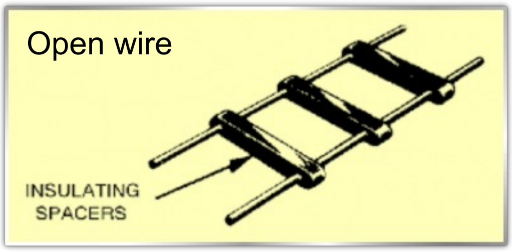
BACK TO BASICS - "COAX LOSSES"

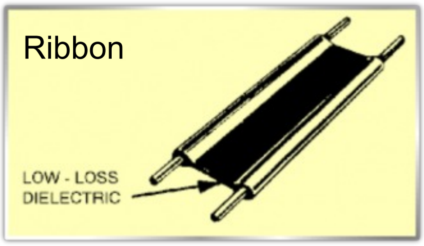
INTRODUCTION

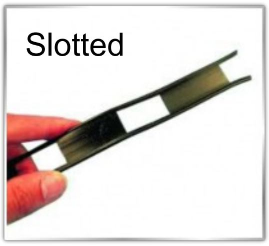
Many radio amateurs are faced with the same problem - namely how to feed their antennas which are some distance from the transceiver in the shack. This talk will initially look at the ideal solution - ie the use of open wire feeder. After discussing its practical limitations, the more common alternative - coax cable - will be considered together with its design, losses and their implications.

OPEN WIRE FEEDER

This basically consists of 2 copper wires separated by either air using spacers (**open wire**) or separated by a dielectric (**ribbon**) which can be **slotted** - see images below :-







The main advantage of such a feeder is that it theoretically introduces very little loss and therefore is ideal for long feeder runs between transceiver and antenna. However, this is only valid if the currents in each wire are equal and opposite such that the radiated signal from one wire is cancelled out by the radiated signal from the other - (this assumes the gap between the wires to be very small compared to the wavelength of the signal). Such a feeder is thus termed a Balanced Feeder. In practice, the presence of nearby objects and/or any imbalance in the antenna being fed, will lead to unequal currents in the wires resulting in net line radiation and thus losses and the possibility of interference or RF feedback. In addition, they cannot be bent without changing their electrical characteristics.

For these reasons, such feeder is restricted to straight runs in the open with the alternative feeder, **coax cable** being used within buildings etc.

COAXIAL (COAX) CABLE

CONSTRUCTION

Coaxial (coax) cable is constructed differently as shown in the image opposite:-
It was first patented by an English engineer and mathematician Oliver Heaviside, in 1880.

The inner conductor can be solid or stranded which is more flexible. To get a better high-frequency performance, the inner conductor may be silver-plated.
Coaxial cables require an insulating (dielectric) material to maintain the spacing between the centre conductor and the shield. The insulator surrounding the inner conductor can be either a solid or foam plastic. A common solid dielectric choice used in lower-loss cables is polyethylene although Teflon (PTFE) can also be used. Cables having a foam dielectric contain as much air or other gas as possible to reduce losses by allowing the use of a larger diameter centre conductor. Foam coax can have about 15% less losses but some types of foam dielectric can absorb moisture. Supports shaped like stars or spokes are even better but more expensive and very susceptible to moisture infiltration.

Many conventional coaxial cables use a braided copper wire to form the outer shield. This allows the cable to be flexible, but there are gaps in the shield layer, and the inner dimension of the shield can vary slightly because the braid cannot be flat. For better shield performance, some cables have a double-layer shield which can be two braids, or as is more common now, a thin foil shield covered by a wire braid.
A common choice for the outer insulating sleeve is PVC, but some applications may require UV or fire-resistant materials.

OPERATION AND ADVANTAGES OVER OPEN WIRE FEEDER

Open wire feeder cannot be bent, tightly twisted, or otherwise shaped without changing its characteristic impedance. They also cannot be buried or run along or attached to anything conductive, as the extended fields will induce currents in the nearby conductors causing unwanted radiation and detuning of the line.
Coaxial lines solve this problem by confining virtually all of the electromagnetic wave to the area inside the cable and can therefore be bent and moderately twisted without negative effects. They can also be strapped to conductive supports without inducing unwanted currents in them.

