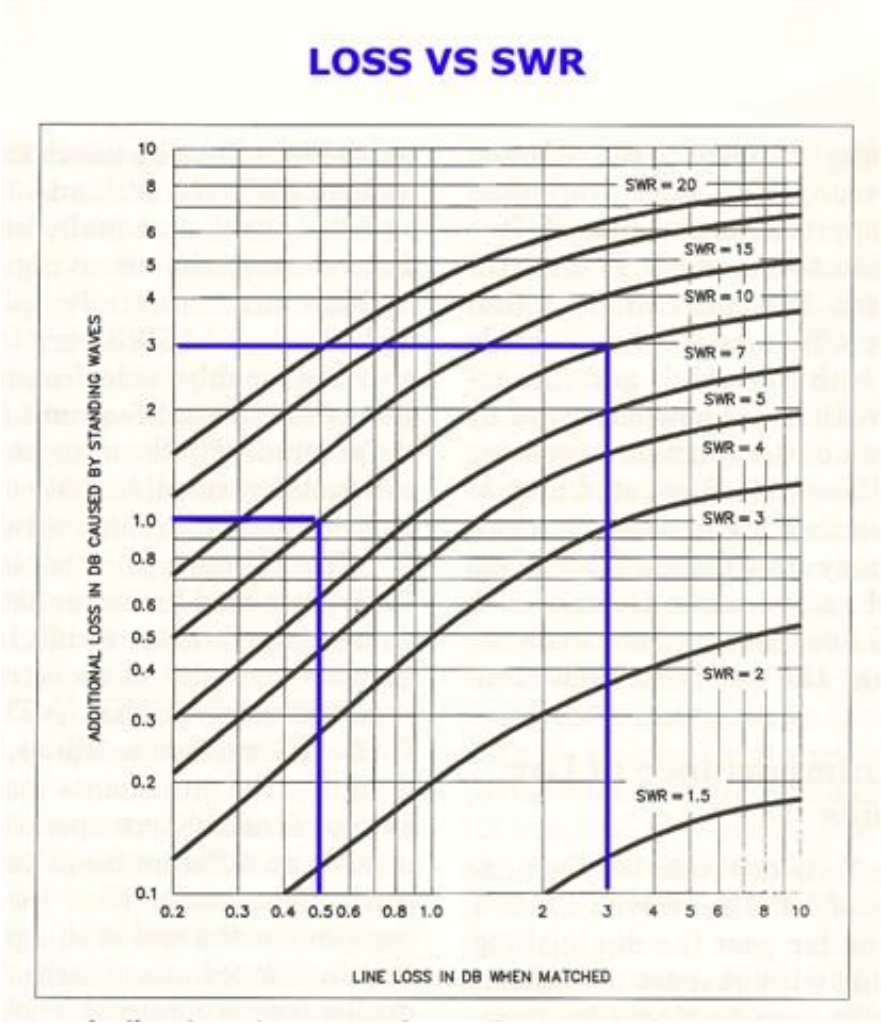
Taking the Mystery out of SWR

SWR FACT

Coax loss increases with increases in SWR

However, this is not an issue with low loss coax

Taking the Mystery out of SWR



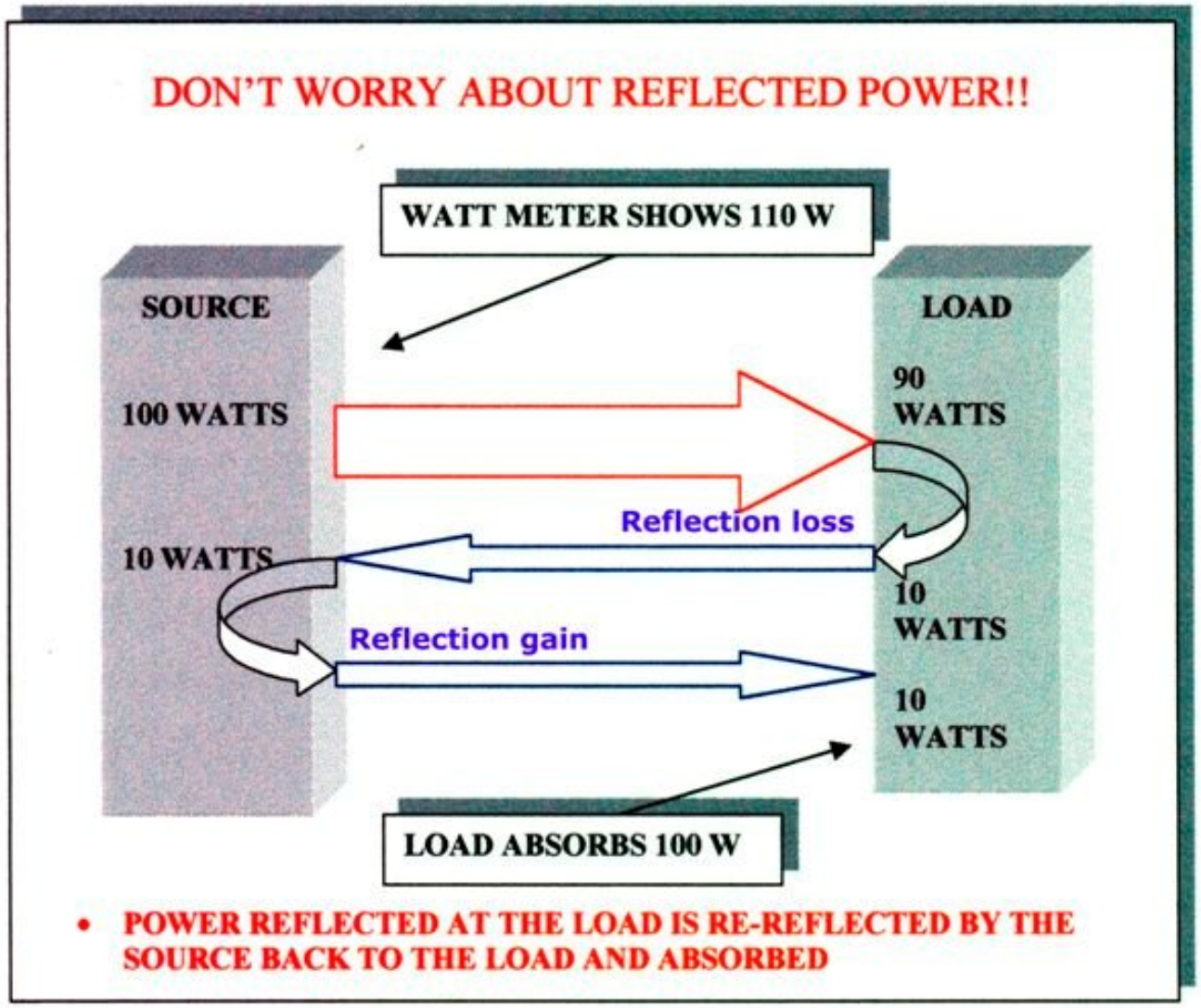
Taking the Mystery out of SWR

SWR FACT

Reflected power is not lost power

Reflected power does not flow back into the transmitter

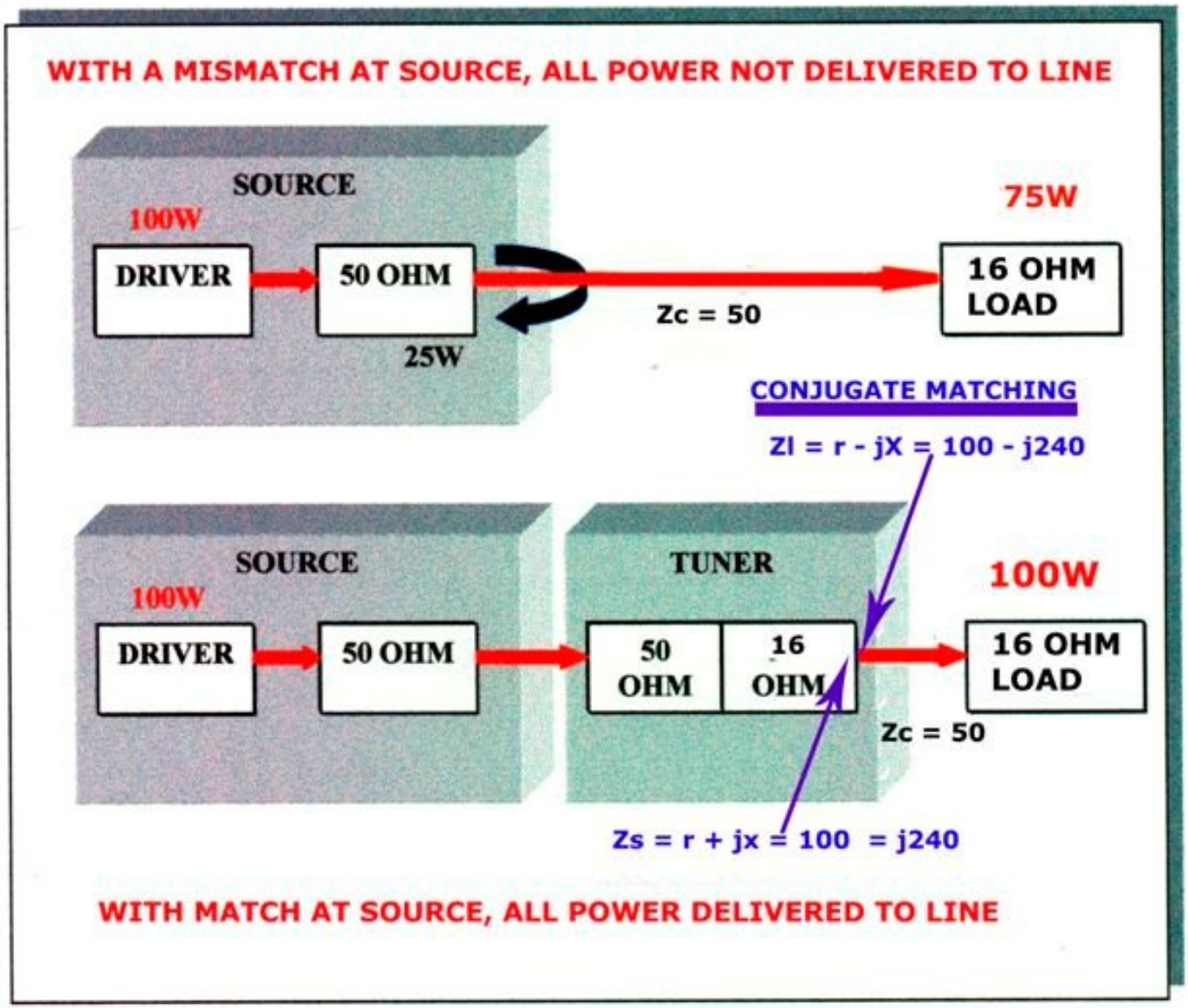
