8 ANTENNAS & TRANSMISSION LINES

Until now we've talked only about the internal generation and reception of CB signals. Those circuits would be useless without some way to transfer the 27 MHz intelligence reliably from one radio to another. So a third and equally important link in the communications chain is the antenna system. Since it's shared by Transmit and Receive, its efficiency and quality affects both modes.

CB operators are generally more concerned with range than with anything else, and since all (legal) CBs have the same transmitter power, it's the antenna system that really determines range. This means the antenna itself, the coax transmission line, and their connectors. In my experience, each of the three system components contributes about equally to antenna problems.

Symptoms of antenna problems include:

1. Poor transmitter and receiver range.
2. No Receive or Transmit.
3. Intermittent Receive or Transmit.
4. Burned out Final and/or Driver RF power amp transistor(s) in the transmitter.
5. S/RF meter on Transmit either pegs hard at full scale, or remains at low end of scale.
6. AWI light comes on.
7. High SWR (over 3:1) indicated, regardless of channel frequency being used.
8. Transmit RF feedback squeal due to high SWR.

Antennas have some unique electrical properties and this chapter must necessarily review some very general antenna theory, with details on specific CB systems as appropriate. Some duplication is unavoidable, but I think you'll find my explanations simpler and a lot less mathematical. However I do urge you to read the reference books listed in CHAPTER 1 for a more complete background. You must thoroughly understand antennas before you can properly analyze a customer's installation or problem.

There's a lot of bad CB antenna information out there that needs to be corrected! Your customer expects honest and accurate advice about specific hardware, as well as the ability to fix his problems. Since antennas will involve maybe half of all CB repairs (and arguments), no professional could limit himself just to inside bench work. Your competition won't!

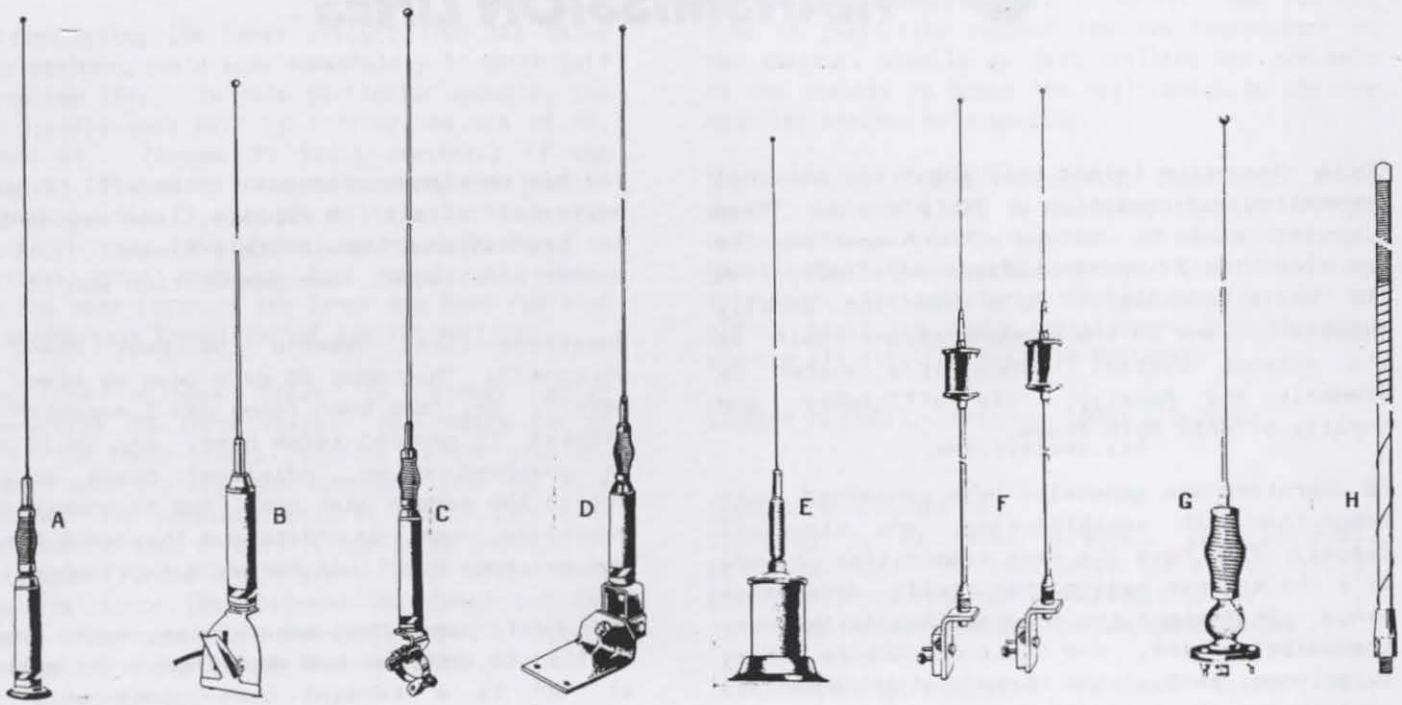
Questions like, "What's the best brand of antenna?", "How many dB gain does my brand XYZ have?", or, "How much range can I expect?" are treated in general terms here, and could only be answered on an individual basis anyway. You're the person best qualified to answer such questions, once you understand the basic theory and get some practical hardware experience.

The next page shows some of the most common mobile CB antennas and mountings. The antenna at "A" is a standard base-loaded whip for mounting in a 3/8" hole on a rooftop. At "B" is a clip-on spring type for temporary mounting on a vehicle's rain gutter. "C" shows a hatchback mount. "D" mounts on the flat top of a camper shell. Antenna "E" is a trunk lid mount and also uses the larger "Big Momma" type loading coil. Oversize center loading coils are also used in the dual mirror-mount "trucker" whips of "F." Antenna "G" is the standard 102" steel whip with its heavy shock spring and swivel ball mount; a 96" fiberglass whip can be substituted for the steel version. At "H" is a typical helically-loaded fiberglass whip; these come in many colors, and sizes from 3' to 7'.

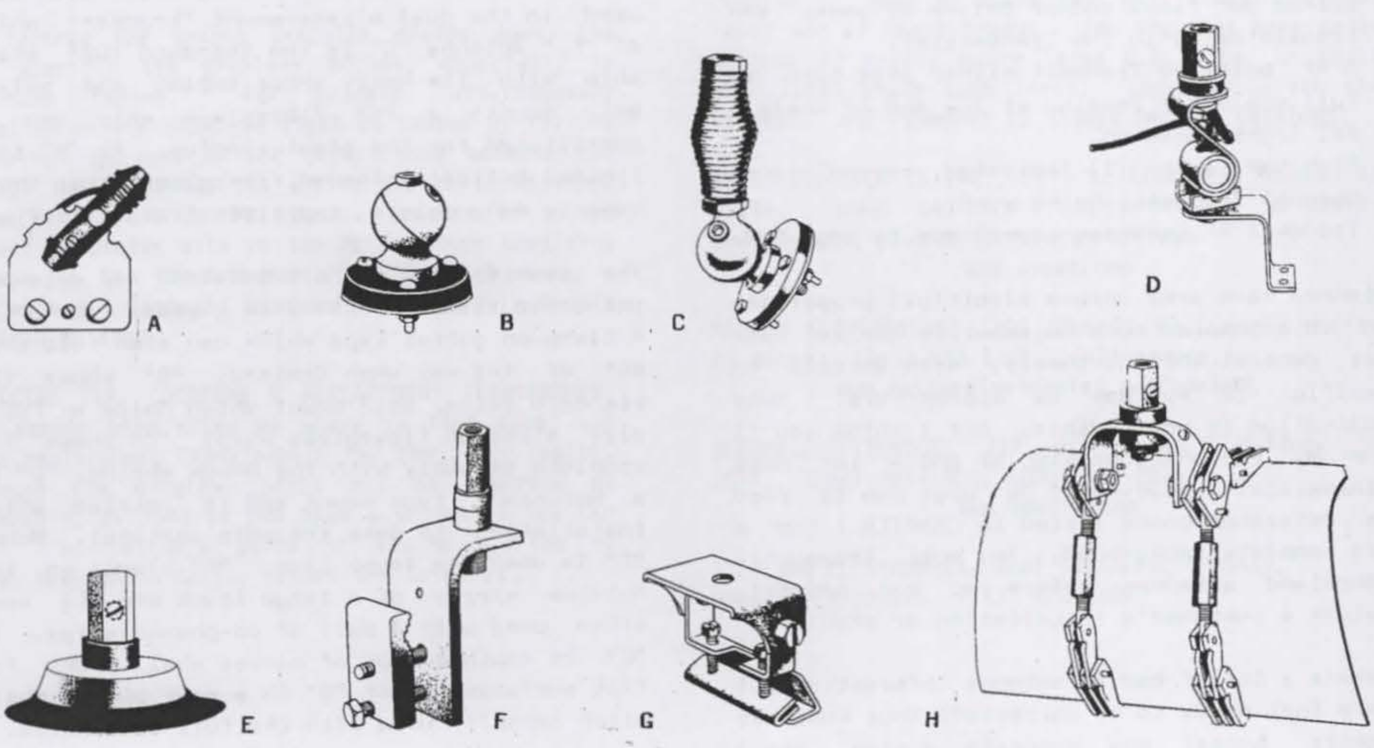
The mounts shown are all intended for antennas using the standard 3/8" x 24 threads. At "A" is a clamp-on gutter type which can also fold over out of the way when desired. "B" shows the standard swivel ball mount which holds a full-size steel or fiberglass whip; "C" shows the complete assembly with the shock spring. "D" is a hatchback type mount and is rotated after installation to make the whip vertical. Mount "E" is used for trunk lids. "F" clamps on the outside mirror of a large truck and is most often used with a pair of co-phased whips. At "G" is another type of camper shell mount for flat surfaces. Mount "H" is a rear bumper chain hitch normally used with the full-size whips.

Almost any desired choice of mount and whip can

MOBILE CB ANTENNAS
(Courtesy Antenna Specialists Co.)



ANTENNA MOUNTS FOR 3/8" X 24 THREADS
(Courtesy Antenna Specialists Co.)



be combined for mobile CB use. For example, whips of "A" and "E" are often combined with a magnetic base for temporary use on a rooftop or a trunk lid. Many brands use standard mounting hardware such that one manufacturer's whip can be fitted to another's mount if so desired. But a few manufacturers like Hustler and K-40 use their own unique mounting hardware, which isn't compatible with other brands.