COAX CABLE LOSSES

When a RF signal passes down a length of coax cable, it suffers attenuation due to the inherent losses in the cable. These losses are introduced due to the following :-
Conductor Copper Losses :- due to the resistivity of copper. However, due to the Skin Effect, RF current is constrained to flow in only the outer layer of the conductor so increasing its resistivity. This effect increases with increasing frequency (so much so that at UHF the conductor may be just a hollow cylinder rather than a solid wire).
Dielectric Losses :- caused by the RF wave passing through the dielectric material separating the central wire and outer sheath. Dielectric losses increase in this order :- (no loss) vacuum - air - (PTFE) - polyethylene foam - solid polyethylene (highest loss)
RF Leakage :- some of the RF can escape through the outer shield leading to additional losses. Double screened cable can help reduce this.

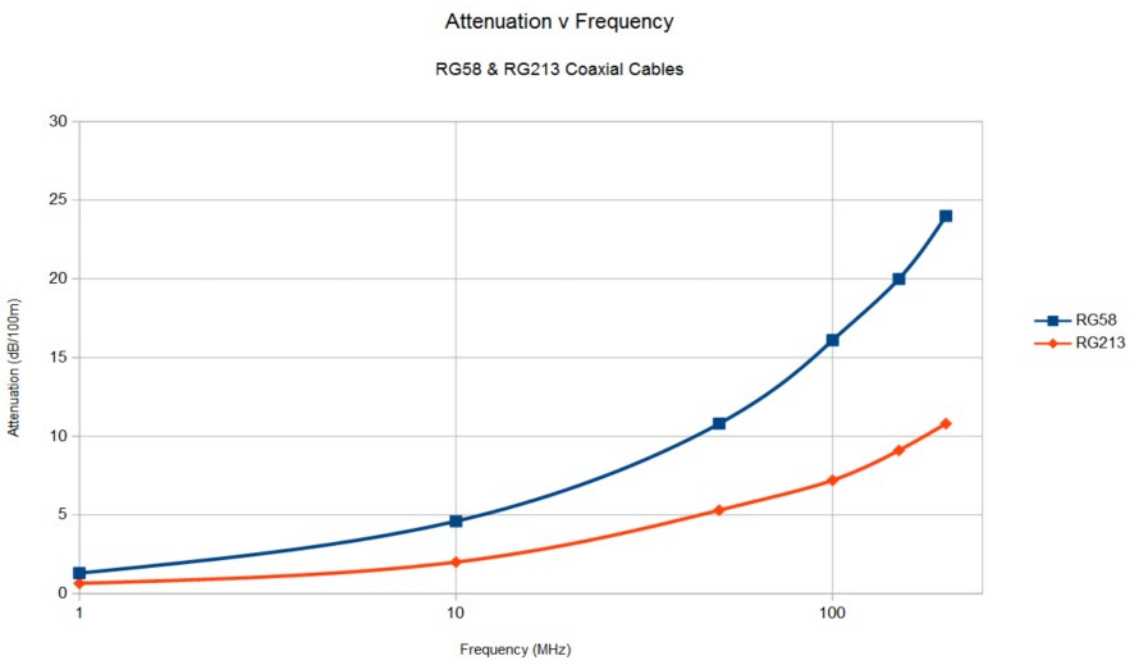
QUOTED LOSSES FOR COAXIAL CABLES USED AT MY QTH

Coax cables in use at my QTH are RG58 and RG213.
RG58 :- typical price £45/100m drum (Westlake). Dia : 5mm. Characteristic Imp : 50 ohm. Length 40m
RG213 :- typical price £150/100m drum (Westlake). Dia : 10.3mm. Characteristic imp : 50 ohm. Length 45m

The following Table lists quoted (ref W4RP) losses at various frequencies (SWR = 1) in **dB/100 feet** (dB/100m)

Cable	1 MHz	10 MHz	50 MHz	100 MHz	150 MHz	200 MHz
RG 58	0.4 (1.3)	1.4 (4.6)	3.3 (10.8)	4.9 (16.1)	6.4 (21.0)	7.3 (24.0)
RG 213	0.2 (0.65)	0.6 (2.0)	1.6 (5.3)	2.2 (7.2)	2.8 (9.1)	3.3 (10.8)

This data is plotted in the diagram below which shows how the attenuation (dB/100m) rises non-linearly with frequency :-



DECIBELS

The attenuation values quoted previously are in Decibels (dB) and hence the following brief explanation may be useful :-
The decibel is a measure of the ratio of two **powers** and is a **logarithmic scale** (to the base 10). Since attenuation is a power loss, it will have a negative value in dB.

