The Great SWR Myth

Why a perfect SWR does not mean you have a good antenna

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Far too often, I am asked for assistance because a new amateur radio operator—and sometimes even an experienced operator—is extremely frustrated with the performance of their antenna system. They proudly explain that their antenna has an SWR of 1.2:1, 1.3:1, or perhaps even a perfect 1.0:1. Yet they struggle to make contacts, cannot reach stations that others are working with ease, or simply cannot hear the signals they believe they should be hearing.

Their frustration is understandable. Somewhere along the way, they were taught, or developed the impression, that a low SWR automatically means they have a good antenna. **Nothing could be further from the truth.** SWR is important, but it is only one small piece of the antenna performance puzzle.

1. What exactly is SWR?

Standing Wave Ratio describes how well the impedance of a load matches the characteristic impedance of the transmission line. Most modern amateur equipment is designed for 50 ohms. When a mismatch exists, some forward-traveling RF energy is reflected. The interaction of forward and reflected waves creates standing waves. An SWR meter measures their relationship, not how much energy is radiated.

SWR	Reflected power	Power accepted at load
1.0:1	0.00%	100.00%
1.1:1	0.23%	99.77%
1.2:1	0.83%	99.17%
1.3:1	1.70%	98.30%
1.5:1	4.00%	96.00%
2.0:1	11.11%	88.89%
2.5:1	18.37%	81.63%
3.0:1	25.00%	75.00%
5.0:1	44.44%	55.56%

SWR	Reflected power	Power accepted at load
10.0:1	66.94%	33.06%

These percentages apply to forward power at the measurement plane. Reflected energy can be re-reflected toward the load. The difference between 1.2:1 and 1.5:1 is small: about 0.14 dB of mismatch loss alone. Spending hours chasing a perfect match may accomplish virtually nothing measurable at the receiving station.

2. The dummy load: the perfect example

A good 50-ohm dummy load provides an almost perfect 1:1 SWR across its rated frequency range. Connect a 100-watt transmitter and transmit. Your radio, SWR meter and amplifier are happy. But how many contacts will you make? Virtually none! The dummy load converts nearly all RF energy into heat rather than radiating it. The meter cannot tell the difference. **An SWR meter is not an antenna efficiency meter.**

3. Where does your transmitter power go?

Power can be lost in feed lines, connectors, loading coils, matching transformers, ground systems, antenna conductors, nearby materials and tuners. Power dissipated as heat is no longer available to radiate.

Measurement	Antenna A	Antenna B	Antenna C
Transmitter power	100 W	100 W	100 W
SWR at antenna	1.1:1	1.5:1	1.0:1
Feed line loss	3 dB	0.5 dB	1 dB
Radiation efficiency	25%	90%	5%
Radiated power	12.5 W	77 W	4 W

These simplified examples assume specified forward power, matched-line attenuation and no recovery of reflected power. Antenna B has the highest SWR but radiates far more power. Antenna C has a perfect match and radiates only about four watts.

4. Radiation resistance and loss resistance

Radiation resistance represents energy radiated as electromagnetic waves. Loss resistance represents energy dissipated as heat. An ordinary analyzer cannot separate them by measuring input impedance. At resonance, efficiency equals radiation resistance divided by total resistance. A 50-ohm antenna with 45 ohms radiation resistance and 5 ohms loss is 90% efficient; another with 5 ohms radiation resistance and 45 ohms loss is only 10% efficient. Both show 1:1 SWR. The difference is about 9.5 dB if their patterns are identical.