Taking the Mystery out of SWR



Taking the Mystery out of SWR

So, with a mismatched feedline system, how do I get all the power out of the transmitter and into the feedline?

Taking the Mystery out of SWR



Taking the Mystery out of SWR

REFLECTION COEFFICIENT

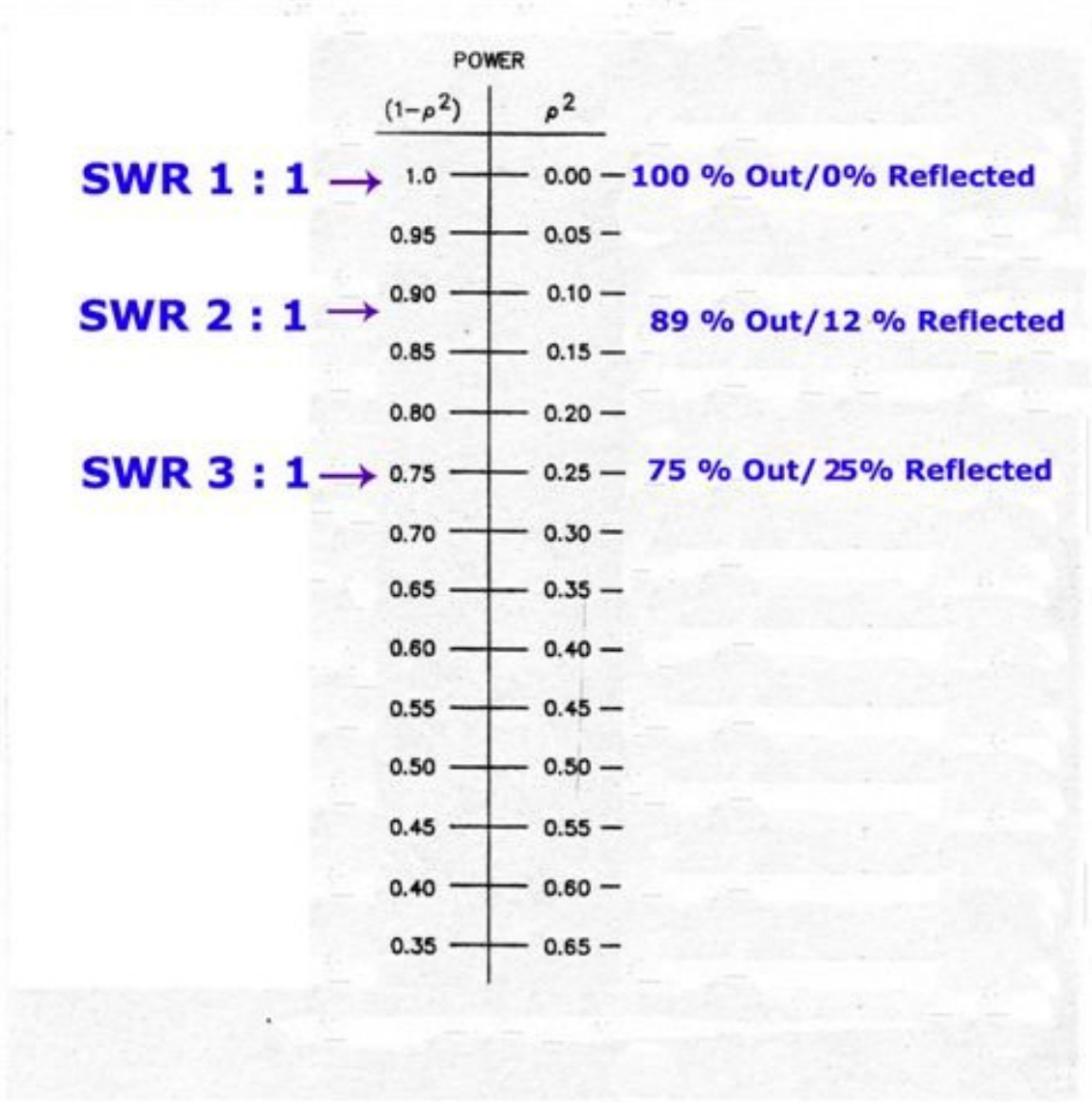
A reflection coefficient describes either the amplitude or the intensity of a reflected wave relative to an incident wave