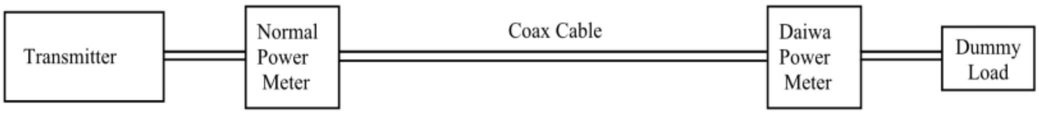
$$\textbf{Attenuation (dB)} = 10 \times \log_{10} (\text{Power Out/Power In})$$

eg : 100W in attenuated to 50W out
Attenuation (dB) = $10 \times \log_{10} (50/100) = 10 \times \log_{10} (0.5) = 10 \times (-0.30) = -3$dB

Hence -3dB represents a 50% power loss (half out), -6dB represents a 75% power loss (quarter out), and -10dB represents a 90% power loss (tenth out). Hence, dBs are added for cascaded or multiplied losses :-
eg: ¼ x ½ = 1/8 represents a -(6 + 3) = -9dB attenuation

PRACTICAL ATTENUATION MEASUREMENTS AT MY QTH

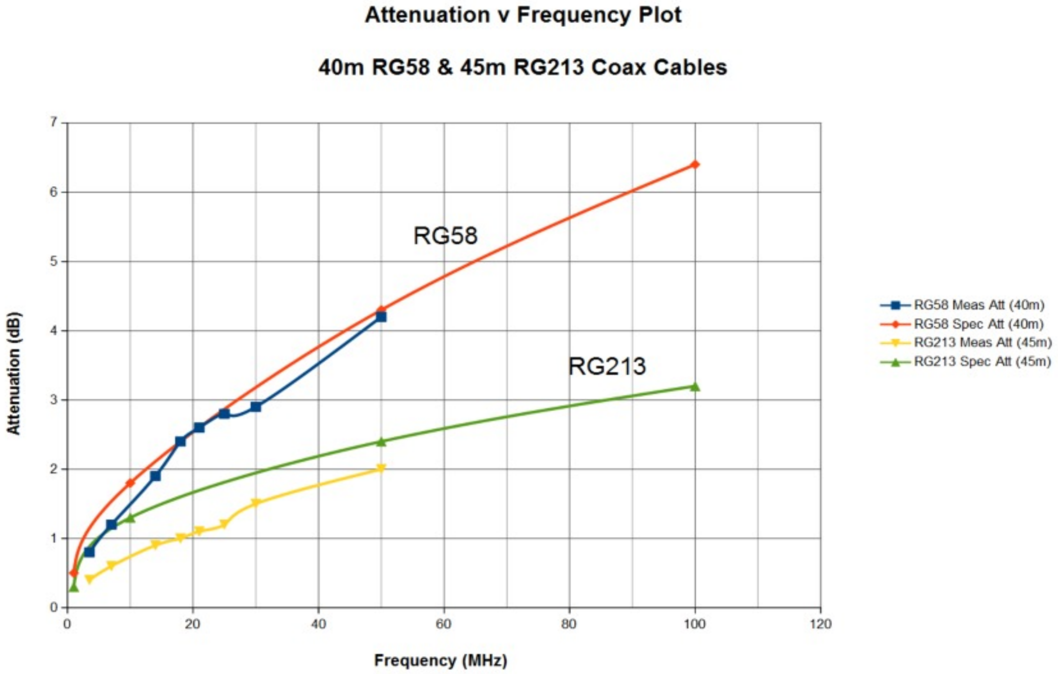
Measurements were made on both cables using a Daiwa CN620A SWR/Power Meter kindly loaned by Laurence (G4XHK). The cable lengths were measured and found to be approx 40m for the RG58 cable and 45m for the RG213 coax.
The Power Meter was first used at the transmitter end to calibrate the normal Power Meter and then transferred to the far end of the cable which was terminated in a 50 ohms Dummy Load - see diagram below.