CHARACTERISTICS OF RADIO WAVES AT 27 MHz

Why Antennas Radiate

An antenna is a tuned circuit of inductance and capacitance, just like any other LC circuit. When connected to an RF voltage source, it oscillates. The differences between antennas and internal tuned radio circuits result from their physical sizes. Ordinary LC circuits are so small relative to their wavelength that most of the energy is used up within the circuit, but a good antenna radiates most of its energy into space. This radiation is the radio "wave."

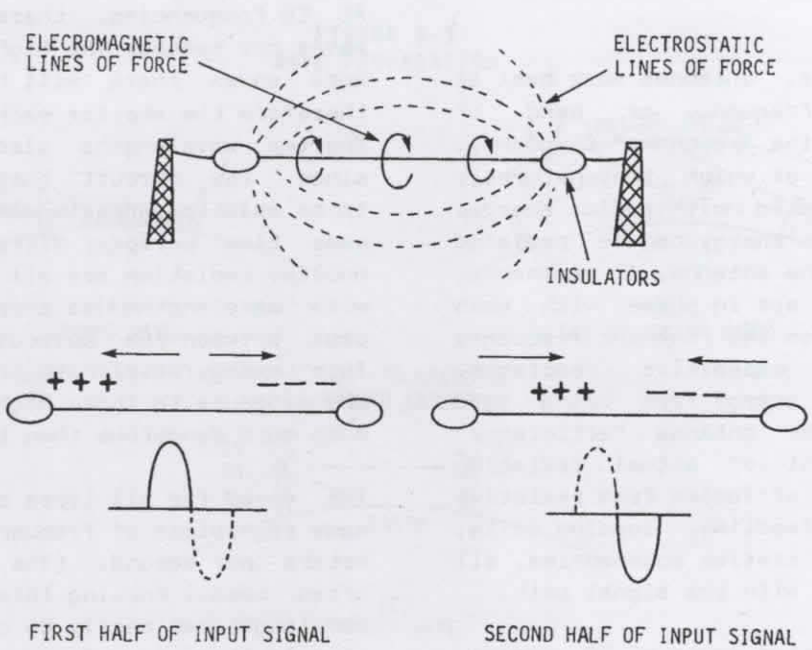
Figure 8-1 illustrates why this happens. When a signal is applied, free electrons are forced to one end and build up a strong negative charge. This leaves the opposite wire end missing its electrons, which results in a strong positive charge. Electrostatic and electromagnetic lines of force are thus generated, which are oriented perpendicular to each other.

With nothing to maintain the charges on the ends they start moving back towards each other, and the magnetic field begins to collapse back into the wire. This collapse drives the excess electrons towards the end that was formerly positive. But then another RF wave comes along. If the antenna is long enough, some electrons won't be able to reach the end and reverse themselves before the driving signal changes again. These electrons are permanently lost as radiation of electrostatic fields into space, and thus a transmitting antenna is created. If such waves should strike another electrical conductor a current of the exact same frequency is induced in it, creating a receiving antenna.

Effect Of Antenna Size On Reception

Although the qualities which make antennas radiate and receive electrostatic fields are basically reciprocal, there's a large practical difference between them. Assuming no losses, virtually all of a transmitter antenna's RF energy is radiated, regardless of its physical size. When receiving though, the antenna can only pick up energy from the incoming wavefront

FIGURE 8-1
ELECTRICAL FIELDS GENERATED IN THE ANTENNA



in a radius within about a 1/4-wavelength from each side of the conductor, meaning 1/4 + 1/4 = about 1/2-wavelength total. All electromagnetic radiation obeys the "Inverse Square Law," which means its strength fades as the square of the distance from the source. For example, if you were to triple the receiving distance from the transmitter antenna, the field strength will be reduced not by 1/3, but by $[1/3]^2$, or 1/9.

Now a 1/2-wavelength 27 MHz CB antenna is about 17' long. But up at say, 470 MHz (which is U.S. UHF-TV Channel 14), a 1/2-wave antenna is only about 1' long. They're equally efficient when transmitting. Using the Inverse Square Law and equal transmitter power, the CB antenna (being 17 times longer) will capture about $[17]^2 = 289$ times more RF energy than the 470 MHz antenna! Therefore the higher the frequency, the less energy received. This disadvantage can often be compensated by the fact that at those higher frequencies, it becomes physically practical to build very high-gain beam antennas.

But antenna gain still isn't anywhere close to the total gain resulting from all the receiver amplifier stages. A top-of-the-line CB beam antenna might have a maximum of 10-15 dB power gain. A typical CB receiver has about 130 dB total gain from antenna to speaker. When combined with the effect of the Inverse Square Law, this explains why you can often hear local stations that are much further away than your ability to transmit to them.

Effect Of Resonance

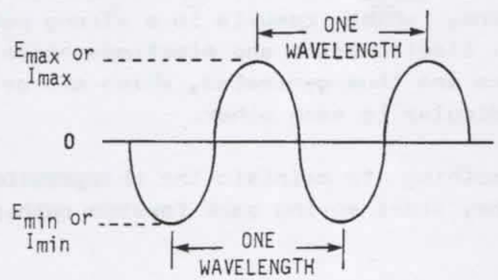
Like all tuned circuits, antennas work best at only one specific frequency or band of frequencies, known as the "resonant" frequency. This is the frequency at which they naturally oscillate when stimulated with radio energy, and where the maximum energy can be radiated from or induced into the antenna. At resonance, all antenna currents are in phase with each other. Moving away from the resonant frequency creates inductive or capacitive reactance, which prevents the RF energy from being used most efficiently. The antenna "efficiency" refers to the amount of actual radiation compared to the amount of losses from resistive heating in the coax feedline, loading coils, connectors, or various station accessories, all of which are in series with the signal path.

With the low transmitter power of CB radios, reactive antennas are extremely undesirable. To maximize efficiency, the antenna must be tuned or made resonant at the desired frequency. In practice this means adjusting its physical length relative to the electrical or RF wavelength. The process of making CB antennas resonant is commonly called "matching" or "SWR matching," or simply "tuning."

Frequency & Wavelength Basics

Since radio waves are sine waves, they have peaks ("maxima") and valleys ("minima"). The frequency of a radio wave ("wavelength") is the number of voltage (or current) maxima and minima per second. A wavelength is the distance from any point on one wave to the same point on the next wave. This is shown in Figure 8-2 by the familiar sine wave.

FIGURE 8-2
DEFINING THE WAVELENGTH



At CB frequencies, there are 27 million such waves per second. The higher the frequency, the more waves there will be in one second and therefore the shorter each wavelength must be. Shorter wavelengths also have more energy, since the circuit that produced them had to be able to generate many more of them in the same time period. Microwaves, X-Rays, and nuclear radiation are all forms of radio energy with wavelengths so short they can literally pass between the molecules of human tissues. This energy/wavelength principle also explains why exposure to those higher frequencies can be much more dangerous than the lower frequencies.

The speed for all types of radio waves is the same regardless of frequency, about 300,000,000 meters per second. (The metric system is most often used.) Knowing this speed, the actual wavelength can easily be calculated. Since CB signals occur in a frequency range of millions of cycles per second or MHz, the wavelength formula is conveniently simplified to:

$$\text{wavelength in meters} = \frac{300}{\text{freq.(MHz)}}$$

At 27 MHz, one wavelength is about $300 \div 27 =$ 11.11 meters, or 36.44 feet. (A meter is equal to 3.28'.) This is the wavelength in air, but will actually be about 5% shorter when passing through a more dense medium like the steel, copper, or aluminum used in CB antennas. So the practical wavelength is about 95% of 36.44', or 34.62'. A simplified formula which accounts for this difference in speed and simultaneously converts the measurement to feet is:

$$\text{practical wavelength in feet} = \frac{936}{\text{freq.(MHz)}}$$

Using this formula, one CB wavelength is about 34.67 feet, which is close enough to the above figure for a practical antenna design.

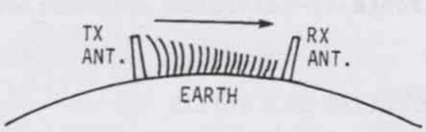
Wave Propagation

Radio waves can be categorized according to how they "propagate" or travel outward from the antenna. See Figure 8-3. "Ground" waves move only along the earth's surface, following the contour of the ground. They'll actually travel about 10% beyond the distance to the horizon due to atmospheric bending. "Sky" waves travel upward into the earth's atmosphere and may be reflected back to the earth under the right conditions, sometimes thousands of miles away. (This is the familiar "skip" or "DX," meaning distance.) "Line-of-sight" or "direct" waves are somewhere in between, unable to move along the ground or to be reflected back from the earth's atmosphere. Which wave form dominates will depend mainly on the operating frequency.

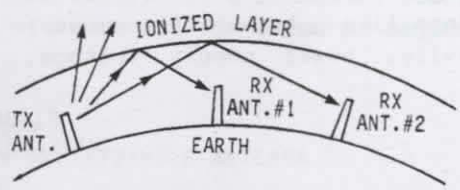
The sky wave reflection is caused by ionized particles in the earth's atmosphere, which form layers at various heights above ground. When sky waves are reflected, they're received only where they return to earth. The area in between is a dead zone completely skipped over by the signal. Figure 8-3B shows two outgoing waves at different angles from the transmitting antenna. The reflection angles and therefore the skip distances are different. Any location besides RX ANT #1 or RX ANT #2 (and beyond ground wave range) can't receive the transmission. This explains why very often only one station in a shortwave conversation can be heard; a third-party listener may be just the right distance to receive one station, but inside the skip zone of the other station. Sky waves can also often be reflected more than once, making communications possible over great distances. For example, Amateur operators in the western U.S. can easily work Japanese Hams using multihop skip; salt water makes an excellent reflector of radio waves.

As the frequency increases, ground waves are absorbed more and more until they disappear completely. This explains why you might hear a commercial AM broadcast station at say, 630 KHz

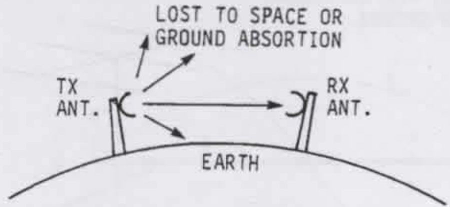
FIGURE 8-3
WAVE PROPAGATION



(A)
GROUND WAVE



(B)
SKY OR "SKIP" WAVES



(C)
DIRECT WAVE

perhaps 150 miles away, but a station with equal power on 1570 KHz may fade out beyond just 30 miles. The fact that distant broadcast stations skip in at night is coincidental and due only to sky wave propagation. At the other extreme are some very low frequency (10 KHz!), high-power military transmitters that are able to communicate with submarines anywhere in the world using only ground waves.