$$p = \frac{Zl - Zs}{Zl + Zs} \qquad p = \frac{SWR - 1}{SWR + 1}$$

$(1 - p)^2$ = % Power available into a mismatch

p^2 = % Power reflected due to a mismatch

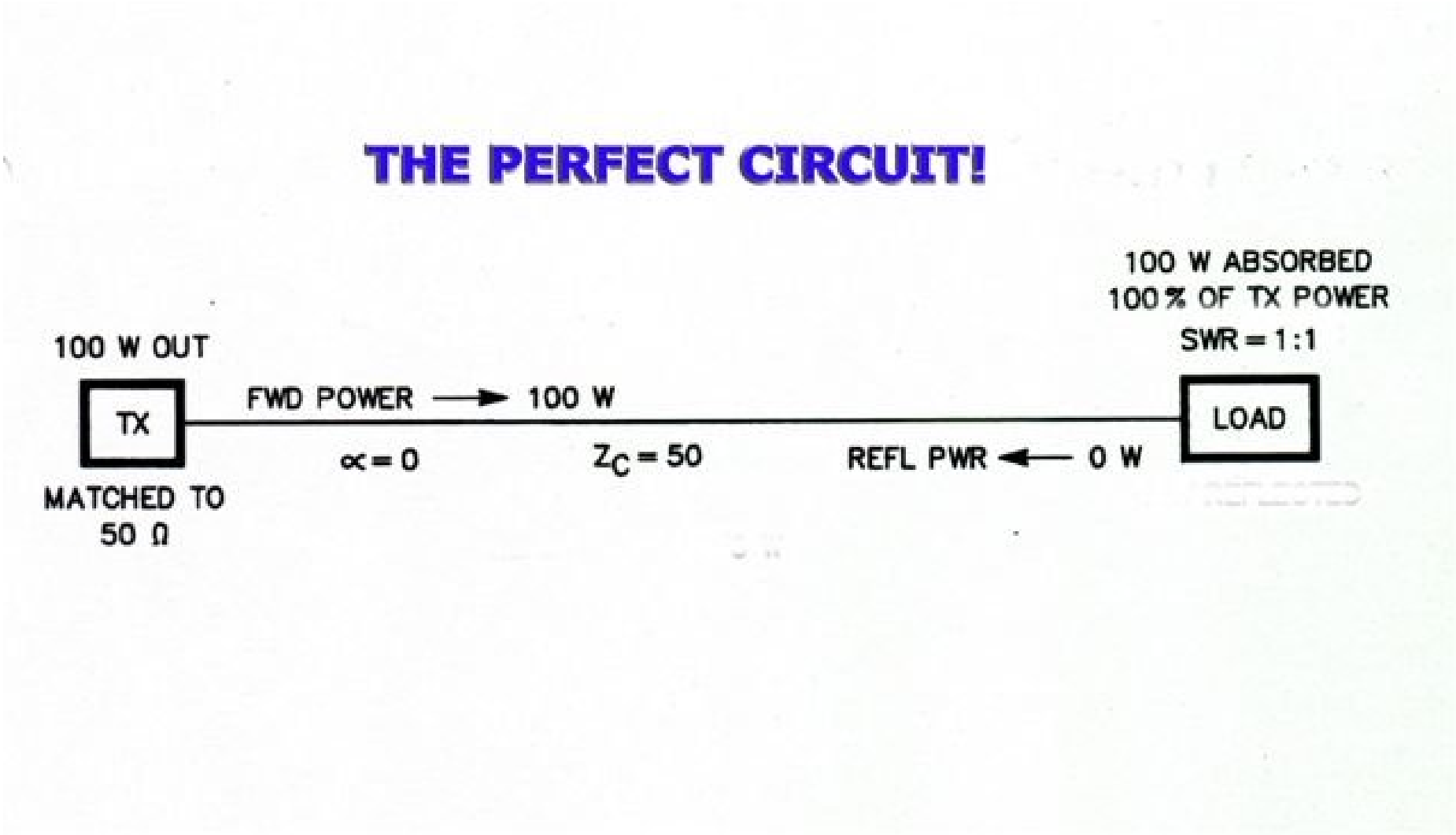
Taking the Mystery out of SWR



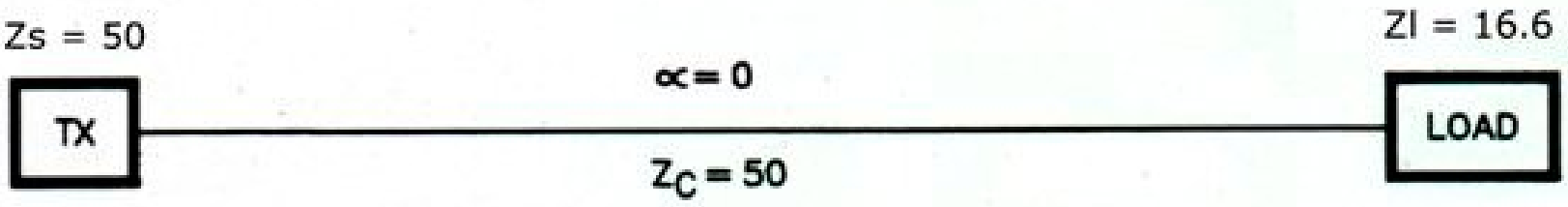
Taking the Mystery out of SWR

Lets discuss matched and unmatched configurations using lossless feedlines

Taking the Mystery out of SWR

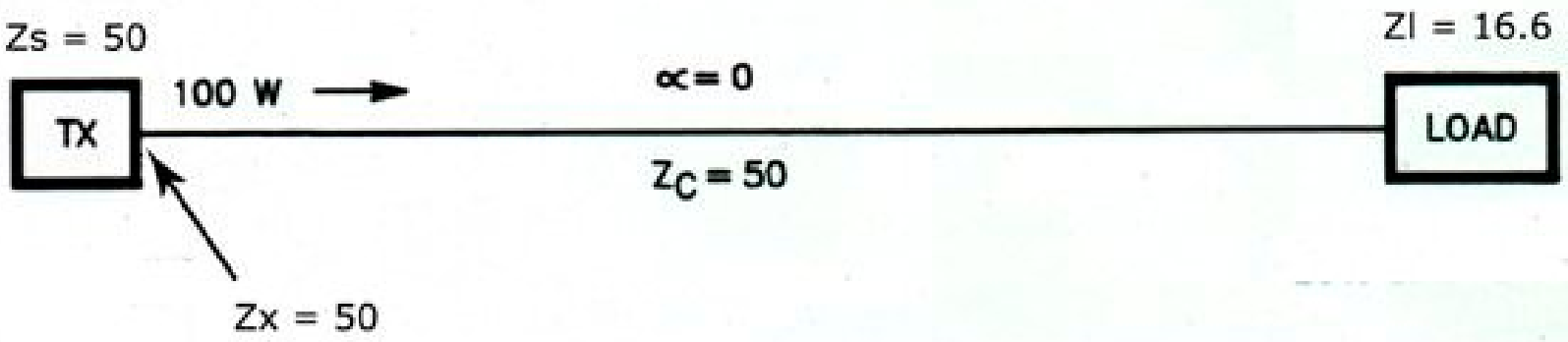


Taking the Mystery out of SWR



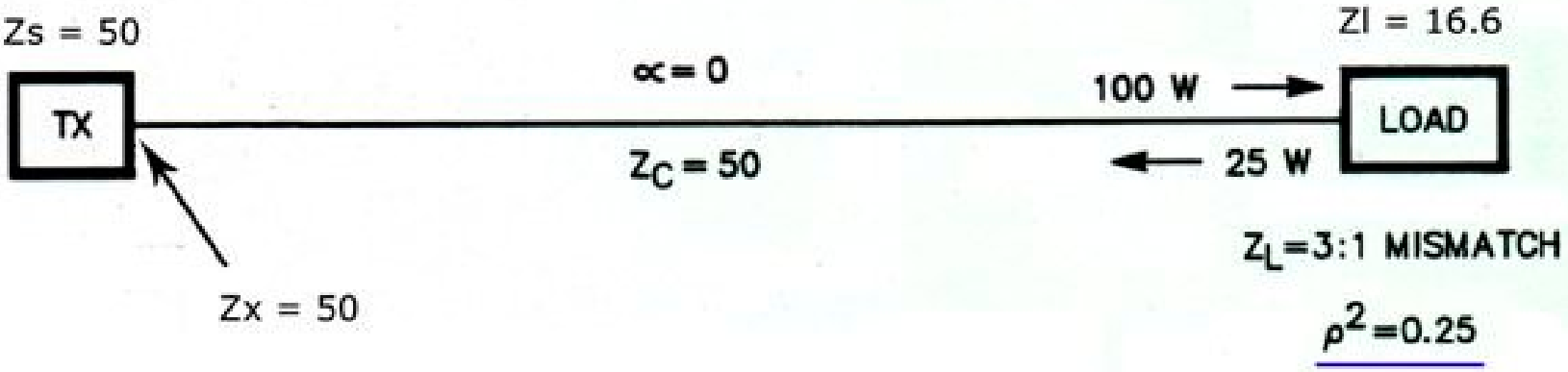
A circuit with an SWR of 3:1 and no matching between the 50 ohm transmitter and the line