Readings of input and output power were taken at a number of frequencies between 3.5 - 50 MHz and the attenuation calculated using **Attenuation (dB) = 10 x log $_{10}$ (Power Out/Power In)** which are given in the following Table (together with the Specification values) :-

	40m RG58 coax cable				45m RG213 coax cable			
Freq (MHz)	**Input Power (W)**	**Output Power (W)**	**Measd Loss (dB)**	**Spec Loss (dB)**	**Input Power (W)**	**Output Power (W)**	**Measd Loss (dB)**	**Spec Loss (dB)**
1				0.5				0.3
3.5	120	100	0.8		120	110	0.4	
7	120	90	1.2		120	105	0.6	
10				1.8				0.9
14	112	73	1.9		112	91	0.9	
18	110	63	2.4		110	88	1	
21	109	60	2.6		109	85	1.1	
25	100	53	2.8		100	75	1.2	
30	98	50	2.9		98	70	1.5	
50	79	30	4.2	4.3	79	50	2	2.4
100				6.4				3.2

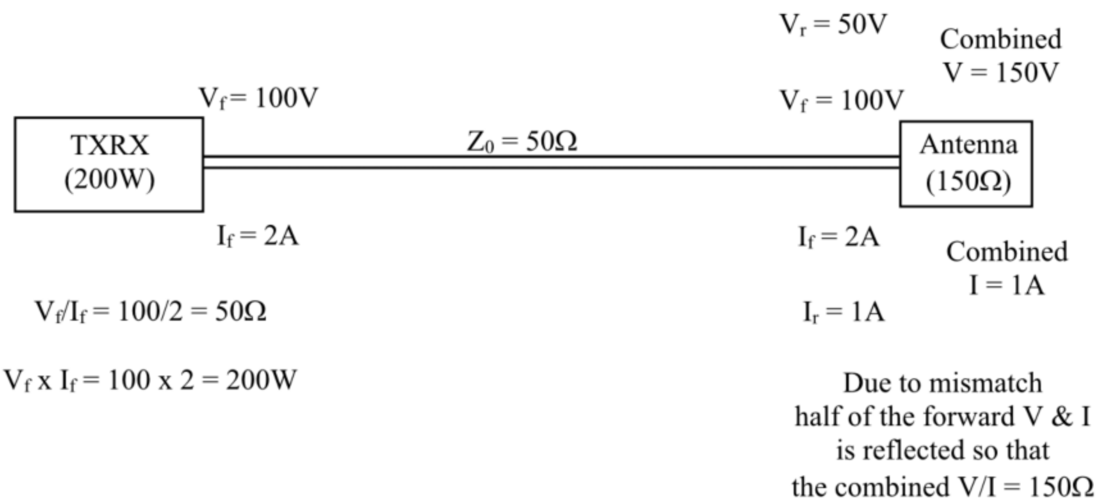
The results are plotted opposite, and there appears to be some agreement between the measured and specified attenuation. However, the measured attenuation for the 45m length of RG213 coax cable is around 0.5dB lower than the specification value suggesting a better quality cable was used.



STANDING WAVE RATIO

As stated earlier, the attenuation figures quoted on the previous page assume that the coax cable is terminated in a matched load (i.e a purely resistive 50 ohm load) and thus all the forward power is absorbed by the load. However, in practice, this necessitates feeding a perfectly tuned antenna (ie resonant at the operating frequency) in order to present a purely resistive load, and designed such that its resistance value matches the characteristic impedance (50 ohm) of the coax cable.
This is rarely the case, and the following diagram demonstrates what happens when a 200W transmitter feeds a 150 ohm resistive load via a length of 50 ohm coax. It can be seen that a reflected wave is produced which combines with the forward wave to produce max and min values of voltage and current every quarter wavelength along the cable. The pattern of values is repeated every half wavelength. ie the antenna impedance appears at multiples of a half wave from the antenna.