Line-of-sight wave propagation is chosen for commercial VHF, UHF, satellite and microwave use, where the small physical wavelength makes highly directional antennas practical. Skip is basically nonexistent. The "shortwave" or HF bands (3-30 MHz) were intended for skip type propagation, since these broadcasters primarily want distant coverage. The end use determines the frequency, and therefore the choice of ground wave vs. direct wave vs. sky wave. Antenna designs can favor any particular type.

The 27 MHz CB band is a shortwave band. Ground waves don't propagate well and when combined with the low (legal) CB transmitter power, communications are limited to just a few miles. Sky waves do propagate very well, which explains why CB is more of a hobby than a serious local business service as originally intended. Many CB operators prefer "shooting skip" (DX) to local communications, which seems only natural. (The FCC may disagree though!)

Predicting how radio waves will behave is a science in itself, and is affected by many factors like antenna height, time of day, time of year, the 11-year sunspot cycle, terrain, temperature, operating frequency, and ground conductivity. Range depends upon all these factors plus things like transmitter power, receiver sensitivity, power supply voltage, losses in cables and connectors, and ambient background noise or interference. That's why there are no definite rules about CB range!

The effective range of all radio waves is directly related to the efficiency of the antenna system. Maintaining high efficiency is a large part of the CB technician's job.

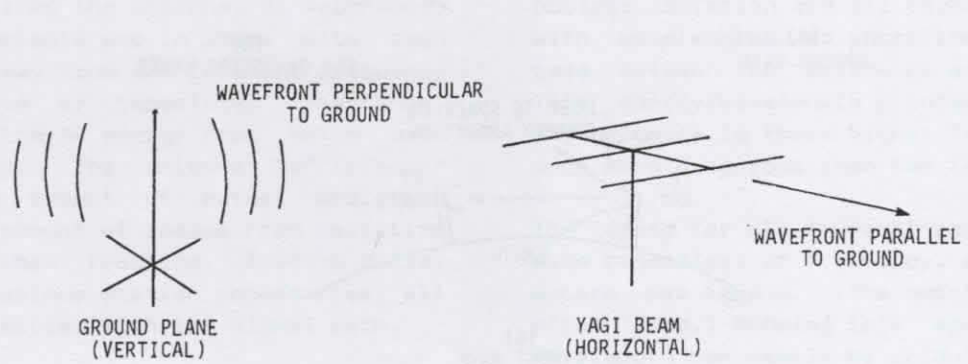
Wave Polarization

The angle of the electrostatic wave relative to the earth is called "polarization." Antennas parallel to the ground radiate horizontally-polarized waves, and those perpendicular to the ground radiate vertically-polarized waves. See Figure 8-4. (Polarization shouldn't be confused with directivity, discussed later.) For best efficiency, the transmitting and receiving antennas usually have the same polarization. Attenuation from cross-polarization can exceed 20 dB at 27 MHz, and some CB base antennas are purposely designed with switchable or "dual-polarization" to take advantage of this. Home satellite TV uses line-of-sight propagation and depends upon cross-polarization, where adjacent transponder channels use opposite polarizations to reduce the adjacent-channel interference.

Another possibility is circular polarization, where rotating radio waves leave the antenna at every polarization angle. It's commonly used in FM and TV broadcasting because of the need to reach homes with horizontal Yagi antennas, cars with vertical whips, and "rabbit ears" with everything in between. This can be further broken down into left-hand rotation and right-hand rotation to control the cross-attenuation.

CB operation is usually vertically-polarized; horizontally-polarized antennas of the required

FIGURE 8-4
WAVE POLARIZATION



length are physically harder to support and not very practical, especially for mobile use. (In CB jargon horizontal polarization is called the "flat side.") A major disadvantage of vertical polarization is its tendency to pick up more ignition noise in mobile operation. Otherwise there's no reason why two stations wanting to communicate on a regular basis can't both use horizontal polarization. For skip propagation polarization doesn't matter, because the waves will bend in many directions when bouncing off the earth's atmosphere to the point where the original polarization changes anyway. That's why you can "shoot skip" regardless of what type of polarization is being used at each end.

ELECTRICAL RELATIONSHIPS IN THE 1/2-WAVE ANTENNA

The "1/2-wavelength" antenna is the simplest LC circuit that will resonate at a given frequency. It's the basis for all CB antenna designs. That's because it's the shortest length of wire or tubing that will allow an electrostatic charge to travel from one end to the other and back again in the time of one RF cycle. Since the charge goes down the wire, turns around and comes back in one cycle or wave, it has actually travelled the wire twice. Therefore the wire needs to be only half this length for one full wave to travel down and back. While this assumes the energy is fed into one end, in practice it's usually fed at the center with the same results. From the earlier formula, this means a 1/2-wavelength at 27 MHz is slightly over 17' long.

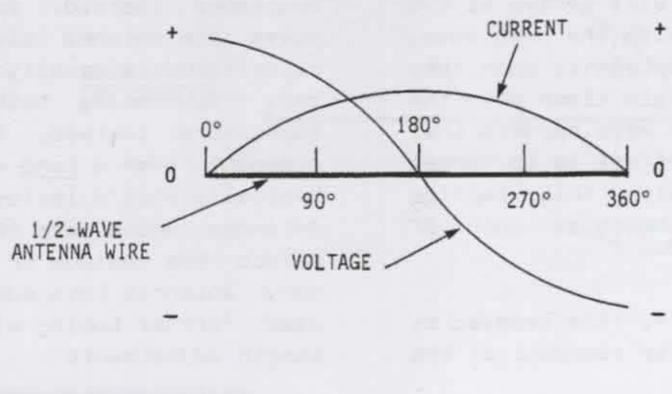
Figure 8-5 illustrates the voltage and current distribution in such an antenna when the RF energy is applied at the exact center. Since electrons accumulate at the ends, they always have the highest RF voltage. And as these electrons try to move towards the oppositely-charged end, the greatest number of them pass through the center, which therefore has the highest RF current. So current in the 1/2-wave antenna is always maximum at the center, and voltage is always maximum at the ends.

The maximum voltage/current points are called the "loops" and the minimum points are called the "nodes." Since by Ohm's Law $R = E \div I$, the lowest impedance point must be the current loop, and the highest impedance is the voltage loop. Most CB antennas are "current fed," or fed at the (low-impedance) center in the case of a 1/2-wave antenna. This is needed to match the low impedance of the transmitter output.

The voltage and current curves resemble the familiar sine wave, which is exactly what they are. If you could put an RF ammeter into the wire at many points, the measured current distribution would confirm this. As the length increases past a 1/2-wavelength, the curves simply repeat at regular 1/2-wave intervals.

The figure shows that at any point where the voltage is increasing, current is decreasing, and vice-versa. So the "phase" or timing of either component has a specific relationship to the other. It's common to describe the phasing of antennas in terms of degrees, where 360°

FIGURE 8-5
ELECTRICAL RELATIONSHIPS IN THE 1/2-WAVE ANTENNA



represents one wavelength. This means 180° is a 1/2-wavelength, 90° a 1/4-wavelength, etc. In this example the voltage and current both go from maximum to minimum every 1/2-wavelength or 180°, but not at the same time; the peaks are shifted out of phase with each other by 90°.

Figure 8-5 also represents "standing waves" of voltage and current, because they appear to be standing still when the antenna is exactly resonant at the frequency of the applied energy. A good analogy is a rope tied to a tree at one end; as you swing the other end up and down at precisely the right speed, it forms a sine wave that appears to stand still. If you change the swinging speed slightly, the wave begins to move away from its previous position. This principle is extremely important: standing waves are required on antennas for efficient radiation, but are very undesirable when they occur on the coax cable transmission line.

Reactance & Antenna Tuning

Unlike the simpler DC circuits, an alternating voltage is only in phase with its current when flowing into a pure resistance. This happens only when the circuit is resonant and has no reactance. But at radio frequencies it's very difficult to have purely resistive loads, because reactance increases with frequency.

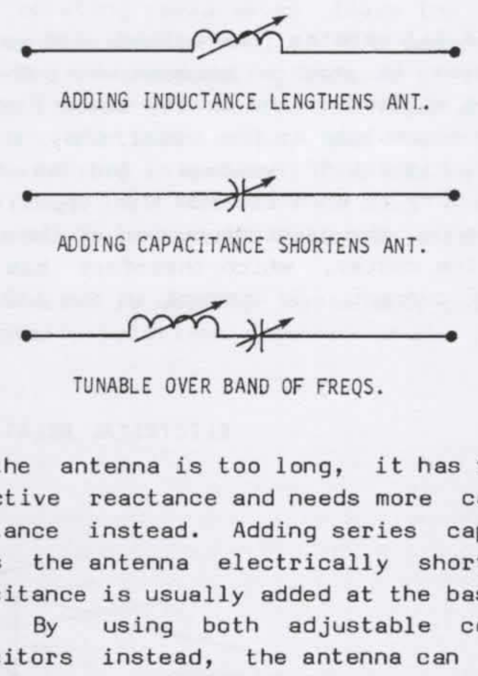
"Reactance" in its simplest terms means the reaction or opposition to any change in current (inductive reactance) or voltage (capacitive reactance) in an AC circuit. This makes sense when you consider that capacitors will tend to maintain a constant voltage, while inductors will tend to maintain a constant current.

Reactance will cause the voltage/current timing relationship to shift away from its normal 90° phase difference, producing standing waves on the transmission line. This is like changing the speed of the swinging rope in the earlier example; occasionally a wave will arrive at the starting point out of sync with the next wave, dampening the second wave's intensity when they meet. Thus there will be certain times when the voltage/current phase in one wave opposes that of the next wave; the net effect is to cancel part of the energy completely. This implies that reactive loads can't absorb as much RF energy as resistive loads.

Since reactance is undesirable, it's removed by making the antenna electrically resonant at the operating frequency; this length is exactly a 1/2-wavelength. That's why you match a mobile CB antenna by making the whip rod shorter or longer; you're tuning out the reactance. At resonance, inductive and capacitive reactances are equal in amplitude but opposite in phase, exactly cancelling each other out.

Now refer to Figure 8-6. If the antenna is too short, is has too little inductive reactance and too much capacitive reactance. More inductive reactance is needed. This can be increased by putting a "loading coil" in series with the wire. The coil adds inductance to make the antenna electrically longer, even though it's physically too short. Loading is the most common tuning method for mobile CB antennas, which are usually much shorter physically than electrically. The loading coil may be placed anywhere along the antenna, like the base or center with steel whips. When a wire antenna is wound around a fiberglass support rod, the loading is continuous through its entire length and usually concentrated at the top.

