Chapter 5

Low SWR for the Wrong Reasons

Sec 5.1 Introduction

I made the statement in Chapter 1 that misconceptions concerning SWR and reflections are prevalent among amateurs, both in print and on the air. So I reiterate, this book was written with one primary goal in view—to identify some of the misconceptions and to clarify some of the confusion resulting from the misconceptions.

One outstanding area of confusion concerns the nature of reflected power and how it is accounted for in the circuit. In short, is it *real* or *fictitious*, *reactive power*, and if it is real, where does it go? The nature of reflected power is discussed in Chapter 3, where it is shown why reflected power is real power not reactive. However, the understanding of this subject is so vital that an entire chapter, "The Reality of Reflected Power," Chapter 8, was written to present additional proof for those who still believe that reflected power is fictitious. And Chapter 4, in discussing the role of reflections in conjugate matching, I delved into the question of where the reflected power goes. I used the stub form of matching to illustrate the wave action that accomplishes the matching function, and that also derives the total forward power from the combined source and reflected power. Recall that learning of this wave action stripped away the mystery of how a mismatched load can absorb all of the power delivered by the source. We learned this as we saw how the reflected power adds to the source power at the conjugate match point so that the reflected power can be subtracted from the total, enlarged forward power at the mismatch point to leave a net power in the load equal to the source power, less only that lost in the due to attenuation in the line.

Now that we have established this relationship between the source, reflected, and forward powers in terms of the wave mechanics of the conjugate match, we have the necessary background for identifying some of the improper usage of SWR. We can also clarify in greater detail the reasons for the misunderstanding that still prevails concerning what happens to the power reflected from an antenna that is mismatched to its feed line. Further clarification of the misconceptions will enhance the appreciation of the mismatched feed line as simply a tuned, resonant impedance-transforming device, particularly as we see somewhat later how the transmatch type of feed-line matching network and the pi-network tank circuit of the transmitter perform the matching function in the same manner as the stub. Additional perspective in relating the discussion to practical feed-line operation will be gained as some of the thoughts presented in Chapters 1 and 2 are now expanded.

If it appeared that the importance of SWR was overly minimized or downgraded in the treatment accorded it in

Chapter 1, I did not so intend. The intent there was to focus attention on the importance of understanding the subject of reflection and SWR correctly and in such depth that we may retain complete control over them in our antenna system design engineering. Thus, instead of letting SWR become *king* to take control and deprive us of a breadth and flexibility of operation, we may use SWR in the system design choices in ways which many are unaware exist.

How many of us have acquiesced to "*King SWR*" in pruning an 80-meter dipole, taking great pains to obtain the best possible match to a λ/2 feed line at a specific frequency, and fearing to operate more than a few kilohertz from that frequency without worrying about the king's ominous threats of damage to our equipment? But how many are aware that King SWR can be outwitted and his consequences averted without pruning either the dipole or the feed line? And how many have been aware that the matching operation can be performed at the transmitter end of the line at any frequency within the entire 75-80 meter band without suffering any significant loss in power in spite of the SWR remaining on the feed line? Although it contradicts the word published in many articles during the past four decades, this revelation is true. This revelation indicates the flexibility or freedom that really is available in our choice of antenna systems designed for all the HF bands, simply by having a better understanding of SWR and reflection.

Sec 5.2 Valid Reasons for Low SWR

There are good and valid reasons for being concerned with SWR and reflection from both the amateur and commercial viewpoints — with this there can be no argument. As we well know, these reasons are concerned basically with voltage breakdown and power-handling capability, efficiency and losses, and with line-input impedance as it relates to transmitter output coupling. However, in amateur practice, power-handling capability and voltage breakdown don't become serious problems unless we try to shove the legal limit of power through RG-58 or RG-59 at a high SWR. Losses and efficiency concern us, but to a much smaller degree than is generally realized, and for a different reason than many are aware, as we'll see very shortly.