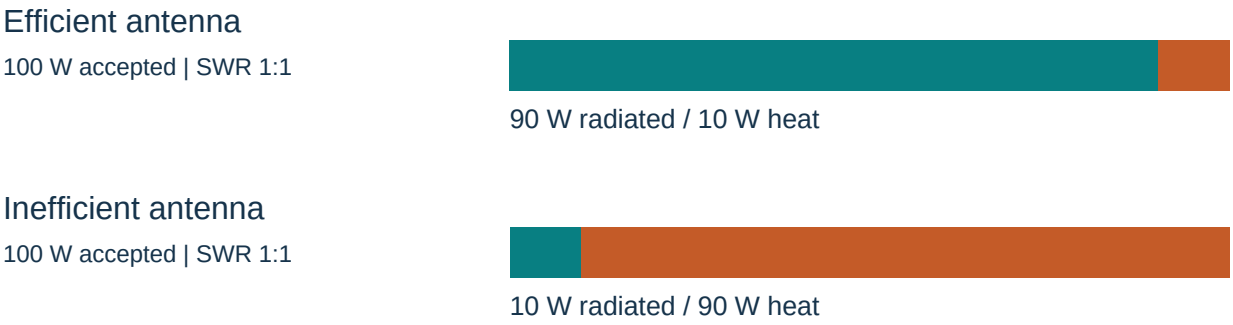


Figure 1. Identical impedance matches, dramatically different radiation efficiencies.

5. Resonance and low SWR are not the same

Impedance consists of resistance (R) and reactance (X). An antenna is resonant at its feed point when net reactance is zero. Its resistance need not be 50 ohms.

Impedance	Resonant?	50-ohm SWR
50 + j0 Ω	Yes	1.0:1
73 + j0 Ω	Yes	1.46:1
25 + j0 Ω	Yes	2.0:1
100 + j0 Ω	Yes	2.0:1
50 + j25 Ω	No	1.64:1

A conventional resonant half-wave dipole in free space has approximately 70–73 ohms feed point resistance. An SWR near 1.5:1 is perfectly normal. A resonant Yagi may require a matching network because its driven element impedance differs from 50 ohms. Neither is necessarily a poor design.

6. Feed line loss: the silent performance killer

Every foot of coax introduces attenuation, generally increasing with frequency. This is especially important on VHF, UHF and microwave bands. A 3 dB loss removes half the power; 6 dB removes three-quarters; 10 dB removes 90%. Feed line loss affects reception as well as transmission. A shack amplifier cannot restore signal-to-noise ratio lost ahead of the receiver.

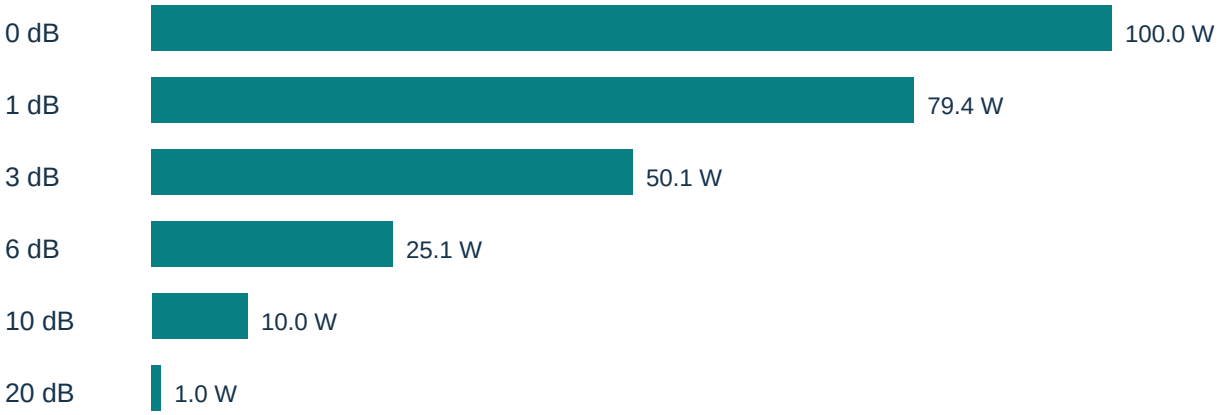


Figure 2. Power reaching a matched antenna from a 100-watt transmitter.

Loss	Power reaching matched antenna
0.5 dB	89.1 W
1 dB	79.4 W
2 dB	63.1 W
3 dB	50.1 W
4 dB	39.8 W
6 dB	25.1 W
10 dB	10.0 W
20 dB	1.0 W

How bad coax can improve your SWR

An antenna with a true 3:1 SWR connected through coax with 6 dB one-way matched-line loss may show about 1.29:1 in the shack. Reflections are attenuated on the return trip. The meter is accurately measuring the smaller reflection that survived the cable. Water intrusion, corrosion and dielectric deterioration can produce this effect. If SWR suddenly improves without adjustment, investigate rather than celebrate.