FIGURE 8-6
CONTROLLING RESONANCE OF ANTENNAS



If the antenna is too long, it has too much inductive reactance and needs more capacitive reactance instead. Adding series capacitance makes the antenna electrically shorter. The capacitance is usually added at the base or the top. By using both adjustable coils and capacitors instead, the antenna can be made resonant over a band of frequencies. (This is basically what's inside a good antenna tuner.) Antennas which are 50Ω and non-reactive will absorb the maximum RF power. But in practice many antennas have additional reactances and need further tuning with loading coils or rod length adjustments.

A 17' CB antenna is obviously only practical for a base installation, and loading is rarely used there. But for mobile operation a loading coil is almost always used. There's not much chance of a mobile CB antenna being too long, so you won't see tuning with capacitance except what's present in the rod length itself.

Effect Of Impedance

"Impedance" refers to an AC load having both resistance and reactance, which means the load depends upon the frequency. In the special case where capacitive and inductive reactances are equal (i.e., at resonance), they cancel each other and the impedance is equal to the pure resistance. For maximum energy transfer from radio to antenna, both impedances must match. To the degree they don't, energy will be reflected back to the transmitter instead of coupling to the antenna and radiating.

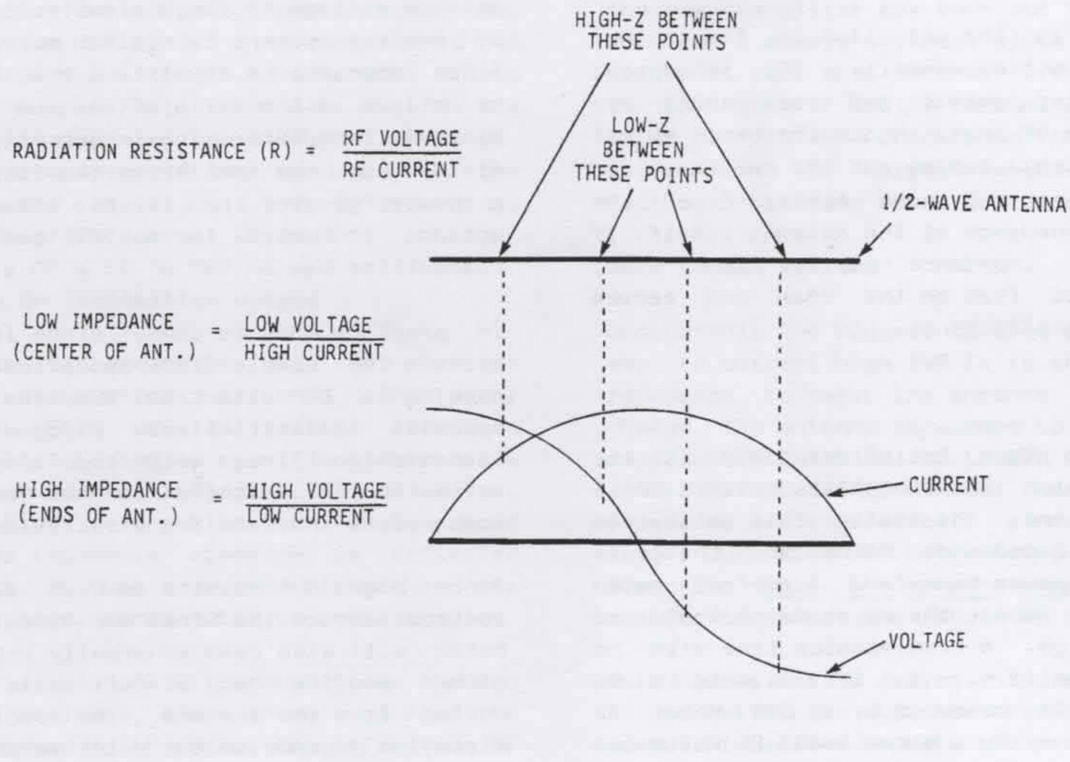
Since impedance is a complex value composed partly of reactance, which in turn depends upon frequency, changing that reactance changes the impedance. CB operation is 27 MHz by design, so you can't change the operating frequency to match a particular antenna impedance. The coax also has a fixed impedance value. Therefore you can only change the antenna impedance to match the other impedances.

All CB radios are designed with a 50Ω output impedance at the antenna socket. For maximum power transfer the impedance connected there must also be 50 ohms. The antenna is usually connected to the radio by 50Ω "coaxial" cable, which is two parallel conductors sharing a common axis; i.e., they're concentric. (A few special cases use 75Ω coax.) Coax impedance is determined by the size of the conductors, their spacing, and the dielectric insulating material between them. Since the cable has the same impedance as the radio, this means maximum transmitter power can be coupled to the radio end of the cable. Whether maximum power can be coupled from the far end of the cable into the antenna is another question entirely!

Radiation Resistance

The "50Ω" antenna impedance figure is a bit misleading. Obviously if the antenna is resonant, there's no reactance and the impedance is equal to the DC resistance alone. But the actual DC resistance in a few feet of

FIGURE 8-7
RADIATION RESISTANCE (IMPEDANCE) ALONG 1/2-WAVE ANTENNA



copper wire or aluminum tubing is typically less than 1Ω. So where do they get 50 ohms?

The 50Ω value is a special one called the "radiation resistance." This is the resistance which, when substituted for the antenna, absorbs the same amount of power as that which actually disappears by radiation. Thus antenna impedance and radiation resistance mean the same thing, if there's no reactance.

The actual ohmic value of radiation resistance is only important when small enough to approach the DC resistance value, since this would mean heat losses are becoming a larger part of the total power consumption compared to the power consumed in useful radiation. If the radiation resistance is at least ten times higher than the DC resistance, there's not much to worry about. Factors which might lower this ratio include close proximity to the ground, or loading coils made of long, thin wire. These conditions sometimes occur in mobile CB antennas. With a value around 50 ohms, the antenna remains very efficient.

Since the voltage/current loops and nodes on a 1/2-wave antenna occur at different points, the radiation resistance (R) is also different between any two points. This is confirmed by Ohm's Law, $R = E \div I$. The radiation resistance could also be defined as the ratio of RF voltage at any point on the antenna to the RF current at that point. Knowing this, Figure 8-7 shows how the radiation resistance or impedance is lowest at the center and highest at the ends, with intermediate values in between. At some point between the exact center and one end the impedance approaches 50 ohms, which just happens to be what's needed for CB antennas.

STANDING WAVE RATIO (SWR)

To absorb (and therefore radiate) the maximum RF energy, the antenna must present a load into which maximum RF current flows for a given transmitter power. The higher the antenna current, the further the radiation. Maximum current flows when the driving source impedance (the transmitter) equals the load impedance (the antenna). Under these conditions there are no standing waves on the transmission line.

The antenna is the only link in the signal chain that's not necessarily a 50Ω impedance; the transmitter output and coax cable are designed to be 50 ohms. Hence the basic object of SWR matching: tuning out the reactance so the transmitter and coax cable "see" the correct 50Ω impedance at the antenna itself. If the antenna impedance varies from this, standing waves form on the coax and reduce power coupling efficiency.

SWR Defined

The "Standing Wave Ratio" or "SWR" is the degree to which standing waves exist on a transmission line. The smaller this ratio, the closer the impedances match and the more efficient the power transfer. A perfect match would be 1:1, while the worst match would be infinitely high. A transmission line with no standing waves (i.e., 1:1 SWR) is said to be "flat." SWR is measured by an SWR Meter or Reflectometer, or by a directional RF wattmeter like the Bird 43. Unfortunately it's the interpretation of SWR that causes so much argument among CB operators and inexperienced technicians! A lot of time, energy, and money is wasted chasing the "perfect match," which isn't even necessary. Such a match is generally only important beyond VHF, because transmission line losses increase with frequency.

SWR is defined more precisely as the maximum antenna voltage to the minimum voltage (VSWR), or maximum current to minimum current (ISWR). Since impedance is equal to $E \div I$, SWR can also be defined as the ratio of maximum impedance to minimum impedance. The larger value is always divided by the smaller so the ratio will be a number greater than 1. For example, a 75Ω antenna connected to a 50Ω coax line and transmitter has an SWR of $75 \div 50 = 1.5{:}1$.

In practice VSWR is used, since it's easy to measure by simple diode rectification of RF driving a DC voltmeter. When two diodes of opposite polarities are bridged across a transmission line, both the forward and the reflected RF voltages can be measured and compared to indicate SWR directly on the meter.

Since high SWR results in high reflected RF voltages around the Final amp circuit, the S/RF Meter will also read abnormally high or low, either pegging hard at full scale or barely moving from the low end. The specific needle direction depends on the relative phases of the forward and reflected voltages when they combine at the S/RF metering circuit. If in phase, the reflected voltage adds to the normal RF voltage to make the meter read higher than normal. If out of phase, the voltages will subtract and the meter reads lower. Most S/RF meters read higher with high SWR, and this is often the first symptom of an antenna problem.

Power Loss Percentage

The heart of the SWR argument concerns the power loss in a mismatch. Most operators wrongly believe that anything worse than 1:1 is something to worry about, when nothing could be further from the truth. Let's prove it!

The ratio of voltage (or current) reaching the antenna to that reflected back down the coax is called the "coefficient of reflection" or "k." This is calculated by,

$$k = \frac{SWR - 1}{SWR + 1}$$

Using the earlier example of a 75Ω antenna with a 50Ω transmitter, the k factor is $(1.5 - 1) \div (1.5 + 1) = 0.2$. Since power is proportional to I^2 or V^2, this means the reflected power is k^2, in this case $0.2 \times 0.2 = 0.04$. So only <u>4%</u> of the power is reflected, which means 96% is delivered to the antenna! An SWR of 1.5:1 is therefore not even significant. Most SWR meters display the reflected power percentages, and that's why an SWR of 1.5:1 corresponds to 4% reflected power, 2:1 to 11%, 3:1 to 25%, 4:1 to 36%, and so on. Furthermore SWR meters are notoriously inaccurate, especially at the ends. (All DC voltmeters are most accurate in the center of the scale.) So low SWR readings aren't necessarily correct anyway.

SWR Effects On Transmitter Output

The biggest concern with high SWR is the potential destruction of the RF power transistors. This usually results from an antenna that's shorted or open. In either case SWR is theoretically infinite. The RF Driver sometimes blows along with the Final, since part of the impedance mismatch is reflected back to it. In tube rigs SWR mismatches are better tolerated, since tubes are more rugged.

With a short, the full RF current flows through the Final transistor, since there's no load to absorb the power. With opens, the reflected RF voltage may be high enough when combined with the DC supply to exceed the maximum safe V_{ceo} breakdown rating, typically about 18-25 VDC for most common Japanese and Motorola RF power transistors. Remember, high antenna impedance develops high RF voltage, while low impedance develops a high RF current. The high reflected voltage can also cause an RF feedback squeal, especially when combined with a linear amp.