Taking the Mystery out of SWR



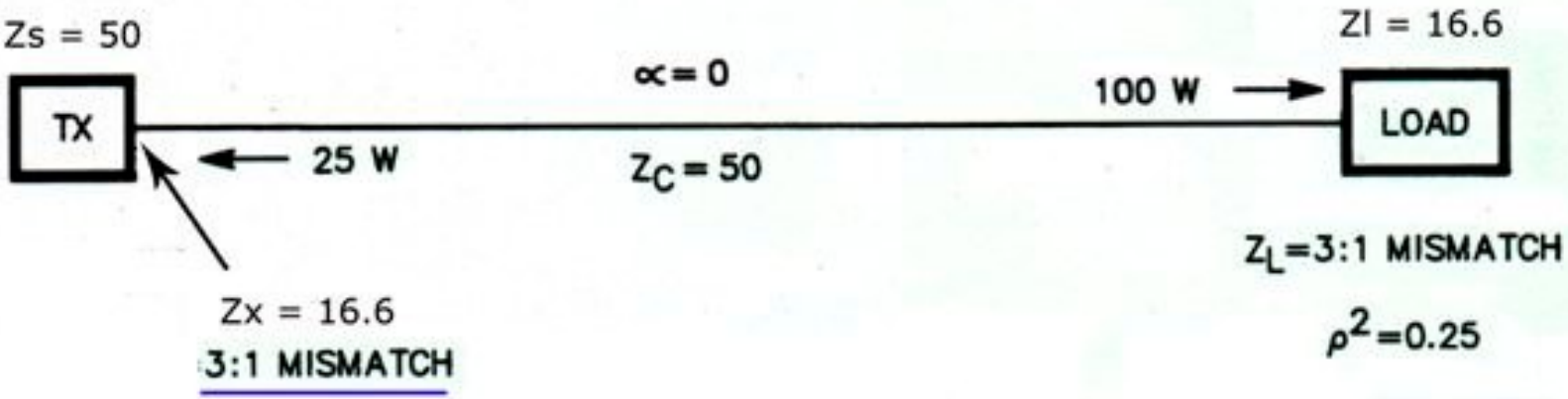
When transmitter first activitated:
Sees a 50 ohm line
Puts out full power

Taking the Mystery out of SWR



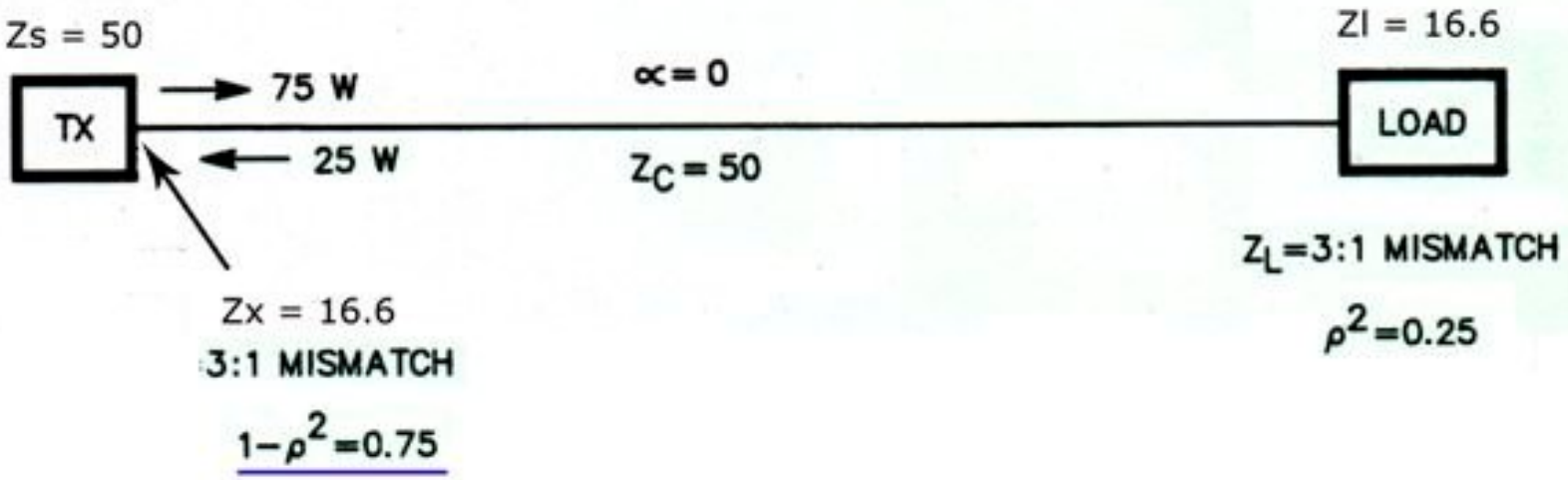
Due to the mismatch, the load:
Absorbs 75 watts (75%)
Reflects 25 watts (25%)

Taking the Mystery out of SWR



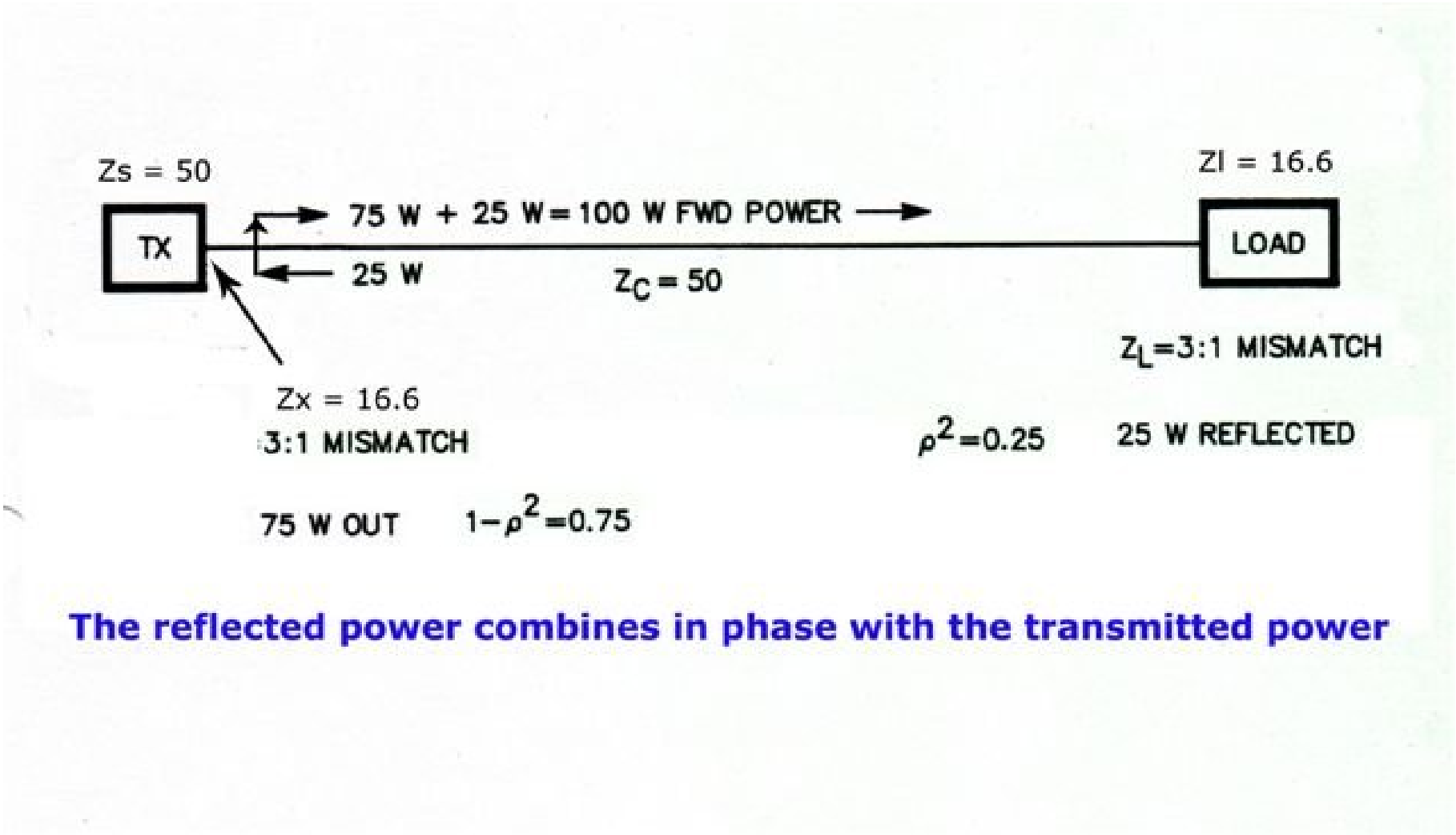
Reflected power arrives at transmitter causing a 3:1 mismatch