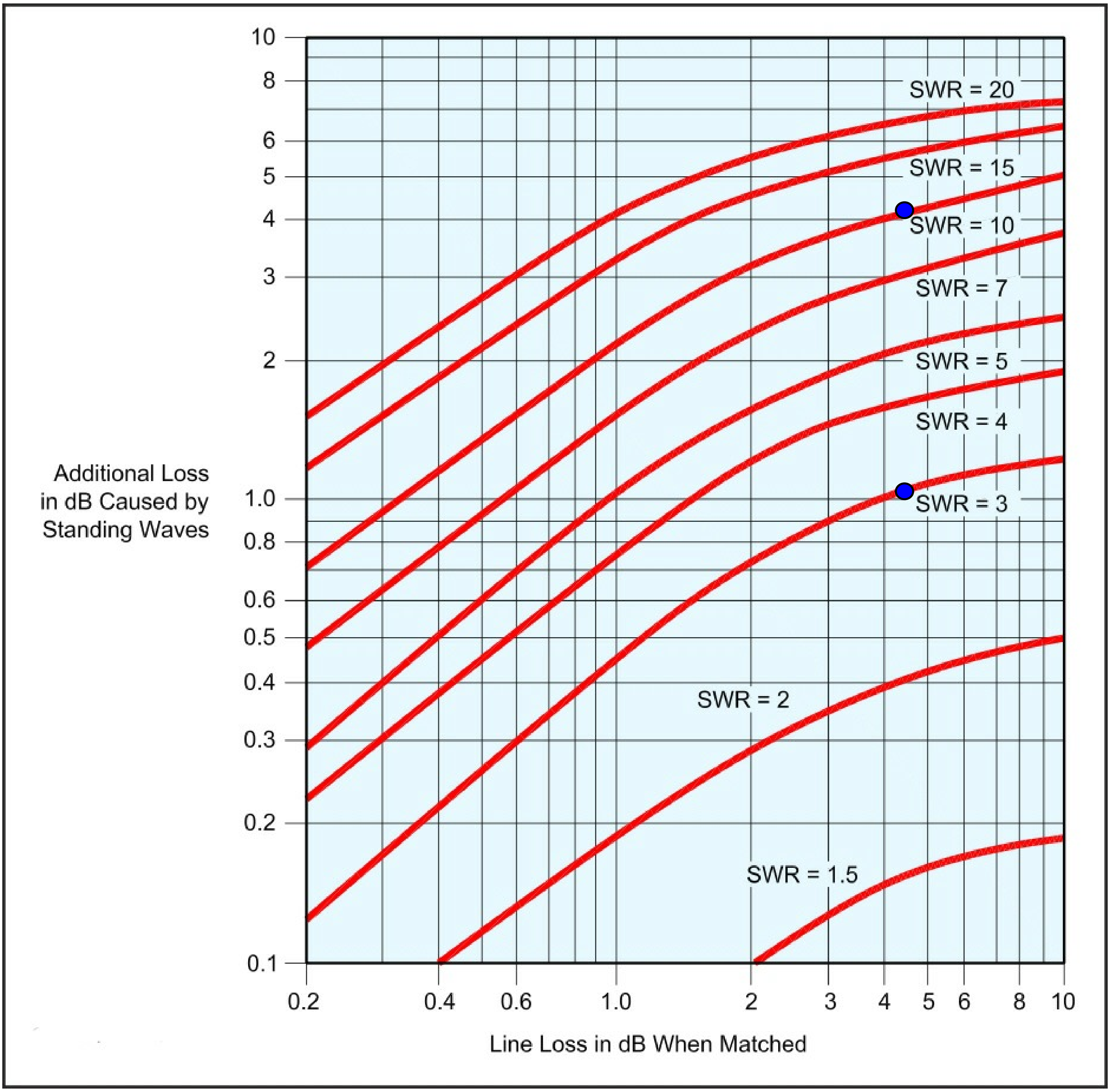
200W, 50 ohm output impedance Transceiver feeding
150 ohm Antenna via length of 50 ohm coax (assumed loss free)



Since the antenna impedance (150Ω) is > cable characteristic impedance (50Ω) then forward and reflected voltages add (150V) but currents subtract (1A).
At a distance λ/4 from the antenna, the voltages subtract (50V) and the currents add (3A).
The ratio of the max to min voltages (or max to min currents) = SWR (in this case 3)

EFFECT OF HIGH SWR UPON LOSSES

The presence of high voltage and current points along the cable leads to additional losses in the dielectric.
eg Consider a 100m length of RG58 coax fed with a 10 MHz signal.
The specified attenuation for such a length of coax at that frequency is 4.6 dB providing the SWR = 1 (flat line).
However, if the SWR = 3 as per the example on the previous page, then referring to the diagram below, the attenuation would rise by an additional 1dB ie from 4.6 to 5.6dB.
However if the SWR = 10, then the attenuation would rise by an additional 4dB ie from 4.6dB to 8.6dB !



