SWR and Transmission Line Loss

Based Uopn QST Hands-on-Radio

November 2010, and the

ARRL Handbook

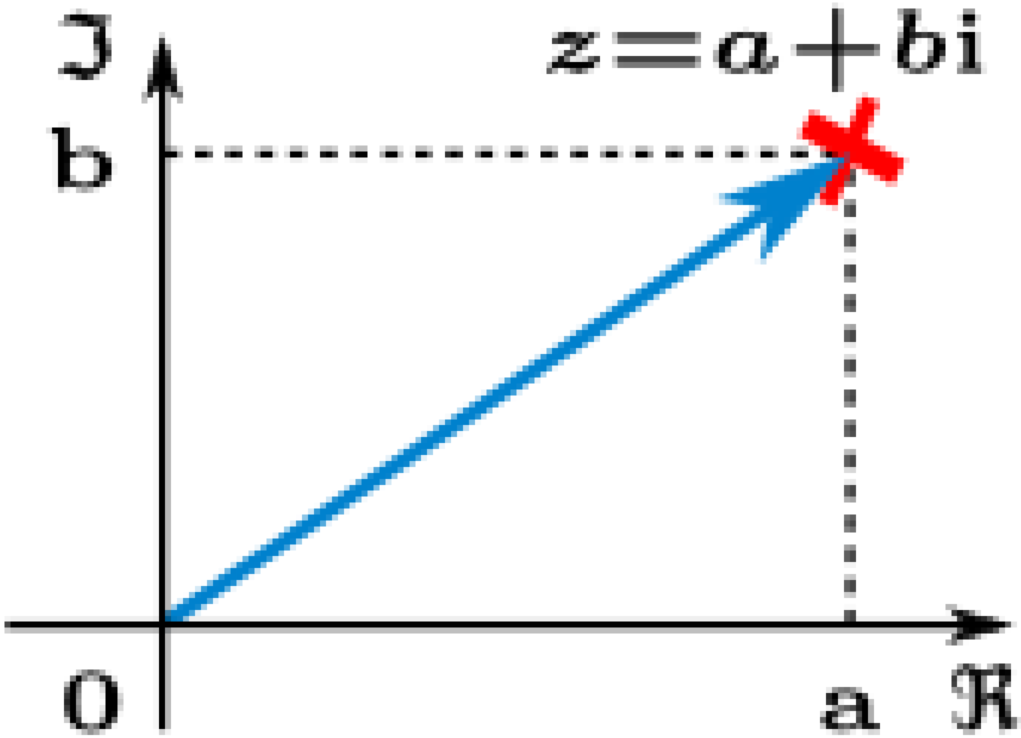
Impedance, Z ohms

- Impedance is the combined effect of Resistance, Inductance and Capacitance
- Symbol is "Z"
  - |Z|= E(rms) / I(rms)   [ignoring phase]
- But   E and I usually differ in phase
- So, to express this phase relationship, Z is usually a *complex number with a "real" part and an "imaginary" part.*

Impedance (cont)

- To express phase, $Z = R + jX$
  - where $j = \text{sqrt}(-1)$
  - So that $(j \times j) = (-1)$ and $(1 / j) = (-j)$
  - And where X is reactance, due to capacitance or inductance.
- "Absolute Z" = $|Z| = + \text{sqrt}\ [R^2 + (X_L + X_C)^2]$, for a series circuit.
- Note that X_L is positive and X_C is negative

$|Z| = \text{sq.rt.}\ (a^2 + b^2)$
Z is a "complex number"



Coax Power Transmission

- If power passing thru coax encounters a load impedance Z_L, different from its characteristic impedance Z_0, then some of the power is reflected back along the transmission line.
- This creates a stationary pattern of voltage along the line called a *standing wave*, where the voltage of the transmitted wave, V_T, is superimposed on the voltage of the reflected wave, V_R, both waves having the same frequency.