Taking the Mystery out of SWR



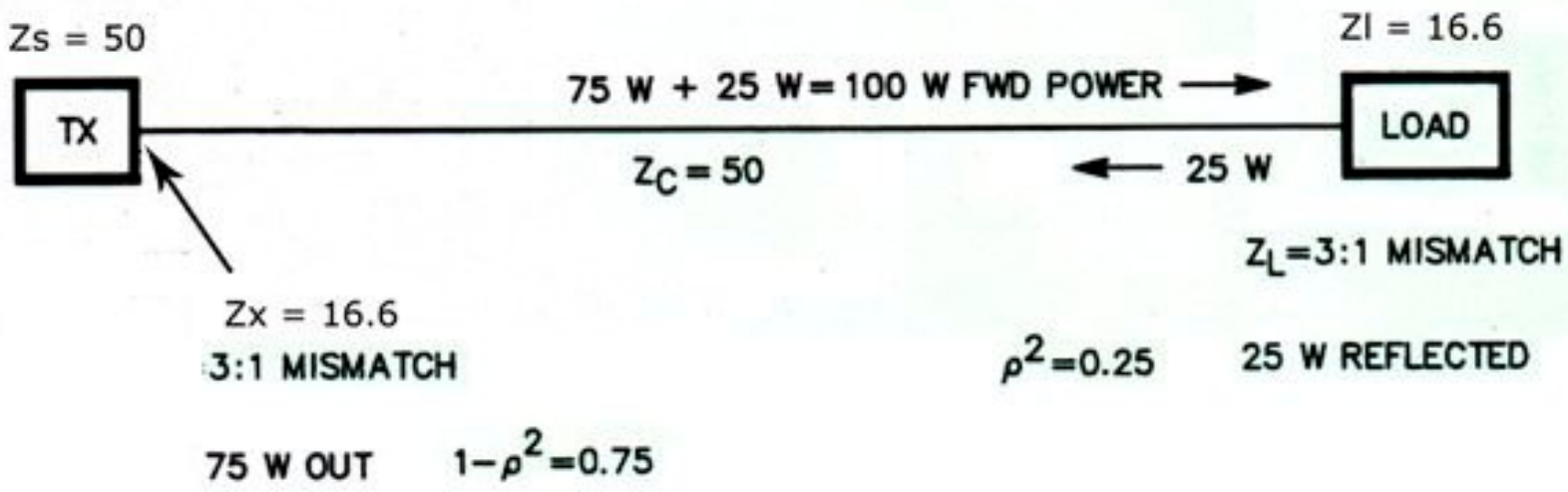
Due to the mismatch, transmitter output reduced

Taking the Mystery out of SWR



The reflected power combines in phase with the transmitted power

Taking the Mystery out of SWR

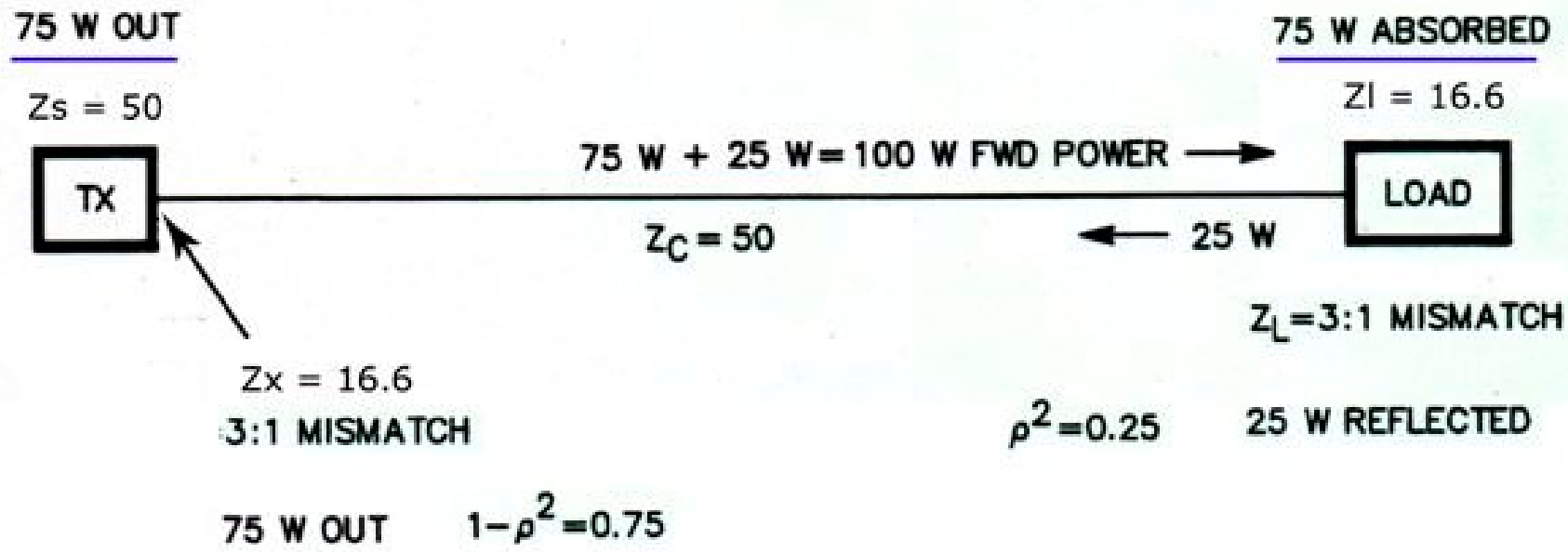


As before, the load:

Absorbs 75% of the Forward Power

Reflects 25% of the Forward Power

Taking the Mystery out of SWR



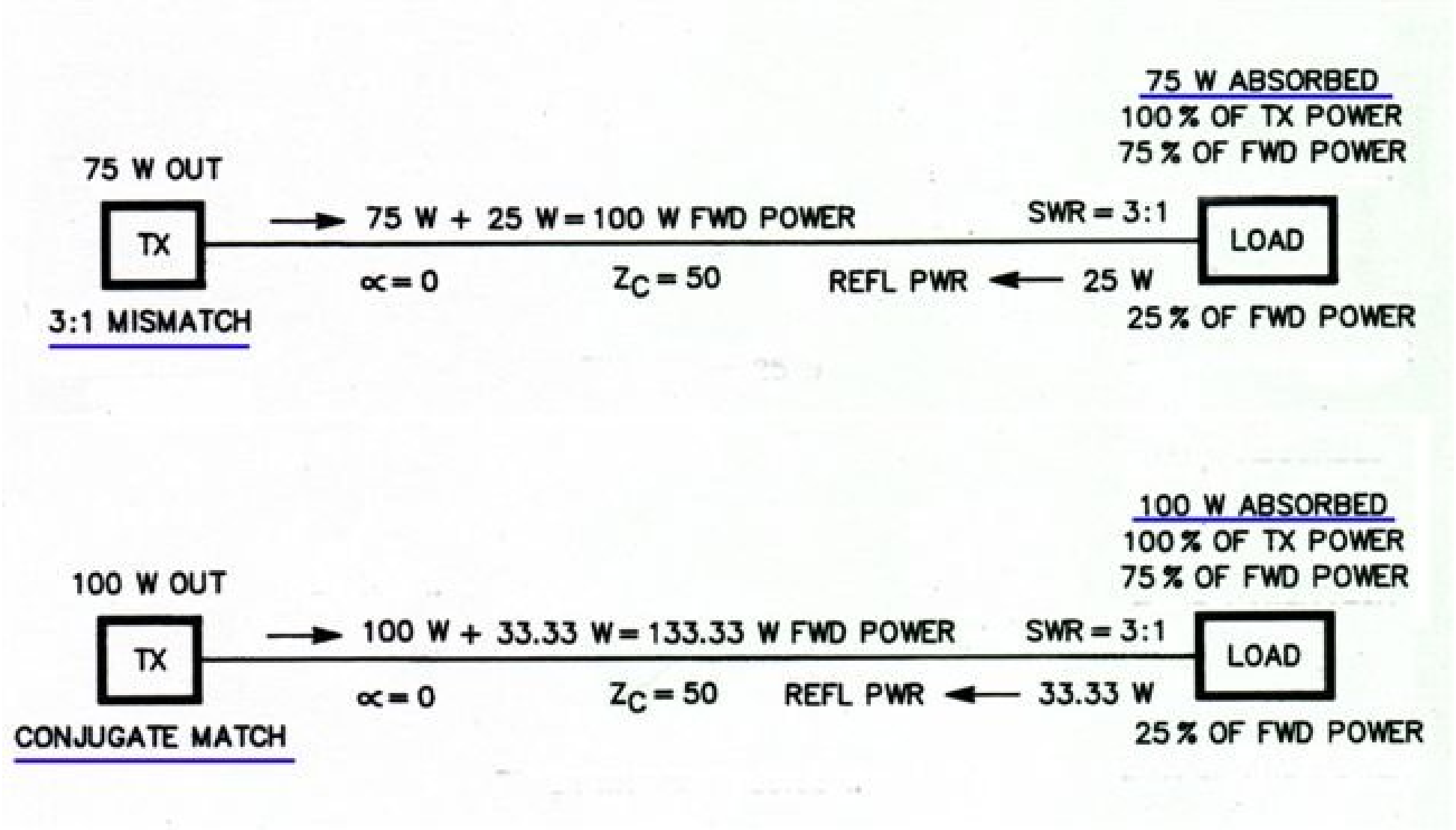
Inspite of a 3:1 SWR, all power into the line was absorbed by the load

