VSWR AND ANTENNA SYSTEMS

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BACKGROUND

In the 40 years of consulting in the RF and Microwave field, I have seen so much misunderstanding about VSWR that it has prompted me to prepare this paper in the hope that it will help to clear up misconceptions and aid in the development of cleaner systems. It is also a major goal to explore the use of VSWR (also called “match”) to monitor antenna systems

VSWR??

VSWR is a measure of how well a particular RF connection (or “LOAD”) is matched to the characteristic impedance of a system. The term VSWR (Voltage Standing Wave Ratio) comes from the early measurement technique using a slotted line and a voltage-calibrated detector that could be moved along the line to see the standing wave that is generated when two parts of a system are connected. In a perfectly matched system, there will be no standing wave and the voltage on the detector will remain constant as the detector is moved along the line, indicating that all of the energy is being transferred from the source into the LOAD. If there is a mismatch in the system, the voltage will vary, and the ratio of the voltage at the peak of the wave and that at the node (nadir) is the voltage standing wave ratio (VSWR) of the mismatch. If the node of the standing wave is zero, then the VSWR is said to be infinite and all of the energy from the source is being reflected to the source.

From the above discussion, it is apparent that VSWR is a measurement of how much energy is being reflected to the source. Knowing what portion of the energy is being reflected gives a direct indication of how much is being transferred to the LOAD. Measurement techniques currently in service use bridges or couplers to measure the reflected power and the measurement results are expressed as RETURN LOSS. There is a direct correlation between VSWR and RETURN LOSS as depicted in Table 1. Thus, VSWR and RETURN LOSS are different ways of expressing the same characteristic, which we refer to as “match”. In working with match, RETURN LOSS is a much easier concept to relate to than VSWR, and since it is the primary means available to measure match, the term RETURN LOSS will be used to describe this parameter. It must be kept in mind that the correspondence to VSWR shown in Table 1 is always valid.

The characteristic which we call “match”, whether expressed as VSWR or return loss, describes how well a particular LOAD is matched to the system in which it is used. Most RF systems are 50 ohms, although other systems with other impedance definitions are in use. It is important to be sure that each element of a system be specified to the same impedance characteristics, otherwise the match characteristics of the elements will not apply in the system. It should be noted also that VSWR and return loss that we are discussing address only the magnitude portion of the match. We are assuming that the elements of our system are broad-band and that the losses of the distribution networks that we will be discussing are resistive, so that the quantities of return loss will add. Otherwise, the results will be less deterministic, and the measurements will all have an additional ambiguity. In other words, we will be presenting the best possible scenario for the predictability of return loss (or VSWR) measurements.

TABLE 1
VSWR TO RETURN LOSS CONVERSION

VSWR	RET LOSS (dB)	VSWR	RET LOSS (dB)	VSWR	RET LOSS (dB)	VSWR	RET LOSS (dB)
1.00	infinite	1.24	19.4	1.66	12.1	5.50	3.2
1.01	46.1	1.25	19.1	1.68	11.9	6.00	2.9
1.02	40.1	1.26	18.8	1.70	11.7	6.50	2.7
1.03	36.6	1.27	18.5	1.72	11.5	7.00	2.5
1.04	34.2	1.28	18.2	1.74	11.4	7.50	2.3
1.05	32.3	1.29	17.9	1.76	11.2	8.00	2.2
1.06	30.7	1.30	17.7	1.78	11.0	8.50	2.1
1.07	29.4	1.32	17.2	1.80	10.9	9.00	1.9
1.08	28.3	1.34	16.8	1.82	10.7	9.50	1.8
1.09	27.3	1.36	16.3	1.84	10.6	10.00	1.7
1.10	26.4	1.38	15.9	1.86	10.4	11.00	1.6
1.11	25.7	1.40	15.6	1.88	10.3	12.00	1.5
1.12	24.9	1.42	15.2	1.90	10.2	13.00	1.3
1.13	24.3	1.44	14.9	1.92	10.0	14.00	1.2
1.14	23.7	1.46	14.6	1.94	9.9	15.00	1.2
1.15	23.1	1.48	14.3	1.96	9.8	16.00	1.1
1.16	22.6	1.50	14.0	1.98	9.7	17.00	1.0
1.17	22.1	1.52	13.7	2.00	9.5	18.00	1.0
1.18	21.7	1.54	13.4	2.50	7.4	19.00	0.9
1.19	21.2	1.56	13.2	3.00	6.0	20.00	0.9
1.20	20.8	1.58	13.0	3.50	5.1	25.00	0.7
1.21	20.4	1.60	12.7	4.00	4.4	30.00	0.6
1.22	20.1	1.62	12.5	4.50	3.9		
1.23	19.7	1.64	12.3	5.00	3.5		

ANTENNAS and VSWR

The purpose of a transmitter antenna is to transfer RF energy from a source into free space. Likewise, a receiver antenna is to transfer RF energy incident upon it to a matched transmission line where it can be routed to a receiver. As antennas are passive, they are bi-directional. In the interest of simplicity, we shall only concern ourselves with transmit antennas.