The chief reason why the amateur should be concerned but not alarmed with SWR is in its relation to line-input impedance and transmitter coupling. This is discussed in great detail in Chapters 6, 7 and 13. There we see how to tame impedance and coupling for any reasonable value of SWR, and in those discussions the relative *unimportance* of having a ***self****-resonant* antenna also becomes evident. But it is of great importance that we first clarify some of the prevalent misunderstandings of SWR and reflected power, because they are causing many amateurs to strive for a low SWR for the wrong reasons, often needlessly. Probably the most serious and widespread misconception concerning SWR prevailing throughout the amateur fraternity is the erroneous notion that there is a direct one-for-one relationship between reduction in reflected power and a resulting increase in radiated power. In other words, many believe that for every decreased watt of reflected power there is an additional watt of increased output. *Not so*, but the number of amateurs who have been misled to believe this invalid and unscientific premise is unbelievable.

Another related concept, popular, but also erroneous, is that, when terminated in a mismatch, the coaxial feed line becomes part of the radiator, causing radiation from the feed line because of the standing wave. (See Chapter 2, statement 18, and Chapter 20, Sec 20.4.) This is untrue because the line voltages and currents, and the standing wave resulting from the mismatch, are entirely contained in and between the outer and inner conductors, inside the coax. No standing wave develops on the outside of the coax because of impedance mismatch. However, feed-line radiation may result from standing waves on the outside of the coax because of current flowing on the outside, if a balanced dipole is fed without using a balun. This feed-line radiation may or may not be of any consequence, but the topic is covered well by McCoy *(Ref 45)*. (Also see Chapter 20 Sec 20.3 and 20.4, and Chapter 21.) There is also no radiation from tuned open-wire feeders, because the current is flowing in opposite directions in each wire; hence the fields developed by the current in each wire are canceled.

Misunderstanding of how the benefits accrue from a low SWR, and of just how little benefit is obtained, is driving many of us to attain SWR values far lower than where the benefits continue to be significant in relation to the efforts expended to attain them. It is for this reason that we often set an unrealistically low limit on allowable SWR that needlessly restricts the operating bandwidth — the range of usable frequencies on either side of the resonant frequency of the antenna — to a far more limited range than is necessary.

In rectifying a misunderstanding such as this, it often helps to first learn how the misunderstanding originated.

Sec 5.3 "Impedance" Bridges2

One aspect of the misunderstanding has been created to some extent by narrow, and often erroneous interpretations of matching principles found in various instructions for instruments such as noise bridges *(Ref 100)* and the antenna-scope for determining the terminal "impedance" of an antenna. Contrary to what is stated in some of the instruction manuals, these devices cannot measure impedance — they can measure resistance only — and then only in the absence of reactance.[1] Look up and compare the definitions of impedance and resistance; the term impedance is often misused when the correct term should be resistance *(Ref 46)*. Consequently, in using these devices we have been coerced into finding only the resistance component of the antenna terminal impedance, and only at the resonant frequency of the antenna, because this is the only frequency where the impedance has zero reactance, or $R + j0$.

In following this approach, erroneous emphasis has been given to requiring the antenna radiator itself to be resonant, thus nurturing the misconception that it needs to be self-resonant to radiate all the power being supplied to it *(Refs 100, 101)*. Thus, many have been misled to believe that the antenna just won't perform properly at any frequency except the self-resonant frequency. (See Chapter 2, statements 5, 6 and 7; *also Refs 20, 21, and 24.*) In addition, emphasis on the further necessity for obtaining an antenna-terminal resistance component equal to the line impedance Z_C has in many cases caused us to go to extreme measures, such as adjusting the antenna height above ground in small increments to achieve that precise resistance reading in quest of the perfect 1.0 match *(Ref 101.)* Also see Chapter 2, statement 15. Adjusting antenna heights in large increments to obtain control of radiation in the vertical plane is realistic. But controlling radiation resistance by adjusting the height is neither necessary nor practical, because the efficiency thought to be gained through this action is illusory.