Coax Power Transmission

- The ratio of the peak to minimum voltage in the *standing wave* is called the *voltage standing wave ratio* or VSWR (or SWR).
- VSWR = $|Z_L|/Z_0$ or = $Z_0/|Z_L|$, whichever is ≥ 1
- Z_0 = sq.rt. [L (in Henries/ft.)/C (in farads/ft.)]
  - Z_0 (Ω) is not a complex number
- If Z_0 = 50 Ω and $|Z_L|$ = 75 Ω then SWR = 1.5
- If Z_0 = 50 Ω and $|Z_L|$ = 25 Ω then SWR = 2.0

Reflection Coefficient, $|\rho|$ (rho)

- $|\rho|$ is dimensionless, a ratio, sometimes called $|\Gamma|$ (gamma)
- $|\rho|$ = positive sq.rt. $(P_R/P_F) \leq 1$, where
  - P_R is the reflected power, and
  - P_F is the forward power
- Note $|\rho| = 0$ when $P_R = 0$ when $Z_L = Z_0$
- And $|\rho| = 1$ when $P_R = P_F$ when $Z_L = 0$ (short) and also, when Z_L = infinite (open)

ρ (rho) is a complex number

$\rho = (V_R / V_T) = (Z_0 - Z_L) / (Z_0 + Z_L)$

$|\rho| = (VSWR - 1) / (VSWR + 1)$

and $0 \leq |\rho| \leq 1$ (VSWR measured at load)

So that $VSWR = (1 + |\rho|) / (1 - |\rho|)$

and $1 \leq VSWR \leq$ [infinity, for an open or for a short circuit]