7. Why antenna size matters

Physical size relative to wavelength affects efficiency. Electrically short antennas often require loading coils, capacitive loading or matching networks. Their radiation resistance may be low, so even small losses become significant.

Band	Half-wave dipole	Quarter-wave vertical
160 m	246 ft	123 ft
80 m	125 ft	62 ft
40 m	66 ft	33 ft
20 m	33 ft	16.5 ft
10 m	16.4 ft	8.2 ft
6 m	9.3 ft	4.7 ft
2 m	38.5 in	19.2 in
70 cm	12.9 in	6.5 in

Dimensions are approximate starting points and depend on frequency, construction and surroundings. An eight-foot vertical advertised for 80 through 6 meters can be matched on 80 meters and make contacts, but generally will not equal a well-installed full-sized antenna. Short antennas can be useful for mobile or space-restricted operation. A successful contact alone does not establish efficiency; favorable propagation can allow very low power to travel great distances.

8. The ground system: the other half of a vertical

A conventional quarter-wave ground-mounted vertical depends on a suitable RF return path. Suppose radiation resistance is 36 ohms and ground and conductor losses total 14 ohms. The resulting 50-ohm match is perfect, but efficiency is 72%. Reduce losses to 2 ohms and efficiency rises to about 95%, while SWR increases to 1.32:1. The antenna got better, not worse.

• Install additional or longer ground radials where appropriate.

• Repair corroded radial connections; use a suitable elevated radial system if designed for it.

• Improve RF bonding in mobile installations and avoid lossy obstructions.

An RF radial system is not the same as electrical safety grounding. A single ground rod generally is not an effective substitute for HF radials. Not every vertical design requires external radials.

9. Height, location and radiation pattern

HF antennas

A low horizontal dipole may radiate strongly at high elevation angles, useful for regional NVIS (Near Vertical Incidence Skywave) communication. A lower radiation angle may be better for long-distance DX. Neither antenna is necessarily defective; the patterns differ.

VHF and UHF

Height, terrain, obstructions and polarization are critical. An antenna in an attic, behind a metal building or below surrounding terrain may disappoint despite low SWR. A horizontally polarized weak-signal SSB Yagi may perform poorly with a vertically polarized FM station. Cross-polarization losses of 10–30 dB or more are possible, although reflections can reduce them.

Directional antennas

Evaluate forward gain, front-to-back ratio, beamwidth, side lobes, polarization and efficiency. Adjusting Yagi elements solely for lowest SWR can compromise gain and pattern. Follow the design specifications and intended matching adjustments.

10. Understanding antenna gain

Gain describes how effectively an antenna concentrates radiated energy in a direction, accounting for radiation efficiency. A flashlight reflector concentrates light without creating more light; a directional antenna works similarly. Gain in dBi is referenced to an isotropic radiator; dBd is referenced to a half-wave dipole. 0 dBd equals about 2.15 dBi. Compare advertisements using the same reference and distinguish modeled gain from installed performance. Low SWR does not guarantee high gain.

11. Common-mode current: is your coax part of the antenna?

Unwanted RF current on the outside of the coax shield can distort patterns, increase household noise pickup, cause RF feedback and interference, and make SWR change when the coax moves. A suitable current balun or common-mode choke can help. A 1:1 current balun is often useful on a coax-fed dipole. Some antennas intentionally use part of the feed line as a counterpoise, so choke placement matters. Do not simply cut coax until the meter looks favorable. Investigate common-mode current and feed line faults.

12. Troubleshooting a poorly performing antenna

Step 1: Verify the radio

Connect a known-good, properly rated 50-ohm dummy load. Verify output with a suitable power meter. Check power settings, supply voltage under load, amplifier, antenna port, attenuator, preamp, receiver sensitivity, switches, filters and accessories.

Step 2: Bypass the tuner

Remove or bypass the tuner to see the actual antenna system impedance. Use low power or an analyzer. Never connect an analyzer to an energized transmitter.

Step 3: Sweep the band

Use a RigExpert or NanoVNA to record minimum SWR, frequency, resistance, reactance and bandwidth. Compare with expected response and previous measurements. Unexpectedly broad low SWR can indicate loss, but legitimate broadband designs exist.

Step 4: Measure at the feed point

Disconnect the feed line and measure directly where practical. Calibrate a NanoVNA with open, short and load at the intended reference plane. Compare shack and feed point results. Cable length can transform R and X even when the cable is healthy.