To emphasize the effects of high RF voltage, I remember when I worked at KPOL in Los Angeles, which was 50,000 watts, AM directional. The towers had base impedances of about <u>600</u> ohms. Touching a tower ball insulator with the wood handle of a shovel would shoot a flaming arc about 2 feet! The RF voltage was tremendous. In that particular case, it didn't mean the SWR was high. The towers happened to be fed at voltage loops with suitable matching networks, since that was the station's FCC-approved antenna system. And AM broadcast transmitters run on tubes, which are high-impedance devices. With CBs using transistors, the antenna must present a low-impedance load to minimize RF voltages. This implies current feed instead.

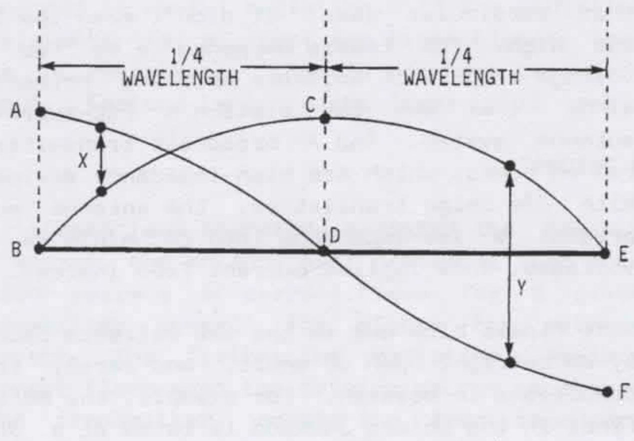
Most Finals blow due to the SWR extremes caused by an outright open or short, and rarely from conditions in between. For example, the MRF477 Final in the Uniden Jackson is rated at a 30:1 maximum SWR tolerance! When you replace a bad Final, <u>always</u> suspect the antenna; check it or the new transistor may burn out too. Obviously you can't always do this, since the radio may arrive at your shop in a different vehicle. Get in the habit of asking antenna questions. And offer a free SWR check when the customer can return with the correct vehicle. Methods for testing shorts and opens are described later.

Coax Length vs. SWR

Undoubtedly the biggest CB argument! The <u>only</u> way to correct high SWR is to change the coax impedance to match the antenna impedance, or change the antenna impedance to match the coax impedance. **CHANGING THE LENGTH OF THE COAX HAS ABSOLUTELY NO EFFECT ON SWR!** Changing the coax impedance isn't practical, since that would no longer match the 50Ω output of the transmitter. Therefore <u>only the antenna impedance</u> can be changed to affect the SWR in CB installations.

This can be easily proven. You must understand it to eliminate customer resistance to the truth! Figure 8-8 repeats the previous 1/2-wave voltage/current graph. Only now assume it represents a 1/2-wavelength of mismatched coax instead of the antenna. Standing waves of voltage and current now appear on the cable. At the two ends current is minimum and voltage maximum, so both ends (A-B and E-F) have the same impedance. (Recall that impedance or radiation resistance is simply E ÷ I or I ÷ E.) Since the pattern repeats itself regularly every 1/2-wavelength, this coax length is an "impedance repeater;" the SWR measured at one end will be the same at the other end.

FIGURE 8-8
SWR ALONG A 1/2-WAVE TRANSMISSION LINE



At the center (C-D), current is maximum and voltage minimum, making the impedance different than at the ends. Compare the center to the ends, which are a 1/4-wavelength away. The voltage/current relationships are inverted; if voltage is decreasing towards the center it's increasing towards either end, and vice-versa for the current. A 1/4-wavelength is therefore an "impedance inverter;" at this spacing center and end impedances oppose each other instead of being the same.

An SWR Meter at the center and either end would measure totally different values because of these different impedances. In fact measuring at many places along the coax (like points "X" and "Y") would give many unique readings. If standing waves weren't there in the first place (which they wouldn't be if the antenna had an impedance of 50Ω), all measurements would be the same. That's where they got the term "flat" line. Coax length changes the apparent SWR when standing waves are present, but not the fact that the antenna is what's causing them!

The cure for suspicious SWR readings is to measure at the antenna itself where practical. Base antennas use standard coax sockets but mobiles don't, so this isn't always possible. Use a 1/2-wavelength of coax or its multiple (2/2, 3/2, 4/2, 5/2, etc.) instead. Such a length repeats whatever impedance actually exists at the antenna, while a 1/4-wavelength feedline inverts it.

Coax Characteristics

The coax length important for SWR measurements is the electrical length, not the physical length. The electrical length will always be shorter than the free space length, since electricity slows down in any material having resistance. This "Velocity Factor" shortens the physical coax length and must be considered. The Velocity Factor is the degree to which the signal slows down when compared to air, and is determined by the type and thickness of the conductors and the dielectric material. These same characteristics also affect signal loss and the coax impedance itself. The chart below lists the most important characteristics of CB

COAX TYPE & DIELECTRIC*		IMPEDANCE	VEL.%	ATTENUATION PER 100 FT. AT 27 MHz	POWER RATING AT 27 MHz (SWR = 1.0)
RG58/U	PE	53.5 ohms	66	2.5 dB	550 watts
RG58/U	CPE	50 ohms	79	2.2 dB	550 watts
RG59/U	PE	73 ohms	66	2.1 dB	720 watts
RG59/U	CPE	75 ohms	79	1.6 dB	720 watts
RG8A/U	PE	52 ohms	66	1.2 dB	1720 watts
RG8/U	CPE	50 ohms	80	0.9 dB	1720 watts
RG213/U	PE	50 ohms	66	1.2 dB	1720 watts
RG8/X	CPE	52 ohms	78	1.2 dB	- - - - -

*PE = Polyethylene, CPE = Cellular Polyethylene ("FOAM") coax. (Incidentally, the "RG" cable prefix is an old military term meaning "Radio Grade.")

The chart shows the Velocity Factor as a percentage of the free space wavelength. Note it's slower in standard polyethylene dielectric (PE) cables than foam dielectric cables. This seems reasonable, because foam cable also has less initial signal loss due to its lower resistance; RF can travel further through foam cable in the same time period. Also note the heavier the cable, the more power it can handle due to larger physical conductors. Power ratings and attenuation depend on frequency, always getting worse with increasing frequency.

Assuming a Velocity Factor of 0.66 for standard cables, this means the electrical length of the cable must be 66% of the computed free space wavelength. So the 1/2-wavelength formula for standard coax is,

$$\text{1/2-wavelength (in feet)} = \frac{468}{\text{freq.(MHz)}} \times 0.66$$

Therefore a 1/2-wavelength of coax at 27 MHz is about 11.44'. A 1/4-wavelength is about 5.72'. In practice 12' and 6' are close enough. For accurate SWR readings in a base antenna, use a multiple of 12'. (Assuming standard coax; for foam types, calculate using the higher Velocity Factor.) Prepackaged mobile antennas usually come with 17' of RG58/U coax to reach from the trunk to the dashboard. This amount is almost 3/4-wavelength, which means it's a potential impedance inverter and may give false readings if the SWR is already high. (An odd multiple of a 1/4-wavelength is the same electrically as one 1/4-wavelength.)

To prove this fact to yourself or to a stubborn customer, make the test cable set-up shown in Figure 8-9. By paralleling two 50Ω dummy loads with a "T" connector, you've made a 25Ω non-reactive impedance. The SWR Meter when placed as shown should read 50 ÷ 25 = 2:1 SWR. You'll find that it does read this with 12' (1/2-wavelength) of coax, but reads something quite different with the 6' (1/4-wavelength) cable! This should end the argument...

Effect of Antenna Tuners & Other Accessories

Antenna Tuners are in-line devices which help reduce SWR by cancelling antenna reactance. Examples are the GC Electronics #18-716 and Gold Line #1046 or #1086. It's important to understand how these work, how to use them, and what to realistically expect from them. In Figure 8-10A, such a tuner is shown installed at the radio end of a 3:1 SWR (i.e., 25% loss) mismatched antenna. When adjusted to 50 ohms, the tuner allows the full 4 watts of RF power to be coupled to the coax. The problem is that the antenna is not resonant and therefore the 3:1 SWR still exists at the antenna end of the coax! All you've done is fooled the transmitter into thinking it sees the correct load. The losses are still there. And as shown, only 1.5 watts is actually available to be radiated. Maximum power can't be coupled from the far end of the cable into a mismatched antenna.

Nothing you can do at the transmitter end of the coax has the slightest effect on antenna SWR. The correct tuner location would be as shown in Figure 8-10B, at the antenna itself. The tuner then becomes part of the antenna and reflects the correct impedance all the way back