The energy applied to a transmit antenna is divided into three parts: Part is reflected to the source (return loss), part is dissipated in the antenna (resistive loss), and part is radiated into space. Antenna materials are selected to minimize the resistive losses and are generally insignificant. The goal of the physical design of the antenna is to minimize the return loss, such that most of the applied power is radiated. The physical design of the antenna will also determine the radiation pattern, but the main concern with the efficiency of the antenna can be directly related to match, whether expressed as VSWR or as return loss. Table II shows the relationship between reflected power and transferred power for a practical range of values. Note that the transferred power also represents the efficiency of the energy transfer.

TABLE II
TRANSFER EFFICIENCY vs MATCH (VSWR and RETURN LOSS)

VSWR	RET LOSS (dB)	% OF POWER REFLECTED	% OF POWER TRANSFERRED (EFFICIENCY)
1.10	26.4	0.2	99.8
1.20	20.8	0.8	99.2
1.30	17.7	1.7	98.3
1.40	15.6	2.8	97.2
1.50	14.0	4.0	96.0
1.60	12.7	5.3	94.7
1.70	11.7	6.7	93.3
1.80	10.9	8.2	91.8
1.90	10.2	9.6	90.4
2.00	9.5	11.1	88.9
2.50	7.4	18.4	81.6
3.00	6.0	25.0	75.0
3.50	5.1	30.9	69.1
4.00	4.4	36.0	64.0
4.50	3.9	40.5	59.5
5.00	3.5	44.4	55.6
5.50	3.2	47.9	52.1
6.00	2.9	51.0	49.0
6.50	2.7	53.8	46.2
7.00	2.5	56.2	43.7

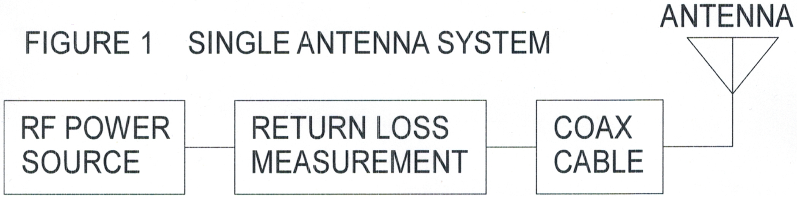
ANTENNA SYSTEMS (ONE ANTENNA)

Since match is a good measurement of the integrity of an antenna, then it has often been assumed that a measurement of match is a valid way to monitor the integrity of an antenna system. This is NOT always the case, as we will demonstrate in the following discussion.

Antennas are typically rated to be around 95% efficient and will exhibit a return loss of 14 dB or better. As can be seen from the chart, a degradation in return loss from 14 dB to 10 dB will result in an efficiency degradation from 96% to roughly 90%. Expressed in terms of decibels, the drop in transferred power is 0.5 dB, which is insignificant in a practical radiated power application. Therefore, **measuring the match of an individual antenna can be a good method of determining antenna integrity.** Setting an alarm threshold of 11 dB return loss, for example, will give a very high level of confidence of detecting a bad antenna while providing good margin to avoid false alarms from a serviceable antenna.

In a real antenna system, one must consider the distribution of power from the RF power source to the antenna. This is nominally through a well-matched coax cable, which introduces loss and isolation between the power source and the antenna. Figure 1 depicts this signal path, including a measurement of match.

FIGURE 1 SINGLE ANTENNA SYSTEM



The Return Loss Measurement will be affected by the loss of the cable. Because the signal from the source passes through the cable en route **to and from** the antenna, the return loss measurement will be affected by twice the value of the cable loss. Table III shows the measured results under differing conditions of antenna match and cable loss. If the Return Loss Measurement were used to monitor this system with an alarm threshold of 11 dB (as described above), only the conditions with low loss cables show an alarm for antenna conditions that are clearly out of spec. The conditions where an out-of-spec antenna goes undetected are highlighted in the table. Of particular note is the condition with a 7 dB cable loss where **the measurement shows an antenna that is in spec, even if the antenna is shorted or missing entirely!**

Where the loss of the distribution interconnect is significant, using a VSWR or any other form of match measurement is **not** reliable.