Review – decibels is a ratio

$$dB = 10 \log_{10} (P_1 / P_2)$$

-10 dB -> $(P_1 / P_2) = 0.10$

0 dB -> $P_1 = P_2$

0.5 dB -> $(P_1 / P_2) = 1.1$

3 dB -> $(P_1 / P_2) = 2$

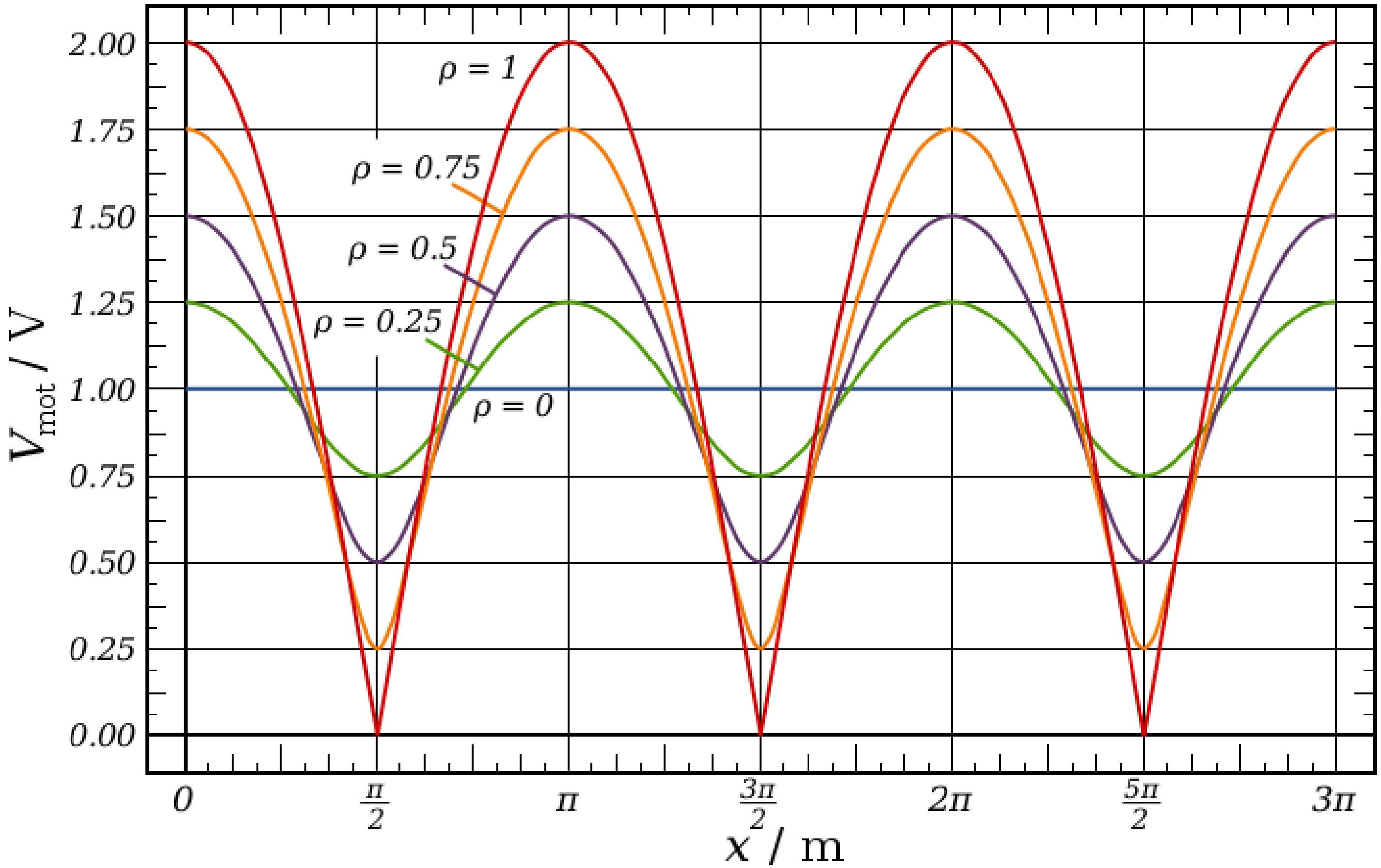
10 dB -> $(P_1 / P_2) = 10$

20 dB -> $(P_1 / P_2) = 100$

Return Loss (dB) Definition

- $|\rho| = \text{sq.rt.} (P_R / P_F)$
- And $0 \leq |\rho| \leq 1$, a positive number
- Return Loss (dB)= $-20 \log |\rho| = -10 \log (P_R / P_F)$
- Since $0 \leq |\rho| \leq 1$ then Return Loss ≥ 0 (dB)
- If $|\rho| = 0.05$ then Return Loss is 26 dB
- If $|\rho| = 0.5$ then Return Loss is 7 dB