The 1.2 dB loss occured in the transmitter.. 100w input, 75W output

Taking the Mystery out of SWR

Now, lets put a tuner in the system to transform the transmitter impedance to the line impedance...conjuate match

Taking the Mystery out of SWR



Taking the Mystery out of SWR

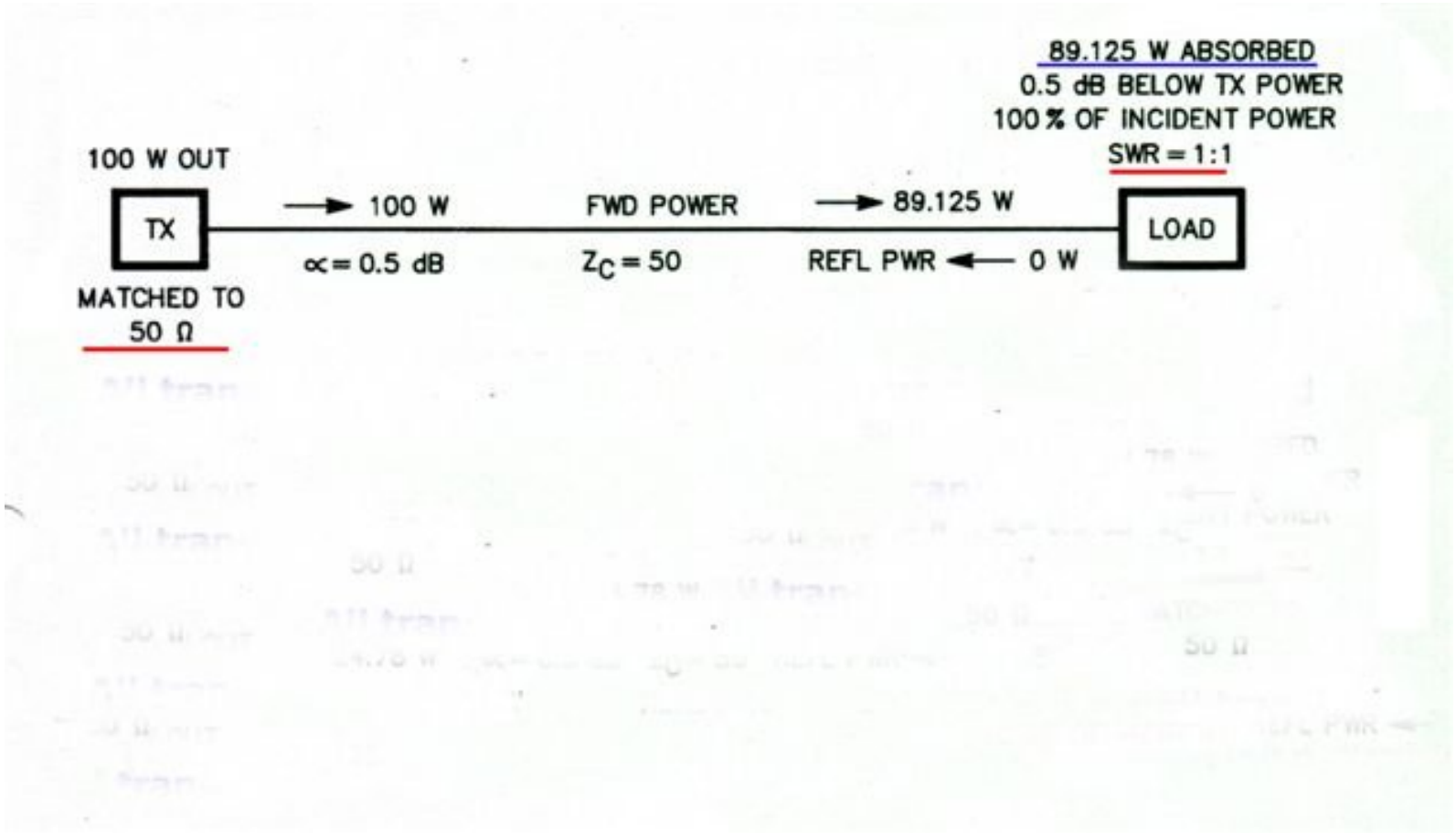
Lets discuss low and high SWR configurations using lossy feedlines

Taking the Mystery out of SWR

SWR FACT

Using good low loss line, working to get the SWR down to less than 3:1 is a waste of time!