The truth of this will become evident somewhat later as we see why there is no justification for expending any matching effort at the load, or antenna, to improve a mismatch of 2:1 or less, simply to remove the standing wave with the expectation of improving efficiency. (See Fig 6-1.) Furthermore, because of the reactance that appears as we depart from the resonant frequency of the antenna, the sacred but overrated perfect match found at some carefully adjusted height can be obtained at only one frequency without retrimming the radiator length, thus continuing the vicious cycle. However, the widespread practice of this philosophy in antenna-system operation has conditioned us to think only in terms of using a $\lambda/2$ transmission line with no reflections, and to obtain its perfect 50-ohm non-reactive input impedance by operating only at the resonant frequency. So we have, in effect, been deterred from learning of the real effect of reactance in antenna impedance, and how the transmission line transforms any antenna impedance in a straightforward and predictable manner for use at the line input.

In becoming so conditioned, many of us have forgotten that we can obtain the

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2 [AUTHOR'S NOTE: The original QST text from which this chapter is adapted was written before noise bridges were constructed with the capability of measuring reactance.]

desired 50-ohm non-reactive input impedance from the line-transformed antenna impedance with a simple line-input matching network in the shack, much more easily than it can be obtained at the antenna. In fact, with most tube transmitters the impedance seen by the transmitter at the input of the feed line for SWR values in excess of 2:1 can be matched for optimum loading by adjustment of the transmitter tank circuit itself. If a transmitter does not contain sufficient matching range, a separate line-matching network (antenna tuner) between the transmitter and line input offers a more judicious matching arrangement than playing games out at the antenna. Chapter 6 explains why there are many situations where this same matching approach should be considered when the load mismatch yields SWR values of even 5:1 or higher, as one departs from the self-resonant frequency of the antenna.

One further misconception exists that has also resulted in needless and unwarranted reliance on the $\lambda/2$ feed line to repeat the resonant antenna resistance at the transmitter. This one concerns the effect of line-input reactance on tank-circuit resonance when the line with reflections is fed directly by the pi network. Consider a tank circuit which is first loaded and tuned to resonance with a resistive load, and then when the load is changed to one containing reactance. If the tank components have sufficient retuning range to compensate for the reflected reactance to return the circuit to resonance at the same load level, all is well, because the tubes still see the same resistive load as before. The misconception about this point has been generated by some writers who apparently don't understand resonant circuits, for they proclaim that the retuning 'introduces' reactance that detunes the circuit, causing improper loading and increasing plate current and dissipation. Wrong! Chapters 7 and 13 contain much more detail on this point.

Sec 5.4 Low SWR for the Wrong Reasons

We have discussed "low SWR for the wrong reason," as practiced (often unwittingly) in using the perfectly matched antenna operated only at the self-resonant frequency of the radiating element. But another wrong reason for desiring a low SWR is interpreting feed-line SWR as the sole indicator of the quality of an antenna's radiating performance across a band of frequencies, with low SWR across the band getting the raves and high SWR getting the boos. This is a definite misuse of SWR information, because there are cases where the low and high SWR values occur in just the opposite relation, with respect to indicating antenna efficiency over a given bandwidth. Reasons for this are given shortly. As a result of this misuse of SWR values, *good* antennas are too frequently rejected as "bad" because the feed-line SWR swings relatively high, and *poor* antennas are accepted as "good" when the SWR remains relatively low.