- Think of Return Loss as a difference in dB between P_F and P_R. Confusing because many texts get it reversed – high dB is low loss.

Standing Waves ("ρ"should be |ρ|)



Line Loss

- Dissipated as heat, due to:
  - Resistive loss (prop. to $current^2$)
  - Dielectric loss (prop. to $voltage^2$)
- Matched Line Loss (ML) is the line loss (obtained from tables) when the load impedance matches the characteristic impedance of the line, or $Z_L = Z_0$
  - ML increases with frequency
  - ML is expressed in dB per 100 feet.
- Additional Line loss is caused by VSWR.

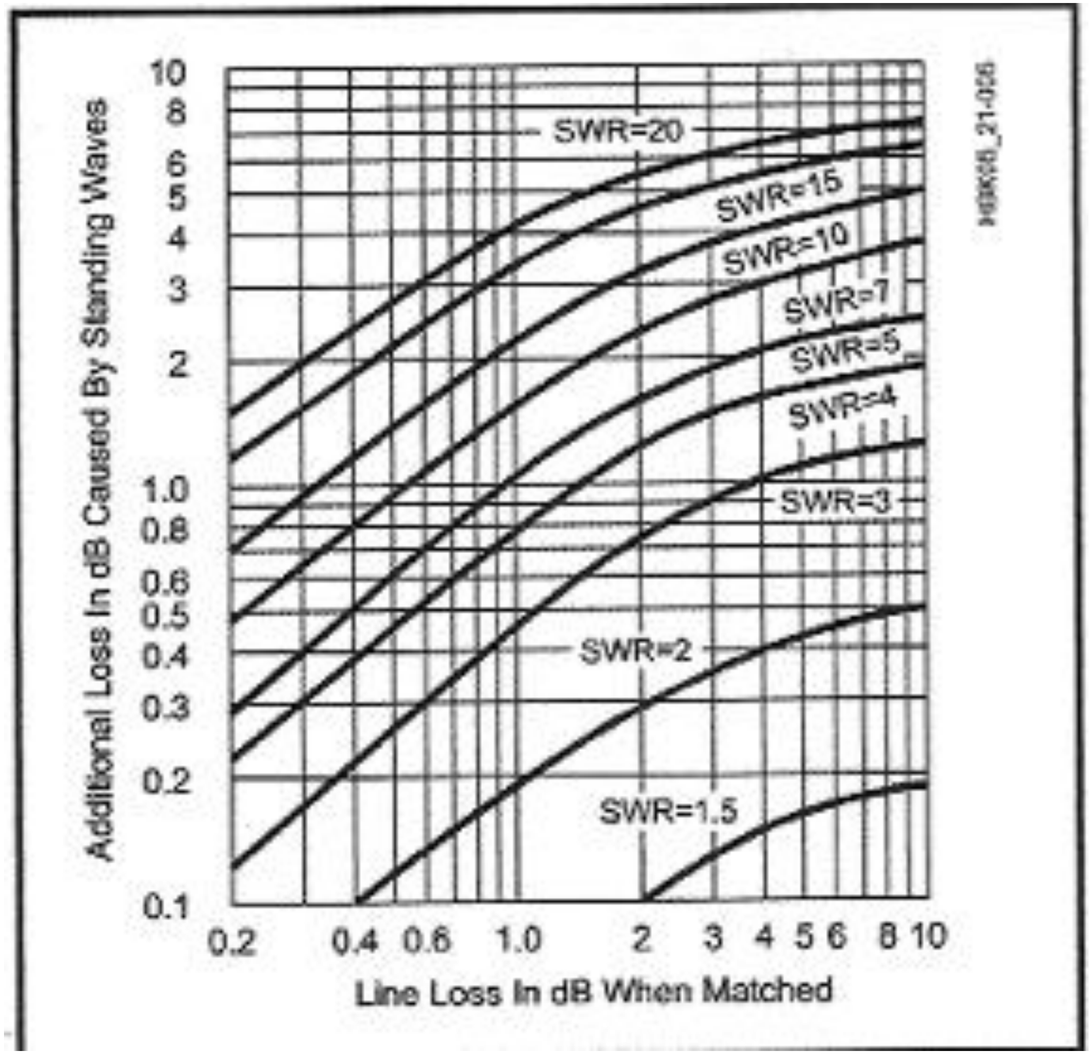
Matched Line Loss (dB/100 ft.) (at 1:1 VSWR)