Taking the Mystery out of SWR



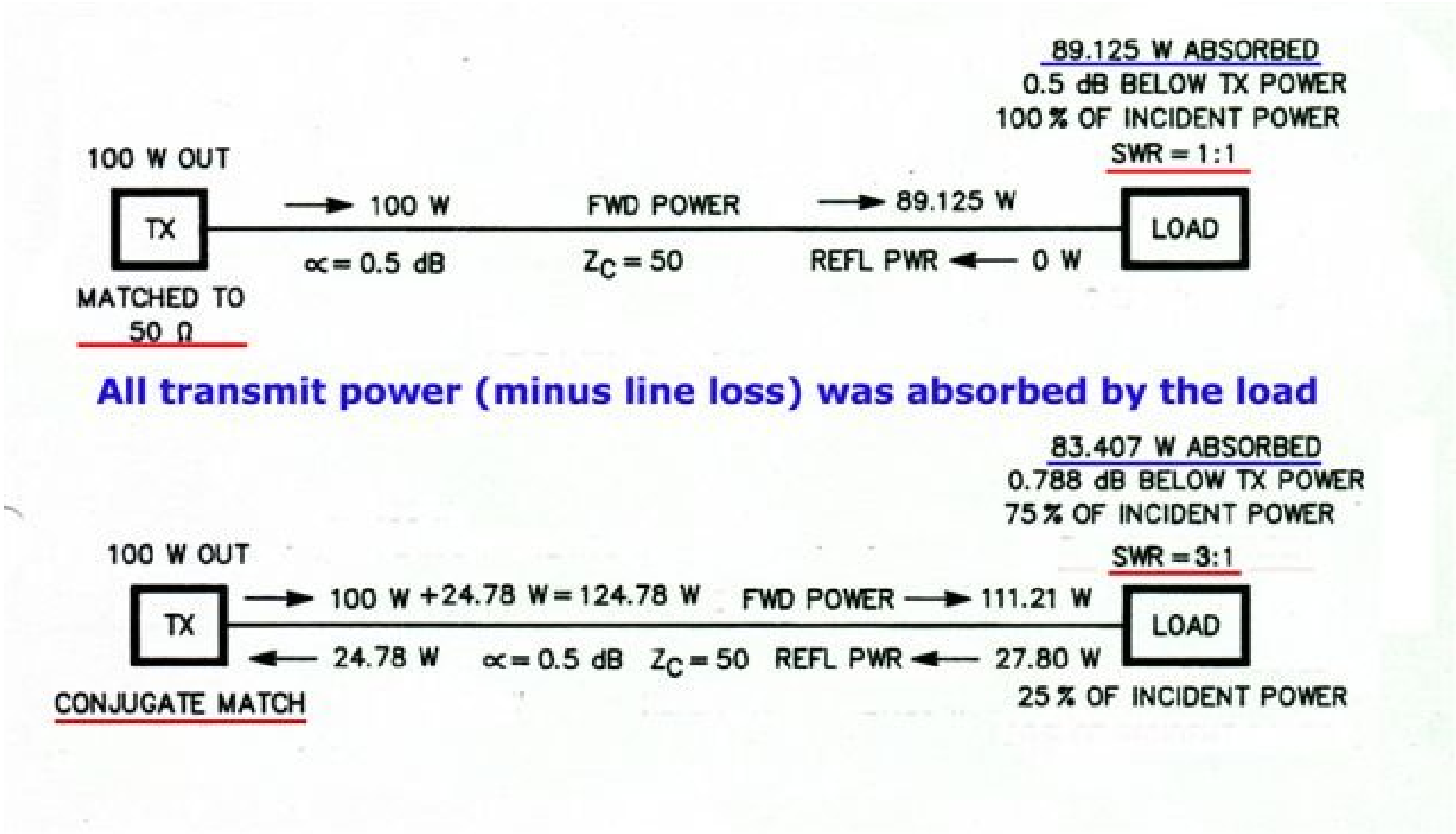
Taking the Mystery out of SWR

Coax Cable Signal Loss (Attenuation) in dB per 100ft*

Loss*	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	RF-9914	RF-9913
1MHz	1.9dB	0.4dB	0.5dB	0.2dB	0.2dB	0.2dB	0.3dB	0.2dB
10MHz	3.3dB	1.4dB	1.0dB	0.6dB	0.6dB	0.4dB	0.5dB	0.4dB
50MHz	6.6dB	3.3dB	2.5dB	1.6dB	1.4dB	1.0dB	1.1dB	0.9dB
100MHz	8.9dB	4.9dB	3.6dB	2.2dB	2.0dB	1.6dB	1.5dB	1.4dB
200MHz	11.9dB	7.3dB	5.4dB	3.3dB	2.8dB	2.3dB	2.0dB	1.8dB
400MHz	17.3 B	11.2dB	7.9dB	4.8dB	4.3dB	3.5dB	2.9dB	2.6dB
700MHz	26.0dB	16.9dB	11.0dB	6.6dB	5.6dB	4.7dB	3.8dB	3.6dB
900MHz	27.9 B	20.1dB	12.6dB	7.7dB	6.0dB	5.4dB	4.9dB	4.2dB
1GHz	32.0dB	21.5dB	13.5dB	8.3dB	6.1dB	5.6dB	5.3dB	4.5dB
Imped	50ohm	50ohm	50ohm	50ohm	75ohm	75ohm	50ohm	50ohm

* **Note:** Coax losses shown above are for 100 feet lengths. Loss is a length multiplier, so a 200 ft length would have twice the loss shown above and a 50 ft length would have half the loss. This multiplier factor is why you should keep cable installation lengths between radios and antennas as short as practical!

Taking the Mystery out of SWR



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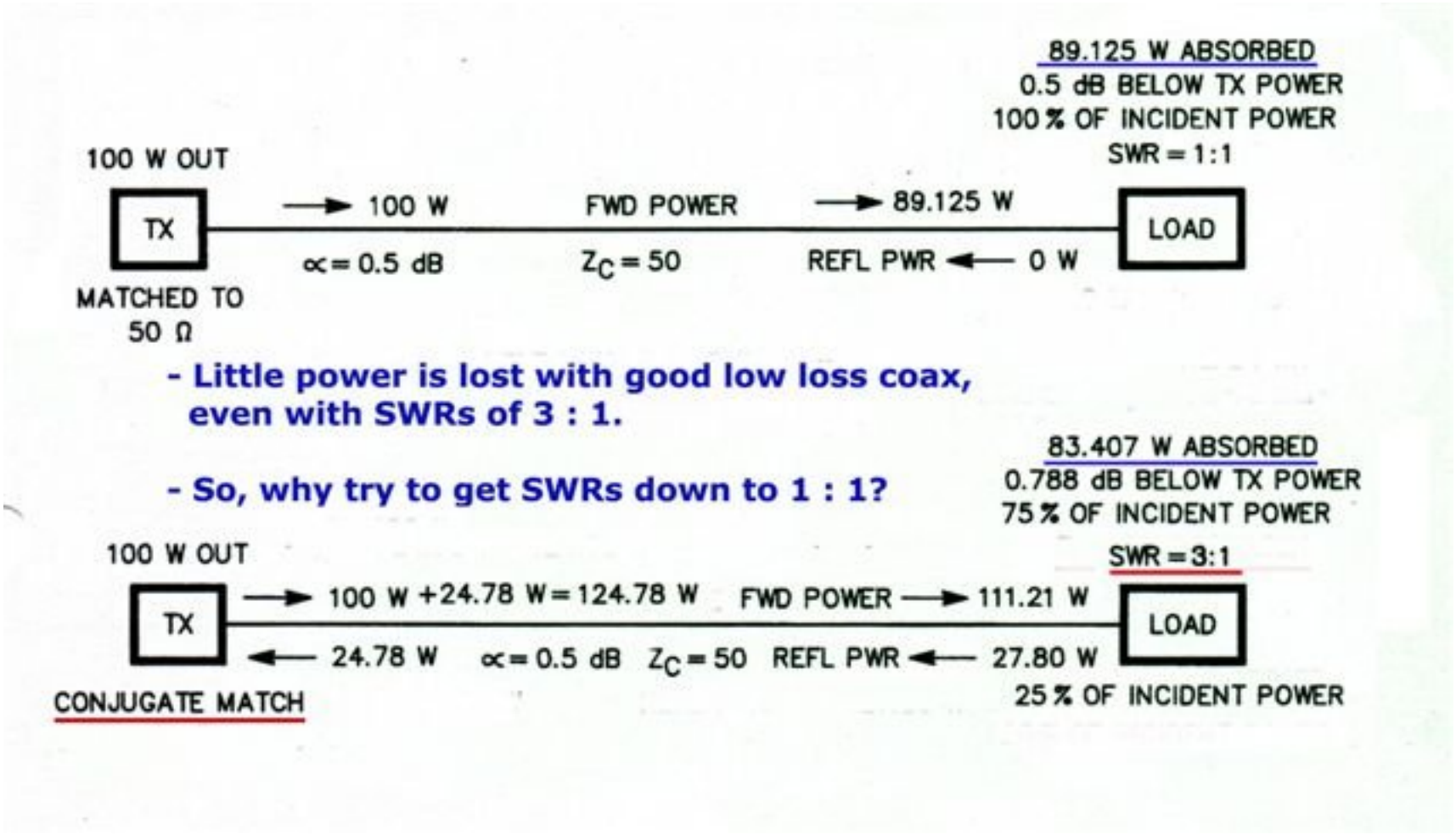

Taking the Mystery out of SWR

SWR FACT

Changing the line length does not change the SWR at the source end of the line

Then why does changing the length of the line some times allow a tuner to better match the line?

Taking the Mystery out of SWR

RG 58A BETWEEN 50 OHM SOURCE AND 150 OHM LOAD (SWR = 3:1)

Length	Input SWR	Input Z	Matched Loss (dB)	Unmatched Loss (dB)
150	1.47	70.52 + j 09.60	4.214	5.311
140	1.51	70.22 – j 14.43	3.933	4.990
130	1.55	50.07 – j 22.76	3.652	4.617
120	1.60	35.60 – j 14.45	3.371	4.363
110	1.65	30.32 – j 01.57	3.090	4.066
100	1.71	32.54 + j 12.50	2.809	3.769
90	1.78	44.91 + j 26.40	2.528	3.456
80	1.85	75.42 + j 28.01	2.247	3.111
70	1.93	92.99 – j 16.37	1.966	2.743
60	2.03	54.52 – j 38.13	1.685	2.367
50	2.13	30.56 – j 24.20	1.405	2.004

SWR does not change with length other than that caused by line loss.
So....why does changing the line length sometimes allows a tuner to better match the line?