In most cases the use of feed-line SWR alone to indicate antenna efficiency is invalid, because SWR indicates only *the degree of mismatch*, not efficiency. However, we will see presently how a relative change in SWR, to a value either lower or higher than a previous value known to be correct in a given antenna system, can indicate that a possible undesirable change has occurred somewhere in the system. That change may affect its radiating efficiency. For example,the popular vertical antenna having from two to four ground radials (an insufficient number for efficient operation), or perhaps having only a buried water pipe or a driven rod for a ground terminal, is one case where a lower-than-normal SWR obtained over a frequency range indicates a poor quality of radiating efficiency, rather than a good one. But conversely, improving the ground system by adding a sufficient number of radials can increase the radiating efficiency to nearly 100%, and this improvement is accompanied by a *significant* ***increase*** *in SWR readings* over the same frequency range to higher values, which are the normal or expected values. With an adequate ground system, the SWR is predictable over the frequency range, because a load impedance of any specific $R + jX$ value yields an exact value of SWR on a given feed line, and because we can determine approximately what the antenna impedance should be at whatever frequency we may wish to use. (Ref 2, Fig 2-7; Refs 47, 48, 49 and 58; Ref 71, p 2-6). But when the ground system is inadequate there is an unknown ground-loss resistance added to the known antenna impedance, which changes the SWR to some lower and unpredictable value. Yet, without being aware of these facts, we often tend to be happier in the discovery of an unsubstantiated low SWR than we are in determining whether we have SWR values that *should* be obtained with the existing configuration. This is a very important concept that requires a clear understanding if we are to avoid misinterpretation of SWR data in our effort to optimize radiated power.

It will help in understanding this concept if we have a clear physical picture of how the ground-loss resistance develops. Still another misconception exists here, this one concerning the current and field behavior in the vertical-over-ground antenna system. Most of us know that conventional grounding techniques used for lightning protection, such as rods or pipes driven deeply into the ground, provide an excellent low-resistance current path for the lightning current (dc). Many are unaware, however, that these techniques are totally inadequate for conducting the entirely different pattern of current flow with the vertical antenna system.

Sec 5.5 Vertical Radiator over Earth

Let us digress a moment for a brief look into the field and current behavior of the vertical antenna system, to see what type of ground system is needed to meet the requirements of a proper current-flow pattern. Consider a base-fed vertical antenna as shown in Fig 5-1. One terminal of a generator is connected to the base of the vertical radiator and the other generator terminal is connected to ground, just below the base of the radiator. During the half cycle in which the conduction current in the antenna flows upward, all the current returns to ground through displacement currents, which follow the lines of force in the RF electric field through the radiator-to-ground capacitance, as shown in Fig 5-1.

The electric field surrounding the antenna, which excites the displacement currents, fills the entire volume of space surrounding the antenna in the shape of an oblate or somewhat squashed hemisphere. This hemisphere intersects the ground to form an imaginary circle having a radius of slightly over 0.4λ for radiators of $\lambda/4$ in electrical height. This radius defines the distance from the antenna at which the returning displacement currents become insignificant, and don't justify radials of greater length. The radius decreases as the height of the radiator decreases, because the size of the hemisphere surrounding the antenna decreases. Also, radials in or on the ground have no resonance-versus-length charac-