Graph showing the additional loss in a transmission line due to SWR

EFFECT OF LOSSES UPON MEASURED SWR AT TRANSMITTER

SWR Meters effectively measure the forward and reflected power at a point in a transmission line - eg coax cable. Since SWR is the ratio of the max voltage (forward and reflected voltage waves added) to the min voltage (forward and reflected voltage waves subtracted) then in terms of the forward and reflected power waves, this becomes :-

$SWR = (V_f + V_r)/(V_f - V_r)$ (ie the sum/difference of the forward and reflected voltage waves)

but since Power, $P = V^2/R$

then $V = \sqrt{P} \times \sqrt{R}$ (where R = 50 ohms)

Substituting gives $SWR = ((\sqrt{P_f} \times \sqrt{50}) + (\sqrt{P_r} \times \sqrt{50}))/((\sqrt{P_f} \times \sqrt{50}) - (\sqrt{P_r} \times \sqrt{50}))$

ie $\mathbf{SWR = (\sqrt{P_f} + \sqrt{P_r})/(\sqrt{P_f} - \sqrt{P_r})}$

Consider the previous example of a 200W transmitter feeding a 150 ohm load via a 50 ohm coax cable.

If the cable is **loss free** then from the above formula :-

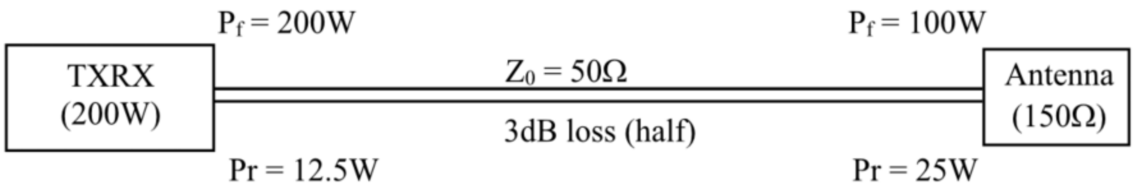
$SWR = (\sqrt{200} + \sqrt{50})/(\sqrt{200} - \sqrt{50})$

ie **SWR** = (14.14 + 7.07)/(14.14 - 7.07) = 21.21/7.07 **= 3** (which agrees with Vmax/Vmin = 150/50)

With no cable losses, the SWR is the same whether measured at the transmitter or antenna end of the cable.

However, if the cable attenuates the signal by 3dB due to losses as shown in the Diagram below :-

200W, 50 ohm output impedance Transceiver feeding
150 ohm Antenna via length of 50 ohm coax (assume 3dB cable loss)



Due to mismatch,
half forward voltage
and half forward
current reflected.
ie quarter of power
reflected