Type	Part Number	O.D (in.)	1 MHz.	10 MHz.	100 MHz.	1 GHz.
RG-174	Belden 8216	0.101	1.9	3.3	8.4	34.0
RG-58A	Belden 8259	0.192	0.4	1.5	5.4	22.8
RG-8	LMR400	0.405	0.1	0.4	1.3	4.5
RG-213	Belden 8267	0.405	0.2	0.6	2.1	4.2
LMR600	TMS LMR600	0.590	0.1	0.2	0.8	2.7
Heliax ½”	LDFA-50A	0.630	0.05	0.2	0.6	2.4

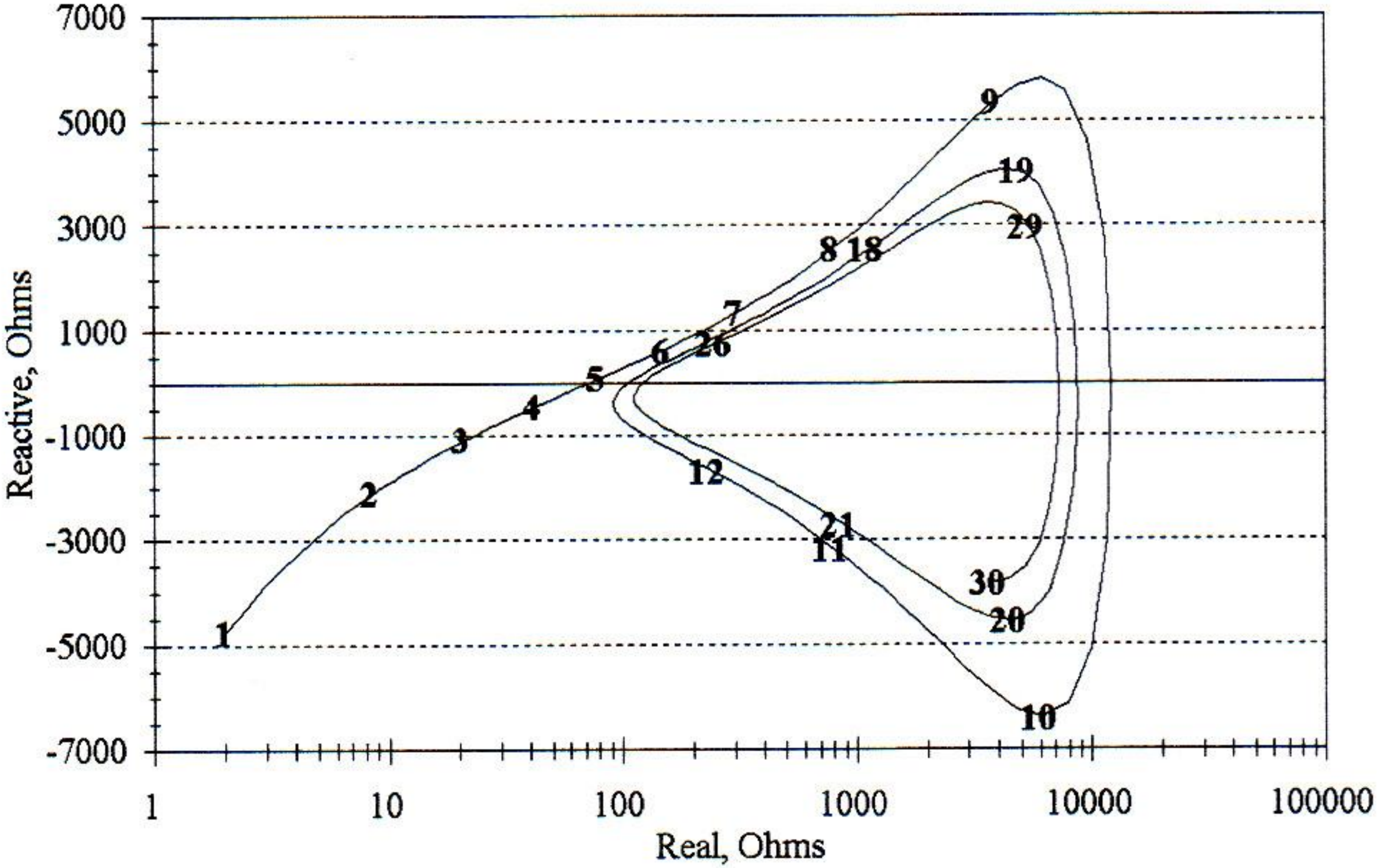
Additional Line Loss Due to VSWR

- If antenna impedance (Z_L) is not equal to transmission line impedance (Z_0) some of the power is reflected back and forth in the standing wave and adds to the Matched Loss.
- Eventually, all power is either
  - Absorbed by the load (radiated by the antenna)
  - Lost as heat in the transmission line, or
  - Absorbed and lost as heat within the transmitter.