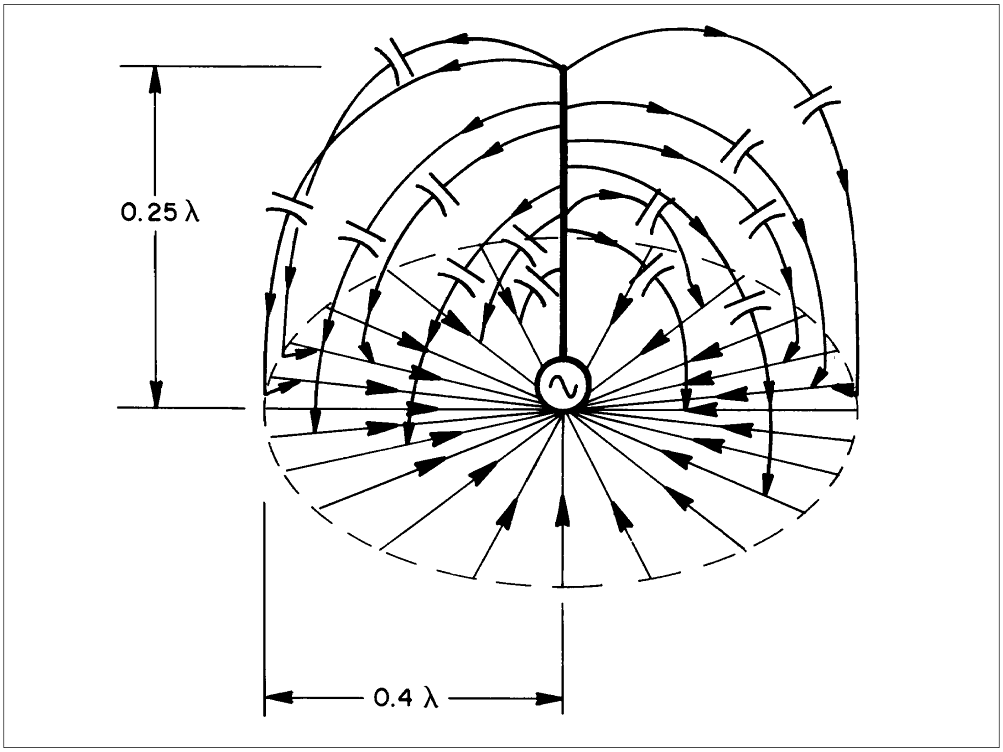

Fig 5-1—The hemisphere of displacement current that flows as a result of the capacitance of a (/4 vertical radiator to the earth or a radial system. At frequencies above 3 MHz, RF currents flow primarily in the top few inches of soil, as explained in the text. Ground rods are of little value at these frequencies, and spikes or large nails are sufficient to secure the outside end of each radial wire. With a sufficient number of radials, annular wires interconnecting the radials offer no improvement in antenna efficiency, as the current path is radial in nature.

teristic; when outward-flowing current reaches the end of the radial, it continues flowing in the ground instead of going to zero and becoming reflected to flow in the opposite direction, as it does in elevated radials. The displacement currents enter the ground *everywhere over the entire surface within the circle* and then flow back radially to reach the grounded generator terminal. So to repeat for emphasis, ground radials are *not resonant*. Although some of the current penetrates somewhat more deeply, most of the current flow at frequencies above 3 MHz is restricted by skin effect to the upper few inches of the ground.

Now a ground system comprising only a simple water pipe or a driven rod or two is simply a terminal — the ground-feed terminal of the antenna system. So all the returning currents using this arrangement must flow entirely through the poorly conducting ground from all directions everywhere within the circle to reach the terminal. This ground system is often measured to have an “acceptably low” resistance *at dc* (which may be satisfactory for lightning protection), but it injects a loss resistance in series with the antenna *at RF*. The RF ground resistance often exceeds the radiation resistance of the antenna itself! Adding a few wire radials to the system provides good conductivity toward the ground terminal for the currents which reach those radials. However, only a tiny amount of the total current entering the earth’s surface inside the circle is intercepted by these few radials.

Thus, all the remaining currents still flow only through the lossy earth, and the result is that we still have a high loss resistance.

If a sufficient number of equally spaced radials (90 to 100) extending out to 0.4λ is present to intercept all the current, all the returning displacement currents find highly conductive paths everywhere within the circle, which lead the currents through negligible loss resistance directly back to the ground terminal of the generator. This can be visualized by examining Fig 5-1. Currents which enter the ground between the closely spaced radials quickly diffract to a radial wire, and thus travel only a short distance through lossy earth before reaching a good conductive path. Thus, with a sufficient number of radials, we have a nearly perfect ground system, which adds only a negligible amount of resistance to the true antenna impedance measurable between the base of the radiator and the ground terminals *(Refs 20, 50, 51 and 57)*. From this we can see why the lightning-type ground system, although in prevalent use, is unsatisfactory for an efficient antenna system *(Ref 57, p 82)*.