FIGURE 8-9
TESTING COAX LENGTH VS. SWR MEASUREMENT IN A REACTIVE LOAD

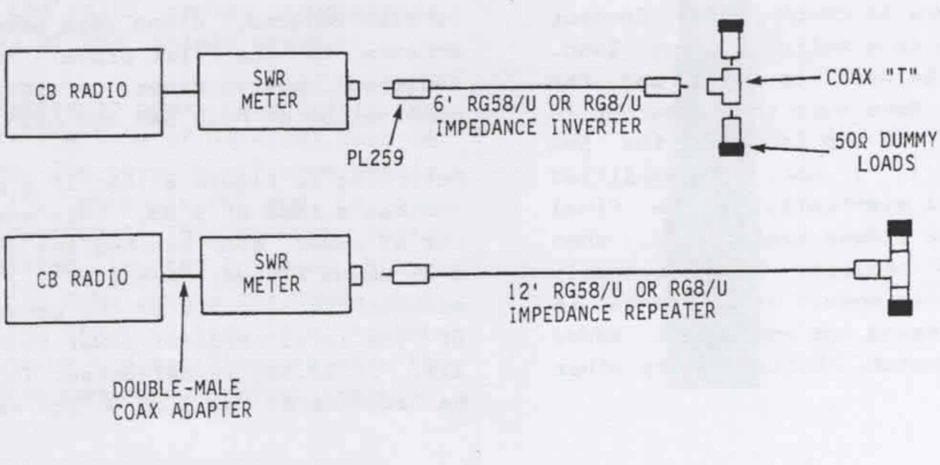
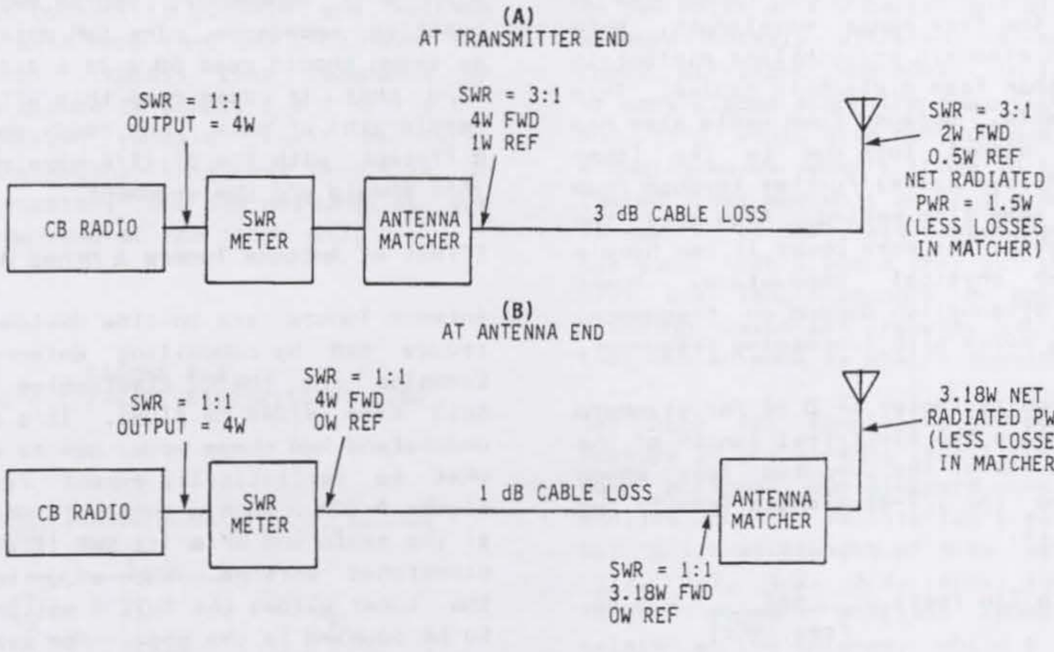


FIGURE 8-10
EFFECT OF ANTENNA "MATCHER" & COAX LOSS ON RADIATED POWER



to the transmitter. Except for the coax loss and a tiny insertion loss from the matcher, most of the original 4 watts is radiated.

This brings up another important point: the correct placement of an SWR Meter is always before other any in-line accessories like a tuner, low-pass filter, coax switch, frequency counter, or linear amp. It then shows the combined effect on impedance from such accessories being added in series. (Assuming the antenna itself was correctly matched.)

Many RF Finals blow by using linear amps with high input SWR. The input SWR can be affected by a mismatched antenna or the wrong amount of RF drive power from the radio. (See CHAPTER 5.) Figure 8-11 shows how to check this. Connect the linear's output to a suitable dummy load, and the SWR meter between its input and the transmitter output. Make sure the CB output is exactly 4 watts. If the amp is good, the SWR should be close to 1:1. If not, the amplified reflected power will eventually fry the Final transistor and/or the linear transistors. When the dummy load is replaced by a properly matched antenna there should be no change in the reading, which means the amp hasn't added any significant mismatch. Ditto for any other in-line accessories.

Coax Losses vs. SWR Losses

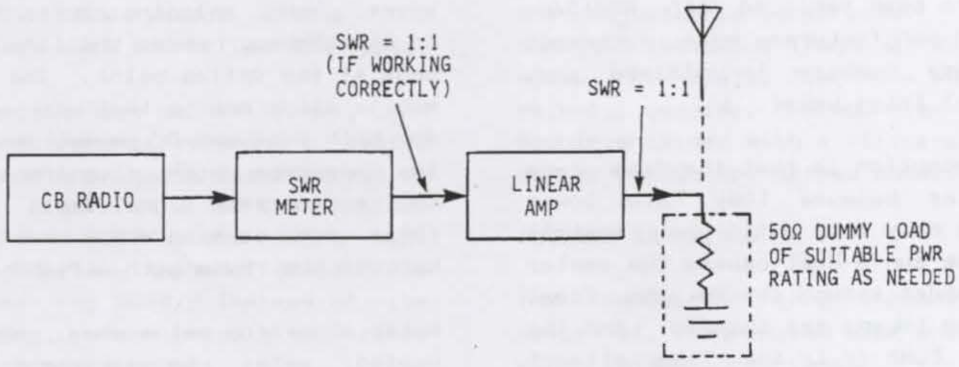
High SWR increases cable losses, which are normally about 2 dB per 100' for RG58 types and 1 dB per 100' for RG8 types at 30 MHz. In small mismatches, the additional SWR losses aren't enough to worry about. For example, at 2:1 SWR the additional loss is only about 0.5 dB even on very long runs. This is an undetectable change at the receiving end. From a practical standpoint, this means a 2:1 SWR is just as good as the mythical "perfect" match.

On the other hand, coax that's already lossy can cause misleading SWR readings at the transmitter end, which is where most people measure it. This is because the reflected power is also reduced, since less power reaches the antenna in the first place. And the actual radiated power drops considerably with a combination of high SWR and high cable loss.

Returning to Figure 8-10A, if a particular coax run has a loss of 3 dB, this means only 50% of the RF power ever reaches the antenna. (Since 3 dB means a power factor of 2.) If the antenna mismatch is 3:1, 25% of the power is reflected. Of the total original power then, 50% of that 25%, or 12.5%, is reflected. This in turn will be attenuated by 3 dB on its way back to the

FIGURE 8-11

TESTING INPUT/OUTPUT IMPEDANCES OF LINEAR AMPLIFIER



transmitter end of the cable, so only 50% of the 12.5%, or 6.25% of the original transmitted power ever returns completely. At such a small level, the SWR at the transmitter end would measure about 1.7:1, even though it's really 3:1 at the antenna end! Not only are the readings misleading, but as shown there's a large difference in the actual radiated power between the top and bottom sketches.

Some Practical Coax Tips

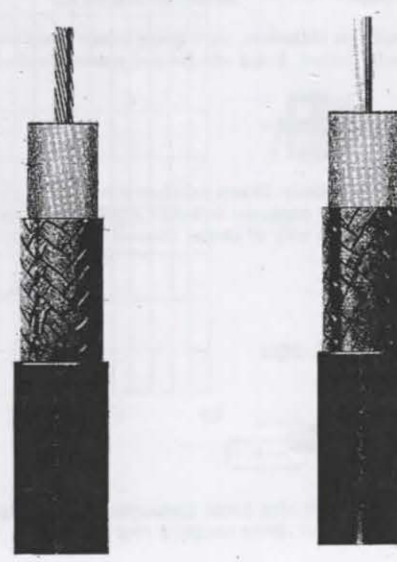
Coax losses are minimized by using quality coax and connectors, and by waterproofing all connections. The coax should specify at least 95% shield braid coverage. Examples: Alpha 9058, Belden 8259 or 8219 for RG58/U, Belden 8241 or 9259 for RG59/U, Belden 8261 or 9212 for RG11A/U, Alpha 9008/9008A, Belden 9251, 8214, Columbia C1198 for RG8/U, and Alpha 9213 or Belden 8267 for RG213/U. (Also the Amphenol equivalents.) RG58 comes with solid or stranded center conductors, electrically the same; use your own preference. You can always tell the good stuff by the density of the braid; the dielectric can't be seen through the braid. Figure 8-12 shows some examples of good coax having stranded and solid center conductors; note the tightness of the shield weave.

A major quality factor in coax, especially for base antennas, is the type of material used in the outer covering. The cheap stuff uses what's known as "Type I", which is PVC and is <u>not</u> suitable for outdoor use! This is what you'd find in preassembled lengths in many hobby stores. It's OK for runs inside the house, but will get brittle and crack outside in a matter of months. It contains a plasticizer to make it flexible, which also causes a chemical reaction or "migration" between the outer covering and the inner dielectric. This eventually ruins the impedance as the cable breaks down. The lifespan of Type I coax cable is only two years from the time of manufacture!

To avoid these problems, insist on "Type IIA" cables, which are made to military specs. These have a "non-contaminating" plastic covering, sometimes listed in catalogs as "NCV." They're more rigid but far superior. Examples are RG213/U, RG8<u>A</u>/U, RG11<u>A</u>/U, RG58<u>C</u>/U, and RG59<u>B</u>/U. So the difference between RG8/U and RG8A/U is that one uses ordinary PVC and the other uses

FIGURE 8-12

EXAMPLES OF GOOD COAX WITH 95% SHIELD COVER



non-contaminating vinyl. The NCV types have a useful outdoor life of up to twenty years. Incidentally, RG8/U is no longer made to Mil Spec because it's been replaced with RG213/U; but many low-end manufacturers have purposely kept the military numbers to mislead you. Insist on the real thing here!

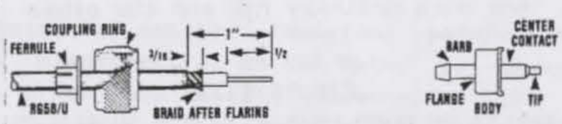
A common misconception is that the foam type cables are better because they have lower losses. This is only true until you install them outside! The sun's heat causes the center conductor to wander around inside the foam, eventually causing impedances changes. And the microscopic air bubbles in the foam attract moisture, also causing undesirable electrical changes. You're much better off with the stiffer, solid dielectric NCV cables from the start. RG213/U is my overall choice for base antennas; it's popular with cable TV companies and many professionals for 50Ω applications. The retail price is only about $0.30 per foot.

Splicing of coax should only be done with appropriate 50Ω "T" or double-female "barrel" connectors, never by direct pigtails on the wires. Hand splicing causes "impedance bumps" or mismatches, where the line is no longer 50 ohms at the splice point. The same is true for mobile slide mounts that use quick-disconnects for both coax and DC power. These not only ruin the impedance match, but the extra male/female splice increases signal loss. Better to ignore their coax section and connect directly to the back of the radio with a PL259 plug.

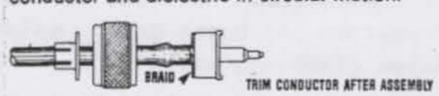
Water absortion ruins coax. When not properly sealed, water can soak right up the braid by capillary attraction, changing the dielectric properties and therefore the impedance. That's why some base antennas show drastic SWR changes in rainy weather. I've seen cases where water ran 20 or 30 feet into the cable from a poorly sealed connector! Don't spare the plastic electrician's tape. Or use a good silicone

FIGURE 8-13
PROPER ASSEMBLY OF COAX PLUGS ON CABLE
(Courtesy Amphenol Div. Bunker-Ramo Inc.)