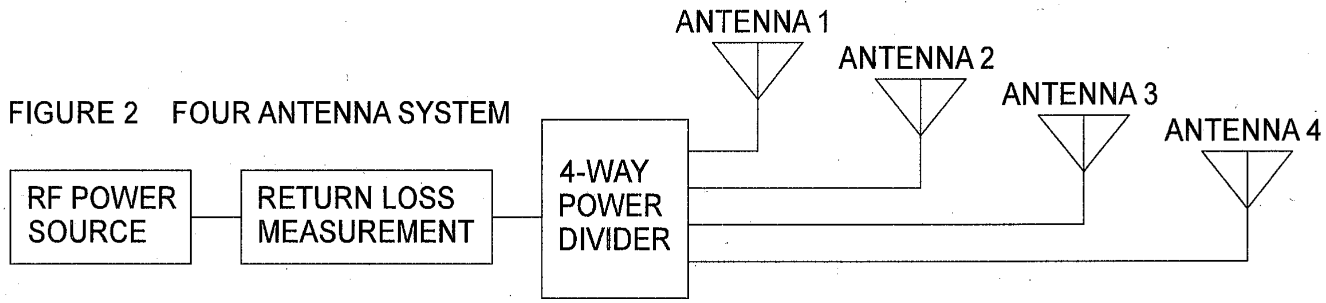
TABLE III
RETURN LOSS MEASUREMENT vs CABLE LOSS and ANTENNA MATCH

ANTENNA MATCH RETURN LOSS in dB	CABLE LOSS dB							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	RET LOSS	**RET LOSS**	**RET LOSS**	**RET LOSS**	**RET LOSS**	**RET LOSS**	**RET LOSS**	**RET LOSS**
0 (open or shorted) (below threshold)	0 dB	2 dB	4 dB	6 dB	8 dB	10 dB	12 dB	14 dB
6 (below threshold)	6 dB	8 dB	10 dB	12 dB	14 dB	16 dB	18 dB	20 dB
10 (below threshold)	10 dB	12 dB	14 dB	16 dB	18 dB	20 dB	22 dB	24 dB
14 (in spec)	14 dB	16 dB	18 dB	20 dB	22 dB	24 dB	26 dB	28 dB

ANTENNA SYSTEMS (MULTIPLE ANTENNAS)

Antenna systems are often built that include multiple antennas, whether in phased arrays or in distribution networks where full area coverage cannot be achieved with a single antenna. Whatever the application, the principles are similar: RF energy from a power source is split into different paths by the use of power dividers (splitters or tappers) and the individual antennas are driven from the outputs of the power dividers (splitters or tappers). Figure 2 depicts such a system that uses a 4-way power divider to drive four antennas. As in Figure 1, we have a Return Loss Measurement placed just after the power source to monitor the system. A four-way power divider has a nominal loss of 7 dB, such that the return loss measurement can never be lower than 14 dB and the system will never show an alarm condition. This is, in fact, the same situation as shown for the 7 dB loss in Table III where **any one of the antennas in the system could be shorted or missing without showing an out-of-spec condition.**

FIGURE 2 FOUR ANTENNA SYSTEM



If we were to use a more complex system, including cable losses, with more power splits, and a higher number of antennas, the problem would become more severe in that there could be more undetected failures. For example, a distribution system could be made up of a combination of splitters, tappers, and cables an example of which is depicted in Figure 3. This is a structure using tappers and a power divider and was designed to yield similar output levels on all antennas. The power loss through the system is shown at various points in the distribution chain and at each antenna. (In the interest of simplicity, cable losses have been ignored.) If we were to implement this system in the lab, we could remove each antenna, one-by-one, and verify that the power at each antenna is as predicted. While doing this test, we could measure the return loss while the antenna is disconnected. In the case of Antenna 1, the return loss would be twice that of the loss, or 20 dB; In the case of Antenna 2, the return loss would be 21 dB; In the case of Antenna 3 it would be 18 dB; and so on, where the complete removal of any antenna in the system would still yield an exceptionally good return loss. Although we have ignored the cable losses in this simplified analysis, the effect of the additional system loss would only serve to provide additional isolation between the system measurement and the individual antennas.