I am not suggesting that λ/4 antennas with less than ideal ground systems should not be used, nor that fair results cannot be obtained without their use. But the difference between no radials, or only 3 or 4 compared to 100, can amount to over 3 dB. This is far in excess of the loss resulting from an SWR of 4:1 or 5:1 on the average coaxial feed line used by amateurs. The point made here is that the value of ground resistance is unknown and unpredictable in systems using less than an adequate number of radials. This makes the resulting SWR readings unpredictable and therefore useless for the purpose of evaluating the quality of the system, unless some means is available for determining what the change in SWR would be if the loss resistance could be switched in or out.

In practical amateur installations, the ground resistance is sufficiently low if only 40 to 50 radials are used with a λ/4 radiator. The small improvement in radiated power for the addition of still another 40 to 50 radials with the λ/4 radiator probably does not justify the extra cost and effort. However, if a *short* vertical antenna (from λ/8 or less to λ/4 is contemplated, remember that the radiation resistance decreases as the radiator is shortened. The ground resistance then becomes a larger part of the total resistance, decreasing the efficiency. Thus, the ground resistance should be kept as low as possible for the full capability of the short antenna to be realized *(Refs 51, 56 and 57)*. There is practically no difference between the radiation capabilities of the λ/4 antenna and a radiator even shorter than λ/8, except for the effect of ground resistance and the loss in the resistance of the inductance coil used to cancel the capacitive reactance in the terminal impedance of the shortened antenna. The professional literature is replete with references confirming this point *(Refs 20, 52 and 53)*.

Sec 5.6 Resistive Losses and SWR

In this section I discuss how any additional resistive losses that are separable from the true antenna impedance affect the true load SWR. By separable I mean such losses as ground-loss resistance, corroded connectors and other poor connections, cold-solder joints, and so on. These all contribute loss resistances that we can control or reduce. In contrast is the resistive component of the antenna terminal impedance, which comprises both the radiation resistance and the inherent conductor-loss resistance in the radiating element. In most cases the conductor-loss resistance in practical radiating elements is negligible, unless excessively small wire is used. There are several useful relationships between load impedance $Z_L = R + jX$, line impedance, Z_C, and SWR. For example, it is well known that when the load impedance is a pure resistance R, equal to the line impedance Z_C, the reflection coefficient (is zero, and the standing-wave ratio is thus one to one. But the reflection is no longer zero and the SWR becomes equal to the ratio R/Z_C when the resistance is larger than Z_C, or Z_C/R when the resistance is smaller than Z_C. It is also well known that ρ and SWR increase with the addition of any reactance component in the load impedance that increases the total reactance, whatever the resistive component may be. This relationship may be verified by observing Eq 3-1. And as noted previously, any combination of R + jX yields an exact value of SWR when terminating a line of given impedance Z_C. We also know that the reactance X appearing in the impedance at the terminals of an antenna contributes more to the rise in SWR at frequencies away from antenna resonance than the change in the antenna resistance. This is because the reactance changes more rapidly than the resistance during the change in frequency, and because no power is absorbed in the reactance.

However, there is an interesting relationship between the resistance and reactance components of a load impedance which is not generally well known. This relationship sheds light on how these two impedance components affect mismatch reflection and SWR, and it also explains why the unknown ground resistance and other losses mentioned above reduce the usefulness of SWR readings. When reactance is present in the load impedance, the minimum possible SWR occurs when the resistance R is greater than Z_C. The value of the resistance that yields the lowest SWR in combination with a given value of reactance in the load, which I call the minimum-SWR resistance, is dependent solely on the reactance present in the load. This value may be obtained from the relationship

$$r = \surd X^2 + 1 \qquad \text{(Eq 5-1)}$$

where

r and x are normalized to the system Z_C

r = minimum-SWR resistancex = reactance present in the load

(For more information concerning Eq 5-1 and its proof, see Chapter 11 and Appendix 1 in Chapter 23.) It can be seen from Eq 5-1 that when x becomes zero, r = 1, for an SWR of 1:1. But it is interesting to know that the resulting SWR *always equals exactly* the arithmetic sum of the minimum-SWR resistance value r, and the reactance value, x. This interesting relationship is shown in the following expression