Step 5: Test the feed line

Inspect jackets, bends, connectors, corrosion, water intrusion, arrestors and adapters. DC continuity tests do not establish RF performance. A 50-ohm dummy load at the far end can reveal impedance discontinuities, but a low SWR does not prove low loss. Measure attenuation with a calibrated two-port VNA or appropriate cable-loss method and compare with manufacturer specifications.

Step 6: Inspect the antenna

Check element lengths and spacing, connections, wires, loading coils, transformers, radials, water intrusion and assembly. Corrosion can introduce loss while leaving SWR acceptable.

Step 7: Evaluate installation

Check height, nearby metal and wiring, polarization, RF return path, terrain, beam direction and suitability for the communication objective.

Step 8: Compare actual signals

Use a known-good reference antenna. Keep transmitter, frequency, power, mode, receiving station and polarization consistent. Switch quickly and repeat in multiple directions. For HF, use Reverse Beacon Network, WSPR, PSK Reporter, web SDRs or cooperative stations. For VHF/UHF, use stable beacons, cooperative stations, calibrated receivers or field-strength measurements. Avoid relying on a single contact or report.

13. Decibels and real-world performance

Improvement	Equivalent power increase
1 dB	1.26 times
3 dB	2 times
6 dB	4 times
10 dB	10 times
13 dB	20 times
20 dB	100 times

A 6 dB improvement in the desired direction is equivalent to increasing 100 watts to 400 watts; 10 dB is equivalent to 1,000 watts. Unlike a transmitting amplifier, improving antenna gain or reducing feed line loss can also improve reception. The best investment is often a better antenna system.

14. When should you use an antenna tuner?

A tuner is an impedance-matching network. Inductors and capacitors transform the impedance presented by the antenna and feed line into a load the transmitter can operate into safely. It does not automatically increase radiation efficiency, repair coax, correct ground losses, change a poor pattern or make an undersized antenna equivalent to a full-sized one.

Shack tuner versus remote tuner

A shack tuner can make a radio see 1.1:1 while the coax beyond it remains at 5:1. High SWR on lossy coax can increase attenuation. A remote tuner at the feed point can allow the coax to operate near 50 ohms, reducing mismatch-related line loss. Neither eliminates losses within the radiator itself.

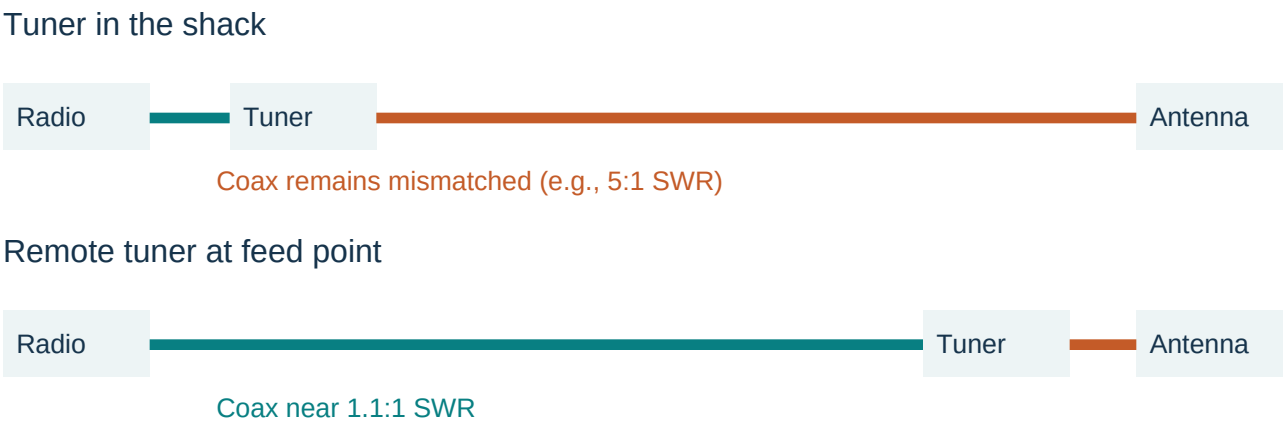


Figure 3. Matching at the feed point can reduce additional coax loss; matching in the shack does not remove the mismatch on the antenna-side line.