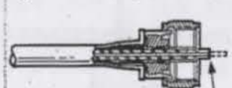
83-58FCP



1. Strip cable — *don't nick braid, dielectric or conductor.* Slide ferrule, then coupling ring on cable. Flare braid slightly by rotating conductor and dielectric in circular motion.

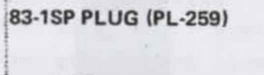


2. Slide body on dielectric, barb going under braid until flange is against outer jacket. Braid will fan out against body flange.



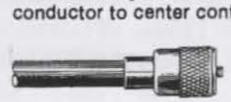
3. Slide nut over body. Grasp cable with hand and push ferrule over barb until braid is captured between ferrule and body flange. Squeeze crimp tip only of center contact with pliers; alternate-solder tip.

83-1SP PLUG (PL-259)



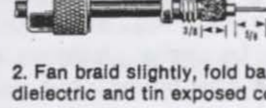
1. Strip cable, *don't nick braid, dielectric or conductor.* Tin exposed braid and conductor. Slide coupling ring on cable.

2. Screw body on cable. Solder braid through solder holes. Solder conductor to center contact.

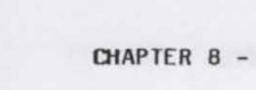


3. Screw coupling ring on body.

83-1SP PLUG WITH ADAPTERS



1. Strip jacket. *Don't nick braid.* Slide coupling ring and adapter on cable. Note — use 83-168 adapter for RG-58/U and 83-185 for RG-59/U.



2. Fan braid slightly, fold back over adapter and trim to 3/8". Strip dielectric and tin exposed conductor. *Don't nick conductor.*

3. Screw body on adapter. Follow 2 and 3 under 83-1SP plug.

rubber sealant such as Radio Shack #64-2314, G.E. 361, or GC Electronics #10-150. Cheap coax gets lossy with age, so expect periodic cable replacement every few years unless the installation already uses the better NCV types.

Coax connector installation can be tricky, and often makes the difference between a system that works right and one that's intermittent or lossy. Refer to Figure 8-13 for the correct installation of the RG58/U and RG8/U type connectors. The solderless Amphenol 83-58FCP is highly recommended for RG58/U instead of the standard PL259 plug, since there's no tricky shield soldering to worry about.

Summary

I hope that I've emphasized the importance of correct SWR measurement and interpretation, and the need for quality coax cable. For mobile installations, cable losses aren't significant and the connection of SWR meters at the antenna end isn't practical. RG58 cable is perfectly acceptable and can be measured from the radio end. But if you have doubts about mobile SWR readings, add a temporary 7' coax test section in series with the 17' line from the packaged antenna. This 24' total makes a full-wavelength line, which is the same as two 1/2-wavelengths for impedance-repeating purposes.

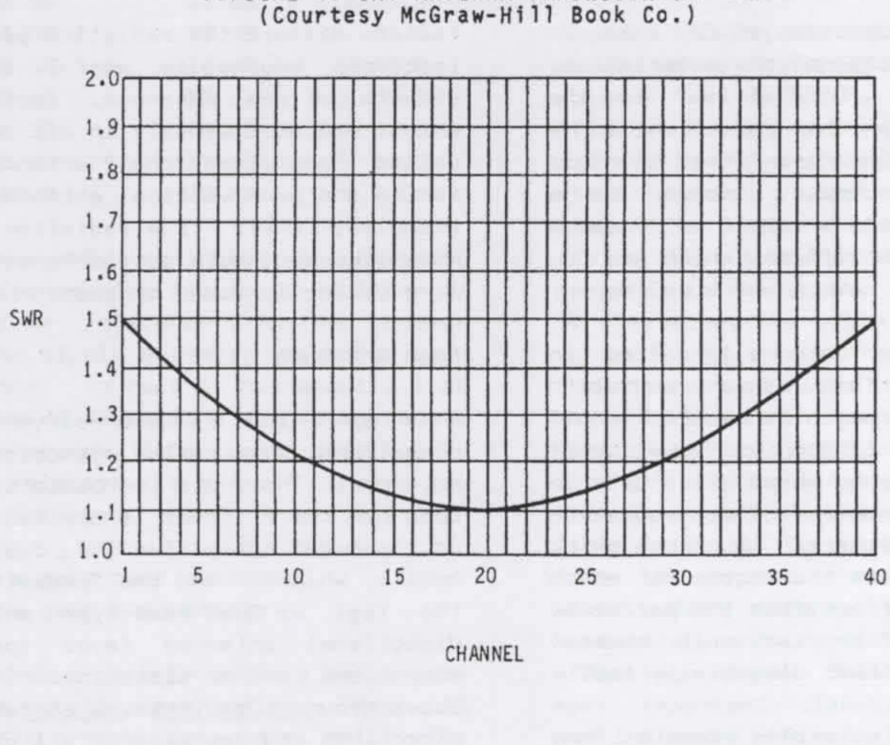
For base installations it's worth the extra effort to meter the antenna end, even though it takes two people yelling back and forth while the adjustments are made. Always use the shortest possible length of RG8A/U or RG213/U coax. For really long runs where money is no object, consider the superior RG214/U; this is double-shielded with a silver-plated shield and center conductor, priced about $1.50 per foot.

ANTENNA BANDWIDTH

The "bandwidth" of an antenna refers to the range of frequencies over which it can work with minimum reactance. Figure 8-14 shows a typical CB antenna bandwidth response as a function of SWR. The factor having the greatest effect on bandwidth is the physical size of the conductor; specifically, the ratio of length to diameter, or L ÷ D. The smaller this ratio, the more broadbanded it will be, and the higher the ratio, the more critical or narrowbanded its tuning over the desired frequency range.

This antenna characteristic corresponds exactly to the Q of ordinary LC tuned circuits, where low-Q circuits have relatively small reactance changes with frequency changes, and high-Q circuits have large reactance changes. Thus a thick antenna (like aluminum tubing) is more broadbanded than a thin steel whip or a wire

FIGURE 8-14
TYPICAL 40-CH. ANTENNA BANDWIDTH VS. SWR
(Courtesy McGraw-Hill Book Co.)



wound on a fiberglass rod. This is one reason base CB antennas are generally more broadbanded and easier to match than mobile antennas. The L/D ratio has little effect on actual radiation resistance, but a great effect on reactance.

This basic principle makes more sense when you consider it in terms of the effective Q. Using the standard formula,

$$Q = \frac{X}{R}$$

where X = reactance
R = radiation resistance,

you can see that Q increases as reactance increases, assuming a constant radiation resistance. As the antenna gets shorter and shorter relative to a 1/2-wavelength the capacitive reactance increases, which increases the Q. It must be loaded with more and more inductance to compensate and make it resonant. Thus the shorter the antenna, the more narrowbanded it becomes. For example, cutting 1" from a 102" steel whip would have little effect on SWR, but that same 1" off a typical 40" loaded whip causes a drastic SWR change.

This explains why short loaded mobile antennas are so much harder to match than full-size versions. It also explains why base-loaded whips with oversize coils (A/S "Formula 1" and A/S MR510 "Big Momma," K-40, Hustler "Super Resonator", etc.) are more broadbanded than those with standard coils on the same whip length. The standard and oversize coils may have exactly the same inductance values, but the larger coil has a lower Q; it has heavier wire and fewer turns on a larger diameter, lowering the L/D ratio. The heavier wire also has less DC resistance, so the radiation resistance remains high relative to DC resistance and heating losses are minimized.

Poor bandwidth is more of a problem now than it used to be, due to the inevitable channel expansion of most American models, and the popularity of export radios having up to 240 channels. This is especially true for mobile operation, where loaded whips are naturally more critical than full-size base antennas. For example, my President Jackson when used with a 1/2-wave Shakespeare "Big Stick" base antenna will cover about 160 of its 225 channels with a maximum 2:1 SWR, increasing rapidly beyond that. There's little you can do about this without using an antenna tuner to extend the range of reactance adjustments. Tuners may be practical for base operation, but obviously inconvenient for mobile use.

GAIN & DIRECTIVITY

Two other important properties of CB antennas are their gain and directional characteristics, both closely related. "Directivity" is the ability to concentrate the radiation in a specific direction. "Gain" or "Power Gain" is the apparent power increase compared to a standard antenna. There's a subtle difference here from the gain in amplifiers, which are DC-powered; antennas don't have power supplies.

The standard comparison antenna is called an "isotropic radiator." This is a radiation source where signal strength is exactly equal at all points equidistant from it. Visualize it as a pinpoint of RF energy whose electrostatic field forms a perfect sphere. Since radiation is exactly equal everywhere, it has no gain. Antenna gain is therefore the degree to which the actual radiation differs from the perfectly spherical radiation of an isotropic source. There can be no gain without directivity too.

Perfect antennas aren't possible, because many factors distort the radiation pattern. But the isotropic source is useful to compare the effects of real antennas. Isotropic antennas which radiate equally in all directions are called "omnidirectional" antennas. The common mobile and base vertical antennas are practical examples; their true radiation patterns look more like doughnuts or flattened balloons than like perfectly round spheres.

Beam Antennas

Antennas which radiate well only in certain directions are called directional or "beam" antennas. There are two basic types, depending upon how the RF power is applied: the "driven" or "phased" array like the dual mirror-mount mobile whips, and the "parasitic" array like the Yagi or Quad base type antenna. Because directional antennas favor specific compass directions and/or elevations (vertical angle above ground), radio waves concentrate in those directions and decrease in all others.

This apparent power increase compared to omnidirectional antennas has exactly the same effect as if it resulted from increasing the transmitter power. It has this effect on received signals too, amplifying those from the favored direction and rejecting all others. A beam's increase in signal strength over a non-directional antenna is called its "forward gain." Beams are commonly used to compensate for the low CB transmitter power limits.