Additional Line Loss due to VSWR



100 Foot Dipole in Free Space



Dipole in Free Space

Note

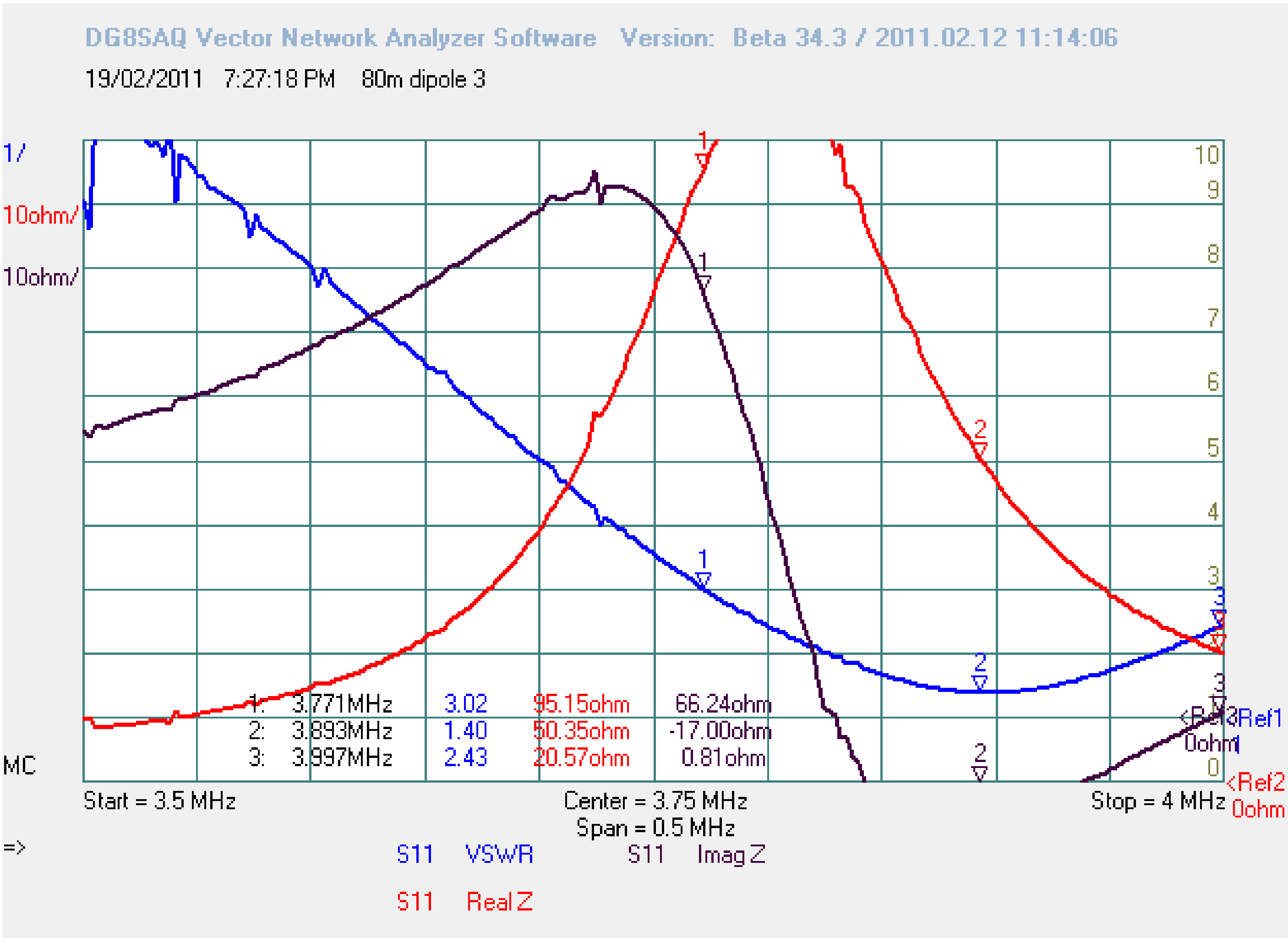
Impedances at the antenna are not the same as impedances at the transmitter

Question

Given impedance at the transmitter

How do you calculate impedance at the antenna and vice-versa?

Example – 80m Dipole – at Xmtr.