Legitimate applications

- Multiband doublets fed with low-loss ladder line or open-wire line.
- Efficient resonant antennas with a natural impedance other than 50 ohms.
- Operating across a wide band, such as the CW and phone portions of 80 meters.
- Space-restricted installations and remote-fed wires with a suitable RF return path.
- Temporary and emergency communications where dedicated antennas are impractical.

If a transmitter folds back to 20 watts due to mismatch, a tuner may allow it to deliver 100 watts. Even after tuner and line losses, more power may reach the antenna. This is a real improvement in power transfer, not necessarily in intrinsic antenna efficiency.

Worked power-budget example

For 100 W forward power, 3 dB matched-line loss, 1.2:1 SWR at the antenna and 50% radiation efficiency: forward power at the antenna is 50.12 W; approximately 0.41 W is reflected; 49.70 W is accepted; about 24.85 W is radiated.



Radiated: 24.85 W

Feed line: 49.88 W

Reflected: 0.42 W

Antenna heat: 24.85 W

Figure 4. Static version of the original interactive calculator. Simplified first-pass model; excludes tuner loss, foldback and recovery of reflected power. Reflected power is shown at the antenna, not as an additional heat loss.

15. When is it time to throw away an antenna?

Before condemning an antenna, verify the feed line, connectors, installation, matching network and operating conditions. Consider replacement when:

• Controlled comparisons consistently show substantially inferior performance.

• Severe corrosion or structural deterioration makes it unsafe or uneconomical to repair.

• Internal components fail and cannot be economically replaced.

• It cannot safely handle your power or duty cycle.

• Excessive resistive loss produces the low SWR, or its pattern is unsuitable.

• Its physical compromises are unacceptable, or repair costs exceed a better replacement.

Be cautious of claims combining extraordinary gain, tiny dimensions, enormous bandwidth and perfect SWR. Size, bandwidth and efficiency involve trade-offs. Broadband operation alone does not prove inefficiency. Do not condemn an antenna merely because it is small, inexpensive, nonresonant or requires a tuner. Sometimes a simple wire dipole costing a fraction of a commercial antenna is the better solution.

16. What should a new operator buy first?

Invest in tools that help you understand your system before buying an amplifier or tuner. A basic toolkit includes a frequency-appropriate SWR/power meter, rated dummy load, antenna analyzer or NanoVNA, calibration standards, multimeter, known-good jumpers and adapters, connector tools and a reference antenna. A simple half-wave dipole or quarter-wave ground plane makes a useful reference. Keep baseline SWR curves, impedance, cable loss and signal reports for future troubleshooting.

17. A word about safety

Low SWR does not establish safety. Matching networks, loading coils and feed points can develop high RF voltages. Keep antennas away from overhead power lines; disconnect transmitters before analyzer testing; never touch energized antennas; observe power and duty-cycle ratings; properly ground and protect outdoor installations; evaluate FCC RF exposure; and use safe tower procedures.

Final thoughts

Amateur radio is about more than purchasing a radio, connecting an antenna and looking at an SWR meter. It is about understanding how RF energy is generated, transferred and radiated. Consider radiation efficiency, feed line attenuation, matching, pattern, height, location, polarization, RF return path and suitability for the intended communication.

I would much rather operate with an efficient antenna displaying 1.5:1 SWR than an inefficient antenna displaying a perfect 1.0:1. I would rather spend money improving the antenna system than purchasing a larger amplifier to compensate for unnecessary losses. And I would much rather understand and correct the cause of poor performance than install a tuner simply to make a meter display a number that makes me feel better.

The next time someone tells you how wonderful their antenna is because it has perfect SWR, ask: How much power reaches the antenna? How much is radiated? Where is it radiated? How well does it receive weak signals? How does it compare with a known-good antenna?

Stop chasing perfect SWR and start chasing actual antenna performance. The objective is not to make an SWR meter happy. It is to get your signal out of the antenna, into the atmosphere and to another amateur radio operator—and to hear that operator when they respond.

73,
Greg – N5XO
HAMster Weak Signal Group
Experiment. Learn. Understand. Improve.

Further reading

ARRL — More About Antenna Tuners
ARRL — Antenna resources
Practical Antennas — A Beginner's Guide to SWR