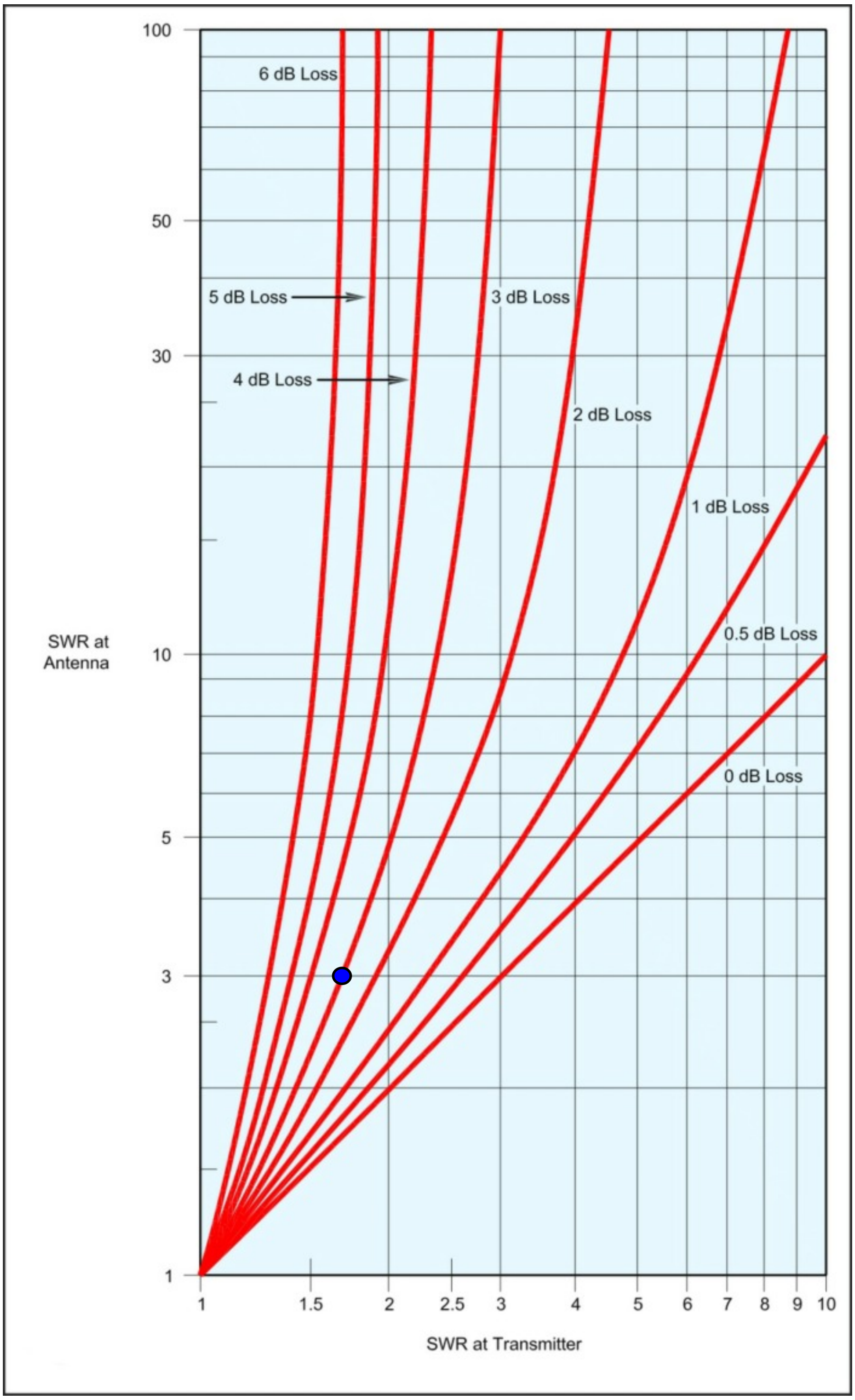
At the antenna end of the cable :-

SWR = $(\sqrt{100} + \sqrt{25})/(\sqrt{100} - \sqrt{25})$ = (10 + 5)/(10 - 5) = 15/5 = **3**

However, at the transmitter end of the cable :-

SWR = $(\sqrt{200} + \sqrt{12.5})/(\sqrt{200} - \sqrt{12.5})$ = (14.14 + 3.54)/(14.14 - 3.54) = 17.68/10.6 = **1.67**
almost half the value !!

The graph on the following page shows the effects of losses upon SWR measurement made at the transmitter.



An interesting implication of this is that a length of open or short circuited very lossy cable can form a pretty good Dummy Load !! This is because any forward power not absorbed in the cable arriving at the far end will be totally reflected and further heavily attenuated on its way back such that virtually no power arrives at the transmitter.

FINALLY A QUICK WAY TO KEEP A CHECK ON CABLE LOSSES

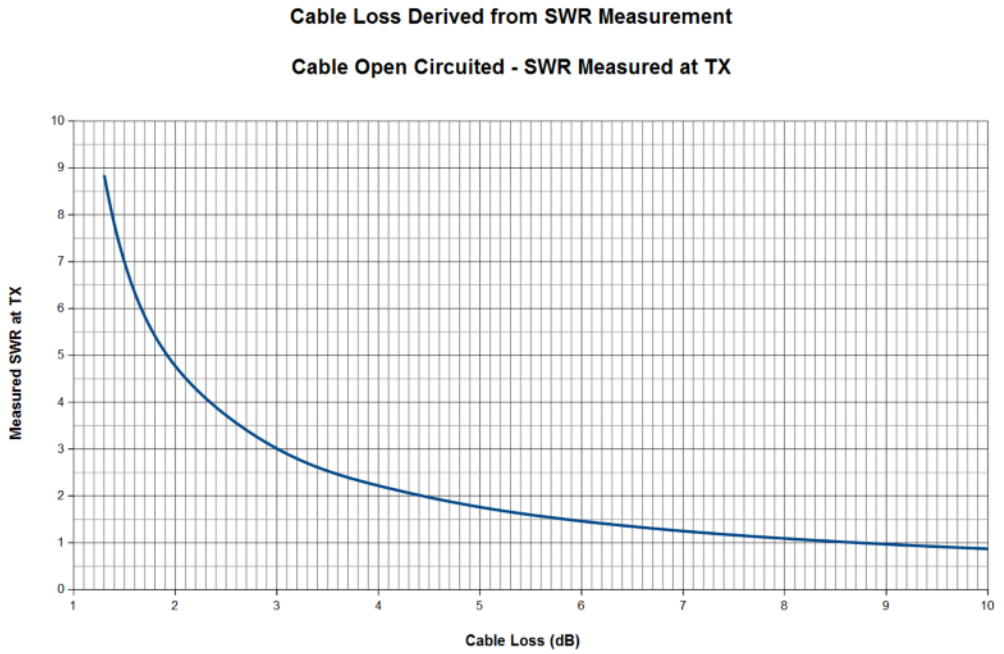
It can be shown that the losses (dB) of an open or short circuited cable can be derived from the formula :-