Regardless of the circuit geometry, a system return loss measurement will be masked by twice the loss of the distribution loss to the antenna in question, so that as the size of the antenna distribution network increases, **a system return loss/VSWR measurement becomes completely ineffective in measuring the integrity of the complete network.**

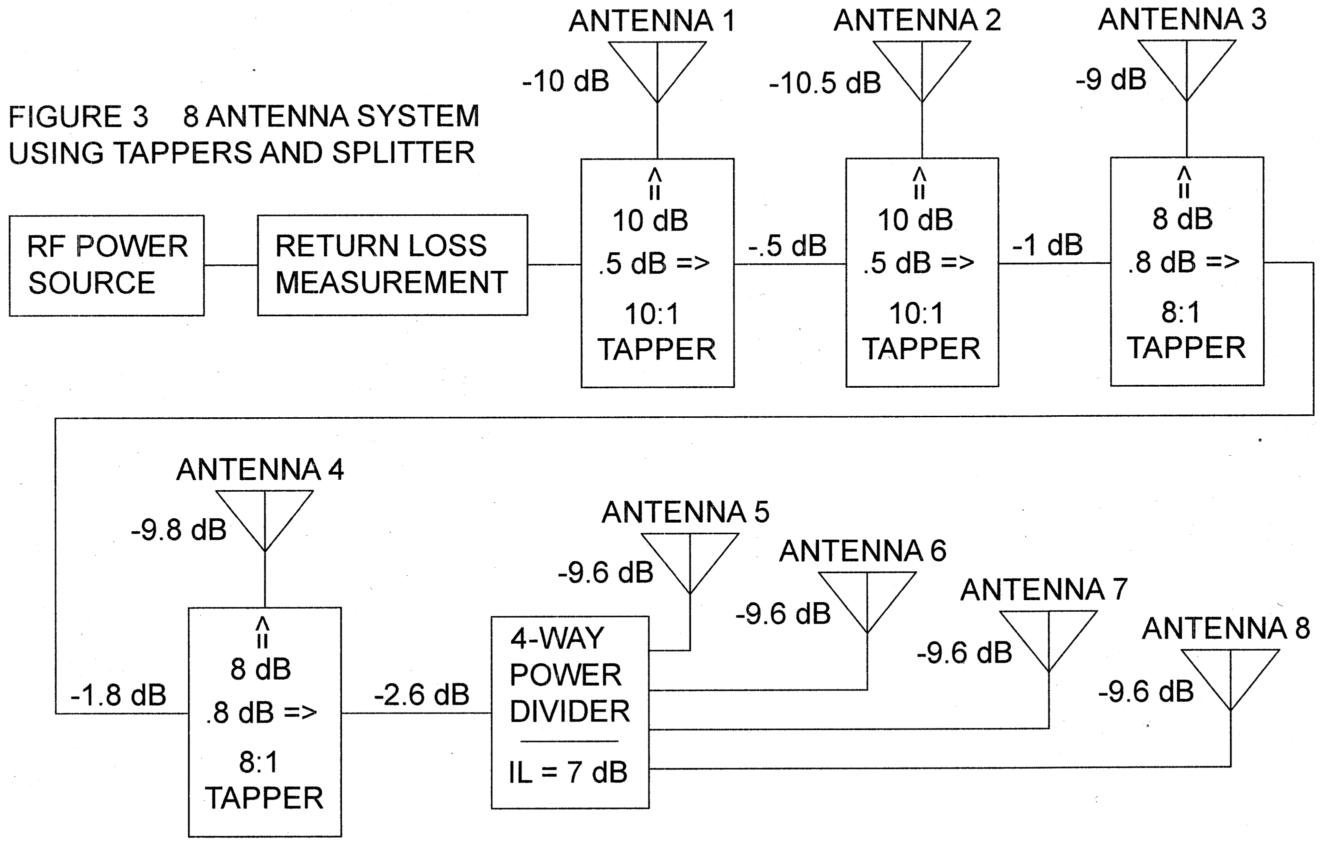


FIGURE 3 8 ANTENNA SYSTEM USING TAPPERS AND SPLITTER

CONCLUSION

VSWR, or matching, is a well-understood attribute of RF circuits. While the above discussion is idealized and ignores the additional measurement ambiguities of phase interference generated by imperfections throughout the system, it should give a good understanding of how match is measured using return loss, and how return loss relates to efficiency and to VSWR. Using the concept of return loss, we have seen how the RF losses in an antenna system can mask a return loss measurement and make it unsuitable for measuring the integrity of an antenna system.