Taking the Mystery out of SWR

RG 58A BETWEEN 50 OHM SOURCE AND 150 OHM LOAD (SWR = 3:1)

Length	Input SWR	Input Z	Matched Loss (dB)	Unmatched Loss (dB)
150	1.47	70.52 + j 09.60	4.214	5.311
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120	1.60	35.60 – j 14.45	3.371	4.363
110	1.65	30.32 – j 01.57	3.090	4.066
100	1.71	32.54 + j 12.50	2.809	3.769
90	1.78	44.91 + j 26.40	2.528	3.456
80	1.85	75.42 + j 28.01	2.247	3.111
70	1.93	92.99 – j 16.37	1.966	2.743
60	2.03	54.52 – j 38.13	1.685	2.367
50	2.13	30.56 – j 24.20	1.405	2.004

Input impedance significantly changes with length.

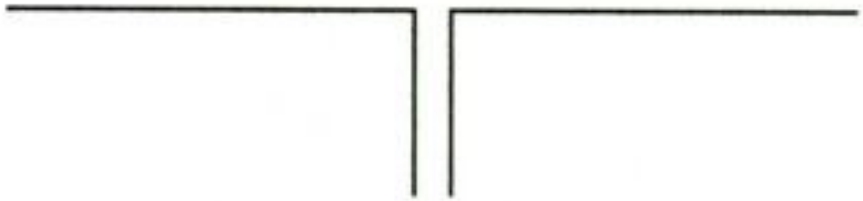
Taking the Mystery out of SWR

SWR FACT

Low SWR is not proof of performance

Taking the Mystery out of SWR

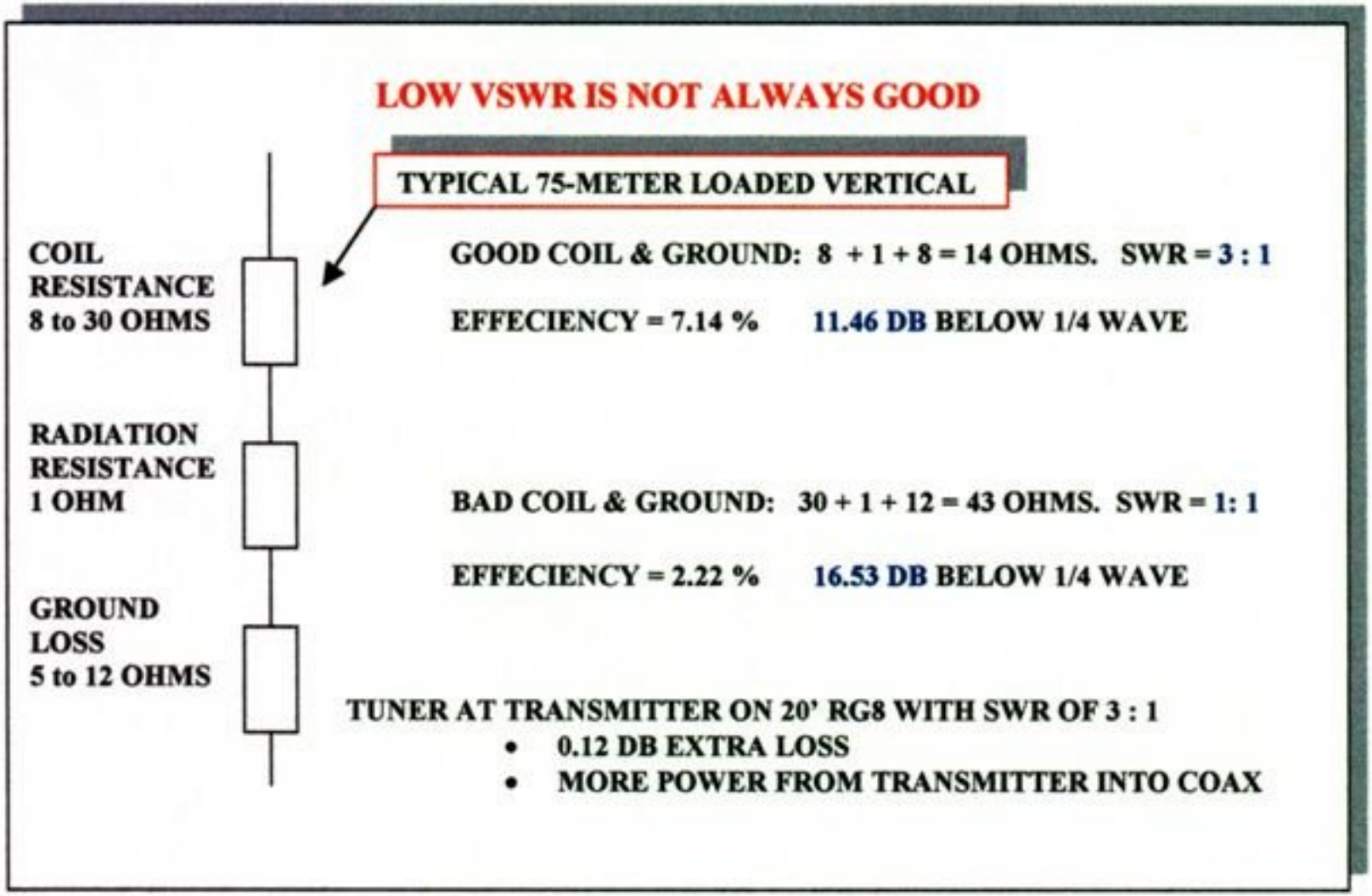
SWR NOT A INDICATOR OF SYSTEM EFFECIENCIY



DIPOLE IMPEDANCE = 100 OHM AT .25 WAVELENGH HEIGHT

200' FEEDLINE	IMPEDANCE	LOSS (dB)	SWR
RG58	50	1.20	1.8
OPEN WIRE	450	0.01	4.5

Taking the Mystery out of SWR



Taking the Mystery out of SWR

HIGH VSWR IS OFTEN GOOD

ANY ANTENNA FED WITH OPEN WIRE AND TUNER WILL:

- **BE 100 % EFFECIENT ON ANY FREQUENCY ABOVE IT'S RESONANT FREQUENCY**
  - **G5RV GOOD EXAMPLE**
- **OPERATE EFFECIENTLY WELL BELOW ITS RESONENT FREQUENCY**
- **HAVE NO LINE LOSS AT ANY SWR**
  - **MAY HAVE TO CHANGE LENGTH DUE TO IMPEDANCE**

ANY ANTENNA FED WITH LOW LOSS COAX AND TUNER WILL:

- **GIVE EFFECIENT BROAD BAND PERFORMANCE:**
  - **75 METER DIPOLE HAS 4 : 1 AT BAND EDGES**
  - **WITH 350' OF RG8, MAX LINE LOSS WILL BE 1.0 DB**

Taking the Mystery out of SWR

SWR FACT

High SWR does not cause the feedline to radiate:

- **Currents on the center conductor and on the inside of the shield are equal and opposite. Thus they cancel.**

- **Radiation caused by current on outside of shield:**
  - **Balanced to unbalanced**
  - **Asymmetrical positioning**

Taking the Mystery out of SWR

SWR FACT

An SWR meter will read the same anywhere along a line with two exceptions:

- **The line is very lossy**
- **Current is flowing on the outside of the coax shield**

Taking the Mystery out of SWR

SO...WHAT DOES ALL THIS MEAN?

- Use low loss coax or open wire

- Use a tuner to broadband antennas:
  - 40/80 meter dipoles
  - Mobile whips
  - All band dipoles or verticals

- Tuner does not need to be at antenna

Taking the Mystery out of SWR

SO...WHAT DOES ALL THIS MEAN?

- Know the expected SWR:
  - A 1/4 wavelength vertical:
    120 radials: 32 ohms SWR = 1.6:1
    4 radials: 50 ohms SWR = 1:1
  - 20 meter mobile whip: 10 ohms SWR = 5:1
  - HF Dipole : 40 to 100 ohms SWR = 1.0 to 2.1

Taking the Mystery out of SWR

SO...WHAT DOES ALL THIS MEAN?

- Be aware of excessive SWR voltage

- Test SWR bridge:
  - Compare with another good SWR bridge
  - Reverse the SWR bridge

  - Note if SWR gets better with time:
    - Corroded or bad connectors add resistance

Taking the Mystery out of SWR

SO...WHAT DOES ALL THIS MEAN?

- Don't bother buying multiband antennas with traps, multi-elements, etc

- Build a dipole, or vertical, as large as possible and use a tuner with open wire or good low loss coax:
    - G5RV with open wire

Taking the Mystery out of SWR