$$SWR_M = r + x \qquad \text{(Eq 5-2)}$$

where

SWR_M = SWR obtained with the minimum-SWR resistance

r = the normalized minimum-SWR resistance

x = the normalized reactance

The relationship shown in Eq 5-2 can help us to understand how unwanted loss resistance, separable from the true antenna-load impedance, affects SWR. In the case of the vertical radiator over earth, the unpredictable ground losses change the SWR from a predictable value, based on known available antenna impedance data *(Ref 48, p 176)* to some unpredictable and usually lower value. A general application of the relationship is presented in the following statements. When the resistance component of the true load impedance is lower than the minimum-SWR resistance, as determined for any reactance component also present in the true load, adding of resistance separate from the true load impedance will cause the SWR to decrease from the value obtained with the true load resistance. This is true until the total resistance is equal to the minimum-SWR resistance. The further addition of resistance will cause the SWR to rise again. These statements apply especially to the vertical antenna of $\lambda/4$ heights or less in proving why ground resistance which reduces the efficiency also reduces the SWR. This is because the true antenna resistance component, R, is generally less than the impedance, Z_C, of normally used feed lines, while the minimum-SWR resistance, R, is always equal to or greater than Z_C.

The effect of reactance in the antenna impedance raises an additional factor of importance in understanding the relationship between SWR values and antenna performance. As stated earlier, the rate at which the SWR rises as the operating frequency departs from the resonant frequency of the antenna depends on the resulting change in the impedance at the antenna terminals, which in turn is dependent on the Q of the antenna. One factor that has a primary influence on antenna Q is the amount of capacitance between the opposite halves of the dipole. (Although it is more commonly called a monopole, a vertical antenna over ground can also be considered as a dipole, because the lower half is simply the image of the upper half, with the opposite polarity.) This dipole capacitance is determined by the ratio of the radiator length L, to its diameter D, the well-known L/D ratio.

The L/D ratio found in the usual simple thin-wire dipole is very high, resulting in a low dipole capacitance and high Q. When the frequency is changed with such an antenna, rapid changes in impedance, reflection, and SWR result. This is why a thin-wire dipole is considered a narrow-band device. However, specific broadbanding steps may be taken to increase the dipole capacitance and thus reduce the Q, thereby reducing the rate of change of SWR. One such step, for example, is decreasing the L/D ratio by using a multiwire cage configuration for each dipole half, or by fanning out multiple wires from the feed point. Curves of SWR versus frequency are valid here in comparing bandwidths obtained while you experiment with different radiator configurations. However, any separable loss resistance must now be either minimized or held constant to prevent it from introducing unknown variables. Otherwise, the unknown variables can cause differing errors in the SWR readings obtained with different configurations, and thus render the results of the experiment invalid. But unless actual broadbanding steps have been taken to reduce the Q, the rate of change in SWR as frequency changes will not differ dramatically between various types of dipoles having roughly equivalent values of Q. These types include the inverted-V dipole. If a dramatic difference is noted with no *valid* broad-banding steps having been taken, troubleshooting is called for to determine the cause. More than likely some unwanted loss resistance will be flushed out, if this is the case.

I have seen SWR curves published with descriptions of quite simple antennas, where it would have been impossible for the SWR to remain as low as indicated over the frequency range shown — the Q of the antenna configuration shown would have simply been too high. Two possible explanations for this sort of contradiction are that (1) perhaps the readings were obtained from an inaccurate SWR indicator — many read on the very low side *(Refs 40, 54)* or (2) as suggested above, an unrecognized trouble existed somewhere in the antenna system which was lowering the Q by means of a separable loss resistance. Yet these articles were published because the antennas they described were purported to have "improved SWR characteristics." How many times have you heard someone praise his newly hung skywire by simply telling how low the SWR indicator reads across an entire band? It should now be clear, and it cannot be emphasized too strongly, that an unrecognized and unwanted loss resistance in an antenna system can cause a low SWR reading when *it should not be so low.* So in Chapter 6 we will explore the relationship between antenna impedance and SWR in detail so that we may determine what is a proper SWR for given conditions.