$$\textbf{Losses (dB)} = 10 \times \log_{10} ((SWR + 1)/(SWR - 1))$$

Where SWR is measured at the transmitter end of the cable.
eg if the measured SWR at the TX = 3, then the losses in the cable are :-

$$10 \times \log_{10} ((3 + 1)/(3 - 1)) = 10 \times \log_{10} (4/2) = 10 \times \log_{10} 2 = 3\text{dB losses.}$$

The following Diagram enables the cable loss (dB) to be derived from the measured TX SWR :-



Both cables at the QTH were tested in this way over the frequency range 3.5 - 50 MHz and the results are shown in the Table together with the cable losses plotted graphically.
The loss was calculated using :- **Loss (dB) = 10 x log $_{10}$ ((SWR + 1)/(SWR - 1))**

	RG58 (40m)		RG213 (45m)	
Freq (MHz)	**SWR**	**Loss (dB)**	**SWR**	**Loss (dB)**
3.5	5	1.6	9	0.9
7	4	2.2	7	1.1
14	3.3	2.8	6.3	1.4
18	3	3	5	1.6
21	2.7	3.4	6	1.4
25	2.5	3.6	4	2.2
30	2.3	4	3.8	3.2
50	1.4	7	3.5	2.6

In both cables, the indicated losses exceed the Specification values by approx 0.5dB. This could be perhaps be part explained by the fact that the Specification losses are for a SWR = 1 whereas the measured losses apply to cables having a high SWR which as seen earlier, leads to increased cable losses.
A recommendation found in a web article is that a good short circuit is preferable to an open circuit.
If the antenna cannot be removed for such a test, try tuning it to a frequency which results in a gross mismatch.

SUGGESTED MODIFIED QUICK METHOD OF CHECKING COAX CABLE LOSSES

Subsequent research on the internet produced an interesting article by Frank Witt (AI1H) entitled 'Measuring Cable Loss' in which drawbacks to the above method together with suggested solutions are discussed.

Firstly, as mentioned previously, the method involves measurements made under high SWR conditions which would result in the cable probably appearing as a complex impedance to the SWR Meter instead of a pure 50Ω resistance as assumed in its calibration. The suggested modification to the method is to measure the SWR at the TX under BOTH short and open circuit conditions. The Cable Loss (dB) is then calculated from :-

$$\textbf{Loss (dB)} = 5 \times \log_{10} [((SWRs + 1)/(SWRs - 1)) \times ((SWRo + 1)/(SWRo - 1))]$$

Where SWRs is the short circuit and SWRo the open circuit measurement.

Secondly, the high SWR values involved in the method are not easy to read and are in a less accurate area of the meter scale. A suggested modification is to include a fixed accurate eg a 4dB attenuator in the cable which would result in lower SWR readings which are easier to read and more accurate. The extra 4dB loss is then simply deducted from the calculated values.
An alternative is to use an Indirect Method which involves measuring the SWR with the coax cable terminated in a 50/2 = 25Ω load and then with a 2x50 = 100Ω load. The cable loss is then calculated from :-

$$\textbf{Loss (dB)} = 5 \times \log_{10} [((SWR_{25} + 1)/(SWR_{25} - 1)) \times ((SWR_{100} + 1)/(SWR_{100} - 1))] - 4.77$$

Again, this results in lower SWR measurements which are easier to read and more accurate.
Unfortunately, neither of the above modified methods have yet been tried due to time constraints but it is intended to try and compare all the methods in the future.

CONCLUSION

This 'Back to Basics' article explained the causes of attenuation in coaxial cables and shown how with a simple power meter, it is possible to obtain a reasonable indication of the cable attenuation in dB.
It showed that cable losses are increased in the presence of high SWRs and that cable losses can appear to greatly improve SWR readings taken at the transmitter end of the cable and so hide any possible antenna mismatch at the far end.
At eg 18MHz, approx half (0.5dB) of the signal power was absorbed by 40m of RG58 coax cable, whereas only a quarter of the signal (1.3dB) was absorbed by 45m of RG213 coax cable.
Finally, a quick test of cable loss was described which would enable the condition of the cable to be checked at regular intervals together with various suggested improvements to the method.

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