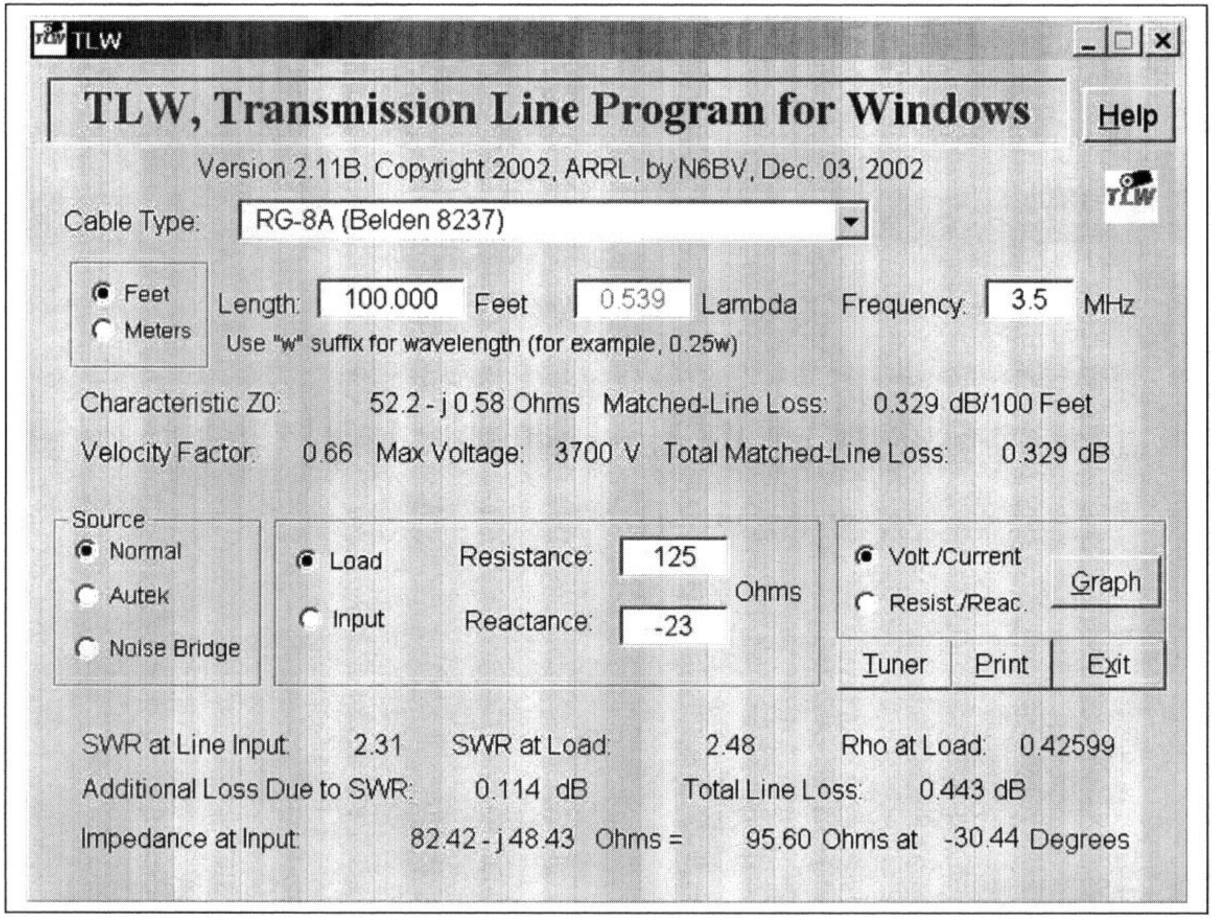


80m Dipole at Xmtr. (cont)

Freq. MHz	ICOM VSWR	VNWA VSWR	VNWA Resist. Ω	VNWA React. Ω	VNWA Calc. |Z|	VNWA Calc. VSWR	VNWA Calc. |ρ|	VNWA Ret. Loss dB
3.500	> 3	10.5	9	44	45	10.6	0.83	0.8
3.771	2.5	3.0	95	66	116	2.3	0.39	8
3.893	1.1	1.4	50	(17)	53	1.1	0.05	26
3.997	2.3	2.4	20	1	20	2.5	0.43	7

Freq. MHz	ICOM VSWR	MFJ VSWR meas.	MFJ Resist. Ω	MFJ React. Ω	MFJ Calc. |Z|	MFJ Calc. VSWR	MFJ meas. |ρ|	MFJ Ret.Loss dB
3.500	> 3	11.4	1	47	47	225	0.99	0.04
3.771	2.5	3.5	62	98	116	2.3	0.55	5
3.893	1.1	1.6	48	(23)	53	1.1	0.23	13
3.997	2.3	2.8	16	14	21	2.5	0.47	6

ARRL TLW Program



Examples from ARRL TLW Program for 80M Dipole

Coax	Length	Freq.	R_T	X_T	ML	SWR_T	SWR_A	$\|\rho\|_A$	TLL	R_A	X_A
RG213	40 ft	3.500	9	44	0.2	11.0	12.9	0.86	1.5	5	36
RG-58A	40 ft	3.500	26	110	0.3	10.3	17.2	0.89	1.8	5	36
RG-174	40 ft.	3.500	32	105	1.0	7.0	30	0.94	2.1	5	36
RG-174	150 ft.	3.500	26	27	3.6	2.4	30	0.94	8.2	5	36
RG-213	40 ft.	3.893	50	17	0.2	1.42	1.44	0.13	0.2	39	13
RG-213	40 ft.	28.300	50	37	0.5	2.1	2.3	0.39	0.6	29	24
RG-58A	40 ft.	28.300	56	33	1.1	1.8	2.3	0.39	1.4	29	24
RG-174	40 ft.	28.300	56	25	2.4	1.6	2.3	0.39	2.8	29	24
RG-174	150 ft.	28.300	50	4	9.1	1.1	2.3	0.39	9.7	29	24

Conclusions

- Transmission line loss increases with smaller diameter coax, with longer coax and with higher VSWR.
- VSWR at the transmitter is lower than that at the antenna.
- The greater the transmission line loss , the greater is this VSWR difference.
- Use of a tuner does not reduce this loss.