Sec 5.7 Reflected Power and SWR

Let us now return to the subject of why we worship low SWR for the wrong reason. As stated earlier, the misunderstanding of this aspect of reflected power is based primarily on the prevalent, but erroneous, notion that any reduction in SWR or reflected power effected on a line feeding a mismatched antenna results in a direct one-for-one increase in radiated power. The erroneous reasoning behind this notion is in the assumption that if power is being reflected by a mismatched load, it cannot be absorbed in the load or radiated, and that the reflected power returns to be lost to dissipation in the transmitter. This assumption is false on both points, for the truth is, except for the power dissipated in the line itself because of line attenuation, *all* of the power delivered to the line by the transmitter is absorbed in the mismatched load. This is true because the power reflected from the mismatch is conserved and returned to the load by re-reflection from the line-input matching circuitry, the antenna tuner, in accordance with the principles discussed in Chapter 4.

In light of the above statement, let us consider a lossless line for a moment. Adhering to the Law of Conservation of Energy, Here it is axiomatic that if all power delivered to the line is already being absorbed in the load (because none can be absorbed in a lossless line), a reduction of the reflected power cannot have any effect whatever on the amount of power taken by the load. And, obviously, there is no power left over to be dissipated in the transmitter.

Following this same reasoning in a real line having attenuation, *all losses in power* must be attributed to the basic I^2R and E^2/R losses arising from attenuation due to line resistance. These losses are unavoidable, even when the load is perfectly matched. The only *additional losses in power* that can be attributed to SWR or reflection occur because the same resistive attenuation is encountered by the reflected power as it travels back along the line from the load to the input. The amount of power lost in this manner is very small at frequencies in the HF range when good-quality, low-loss line is used. This is because during its return to the input, the reflected power suffers only the same amount of line-attenuation loss as the forward power suffers in its forward travel toward the load. And as stated previously, all the reflected power which arrives back at the input now becomes part of the forward power due to total re-reflection at the input.

Another way of explaining the relationship between SWR and lost power is to recall from Chapters 3 and 4 that, because the forward power is the sum of the source and reflected powers, the forward power is greater than the source power whenever the SWR is greater than 1.0. Thus, for a given source power, the resistive losses are somewhat higher in the portion of line where the forward power is higher than the source power, simply because the average line current I and voltage E are higher in that portion of the line.

So from this discussion concerning improper usage of SWR data, we learn that from the viewpoint of efficiency, our concern for SWR involves only the loss from line attenuation. Hence, we can tolerate a higher SWR when the attenuation is low, but when attenuation is high the SWR limit must be lower for the same amount of additional power lost from SWR. The exact relationship between SWR and line losses for different values of line attenuation is shown graphically in Figs 1-1 and 6-1. From these graphs we can easily see that the amount of power actually lost is in sharp contrast to the amount mistakenly assumed to be lost in the improper concept of SWR, where it is thought that a reduction in SWR or reflected power results in a direct equivalent decrease in the amount of power lost in the system.

There is a certain twist of irony behind these various misunderstandings of reflections that have prompted the wrong interpretation or usage of SWR. The irony is that the correct reasons why SWR should be considered are frequently overlooked in the wrong usage, while the basis so generally accepted in support of the wrong usage doesn't even exist in the coupling methods used by amateurs to transfer power from the transmitter to the antenna. A part of this obtuse logic seems to have originated from the confusion among both amateurs and engineers in the meaning of "a matched generator." To some it means being matched in only one direction, and to others it means being matched in both directions. A "matched" signal generator is generally considered to be Z_0 matched, or matched to the line impedance in both directions. However, in transmitter operation, the match is in one direction only — forward — because of the total re-reflection of the load-reflected wave by the matching circuitry at the input to the transmission line. This subject is treated in great detail in Chapters 6, 7, 16, 17 and 19.