Measurement of Gain

Signal strength follows the Inverse Square Law, decreasing logarithmically with distance. It's convenient to describe antenna gain in terms of decibels, which are a logarithmic function. The standard dB power factors described earlier also apply to antennas. For example, an antenna having 3 dB power gain means that its effective strength is double (x2) that of an antenna with 0 dB gain. Put another way, this means a 4-watt transmitter using a 3 dB gain antenna has the same effective signal strength as an 8-watt transmitter using a 0 dB gain antenna. The following summarizes the power multiplication factors for practical CB antennas:

dB GAIN	POWER FACTOR	dB GAIN	POWER FACTOR
1 dB =	x 1.26	11 dB =	x 12.6
2 dB =	x 1.60	12 dB =	x 15.8
3 dB =	x 2.00	13 dB =	x 20.0
4 dB =	x 2.50	14 dB =	x 25.1
5 dB =	x 3.00	15 dB =	x 31.6
6 dB =	x 4.00	16 dB =	x 40.0
7 dB =	x 5.00	17 dB =	x 50.1
8 dB =	x 6.30	18 dB =	x 63.1
9 dB =	x 8.00	19 dB =	x 80.0
10 dB =	x 10.0	20 dB =	x 100.4

Gain figures are only meaningful when compared to a known reference. The isotropic radiator is only one possible reference. Another common reference is the dipole antenna, which has gain in two directions. In fact it has about 2.1 dB gain in the favored directions when compared to an isotropic reference. It's common practice to specify gain relative to one of these two references, as follows:

dBi = gain over isotropic
dBd = gain over dipole

Thus to state that a certain antenna has a gain of "7.5 dB" is totally meaningless. Most CB operators don't know this and fall for misleading claims by manufacturers. For example, a two-element Yagi beam has a theoretical gain of about 7.5 dBi, which is the equivalent of 7.5 dB - 2.1 dB = 5.4 dBd. Not so impressive when expressed this way, is it? Manufacturers are famous for using dBi (often without telling you), since it's always a bigger number and therefore more impressive. Be aware! Demand to know their reference point.

Front-To-Back Ratio

Since directional antennas have power gain for receiving too, the relative signal strengths from the desired and undesired directions can also be compared and expressed in dB. For a beam antenna this is called its "Front-to-Back" ratio, or F/B. The "front" is the desired direction and the "back" is 180° opposite; i.e., if the front is facing East, the back is West, etc. So a "25 dB F/B" means that signals received from the East direction will be 25 dB stronger than comparable signals from the West.

Some antennas are "bidirectional," meaning stronger in two directions (say, East/West) and weaker in the two perpendicular directions. (North/South.) Practical examples are the dual co-phased trucker whips. For such antennas it's really more accurate to discuss "Front-to-Side" rather than Front-to-Back power ratios.

ANTENNA RADIATION PATTERNS & FIELD STRENGTH

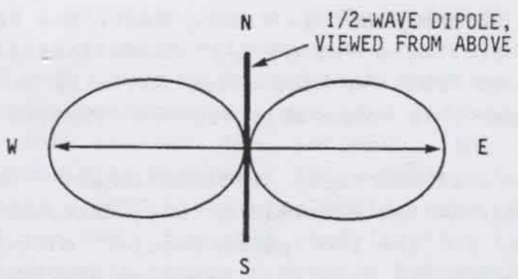
A graph showing the relative strength of radio waves as a function of direction from the antenna is called a "radiation pattern" or "field intensity pattern." All real antennas radiate in three dimensions, making it hard to visualize in a book drawing, so use some imagination here. The most important radiation fields are those in the horizontal plane or parallel to the earth, and the vertical plane or elevation, the angle above the earth.

The concept of field intensity is not the same as polarization. Most CB communications is vertically polarized, but the actual field strength varies greatly. Polarization is the orientation of the waves relative to the earth; field intensity is the total strength resulting from the entire three-dimensional field of waves. Each antenna type will have different horizontal and vertical radiation patterns affecting range. This section describes their most important directional qualities. Later we'll discuss SWR matching methods for each.

The 1/2-Wave Dipole

The basis for studying horizontal radiation is the 1/2-wave dipole. It's rarely used for CB though because it's horizontally polarized, being wire or tubing mounted parallel to the earth's surface. The pattern is bidirectional, with the strongest field at right angles to the direction of the wire. The typical "Figure 8" pattern of a 1/2-wave horizontal dipole antenna is shown in Figure 8-15. The strong directions are called the "lobes" and the weak ones the "nulls." In this example the lobes go East and West, the nulls North and South.

FIGURE 8-15
HORIZONTAL PATTERN OF 1/2-WAVE DIPOLE

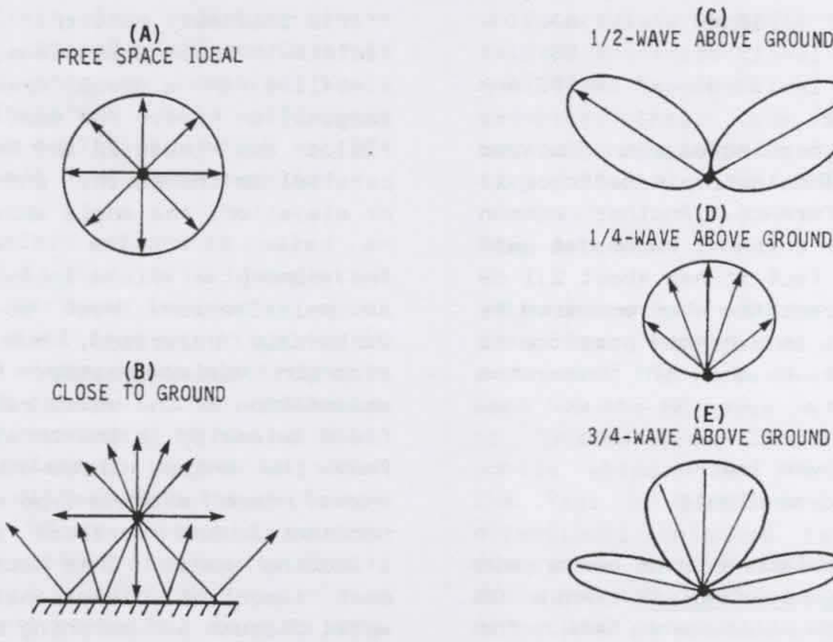


What about its vertical pattern? The dipole is radiating not only East and West, but also towards the sky and the earth, since antennas have three-dimensional fields. Therefore it also has a vertical radiation pattern to consider. This is especially true for base antennas because the height above ground has a direct effect on the vertical radiation angle of the strongest lobe(s). You can't do much about the effects of height in a mobile installation, but you can for a base antenna.

The effect of height above ground is shown in Figure 8-16. Figure 8-16A represents a 1/2-wave dipole in free space. Imagine it's a horizontal wire sticking straight up out of the page at you, which is why you see just a dot; you're looking at it from one end. Under perfect isotropic conditions the field around the wire would be exactly the same in all directions, so the pattern shown is a perfect circle.

A real antenna isn't perfect. If placed closer to the ground (Figure 8-16B), some of the downward waves will bounce off the ground and be reflected back towards the antenna. Whenever a radio wave bounces off an object, its phase reverses. In Figure 8-16C the antenna is a 1/2-wavelength above ground, which means it takes the time of one full wavelength to travel to

FIGURE 8-16
HOW VERTICAL RADIATION CHANGES
AS A FUNCTION OF HEIGHT ABOVE GROUND
(Viewed end-on)



the ground and bounce back; 1/2 + 1/2 = 1. The reflected wave reaches the antenna just as the next wave appears, but exactly out of phase with it. This cancels the upward radiation, resulting in two main lobes with the maximum strength about 30° above the horizon.

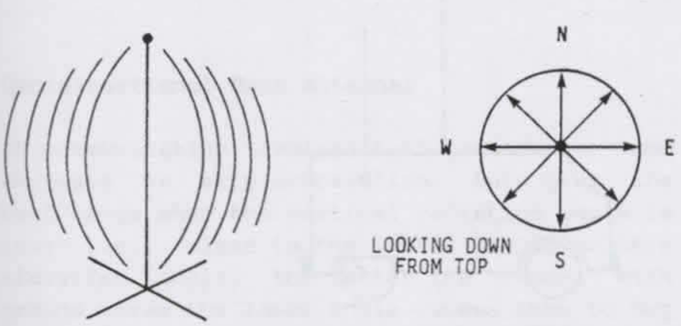
In Figure 8-16D the antenna has been lowered to a 1/4-wavelength above ground, so some of the reflected waves arrive in phase and add to the vertical radiation. The elevation angle of the strongest field is now higher above the horizon. This partly explains why mobile CBs have less ground-wave range than the higher base antennas; the higher angle of a mobile whip sees a closer horizon than that possible in a base, so the wave can't travel as far. At 3/4-wavelength above ground (Figure 8-16E), the effect is a combination of the 1/2-wave and 1/4-wave height, increasing both the horizontal and vertical lobes. As the height is raised still further more lobes develop, one for each additional 1/4-wavelength above ground.

By the way, these sketches show the lobes and nulls as being very sharply defined. In reality the imperfectly-conducting earth and shifting phases cause them to blend together somewhat. Don't take these mounting heights too literally when planning a base antenna installation.

Omnidirectional Mobile Antennas

Most mobile and base CB antennas consist of a single vertical radiating element. The horizontal radiation is equal in all compass directions, assuming there aren't any nearby objects or irregular ground conditions to distort the pattern. (In practice there always are.) Figure 8-17 shows the ideal horizontal pattern of such antennas. Note it's also a perfect circle like the ideal dipole, but this time it's rotated 90° so you're looking down on its top instead of horizontally end-on.

FIGURE 8-17
OMNIDIRECTIONAL RADIATION PATTERN
OF VERTICAL ANTENNA



In a real installation this pattern will be distorted. The worst distortion occurs in mobile operations when the whip is mounted somewhere other than the exact center of the roof; i.e., the "ground plane" is irregular. The strongest field will generally be in the direction of the greatest mass of vehicle body. With the antenna in the center of the roof the mass is roughly equal in all compass directions and this is usually the best location, although not always practical with long whips or low garages. With the whip on the trunk lid or a corner of the rear bumper, the pattern is distorted. Figure 8-18 shows this effect.

<u>Never</u> mount the whip on the bumper of a van or camper; the close proximity to the body not only distorts the pattern, but the coupling capacitance between the whip and vehicle body causes a serious SWR mismatch. Mount the whip up as high as possible. See Figure 8-19.

Effect Of Loading Coils On Field Strength

Loading coils are added to most mobile CB antennas to compensate for capacitive reactance; i.e., the antenna is physically shorter than the required electrical length. In addition to the whip mounting location, the location of the loading coil on the whip can have a marked effect on performance.

The larger the antenna current, the greater the field strength. Since reactance limits current flow, the only part of a loaded antenna that carries a significant current is that section <u>before</u> the loading coil. Thus with base loading there's very little current in the rod. With center loading there's current from the center down, and with top loading (or the full-size steel or fiberglass whip), current flows along the entire length. ("Top-loaded" fiberglass CB whips aren't truly top-loaded; the wire's concentrated at the top, but is continuously or helically wound along the entire length. This effects its current distribution.) The straight length before the coil also affects radiation resistance, being higher with center or top loading than with base loading. This makes it easier to transfer power, since from Ohm's Law $P = I^2R$, and "R" is higher with top loading.

FIGURE 8-18
RADIATION PATTERNS OF MOBILE ANTENNAS
BY MOUNTING LOCATION

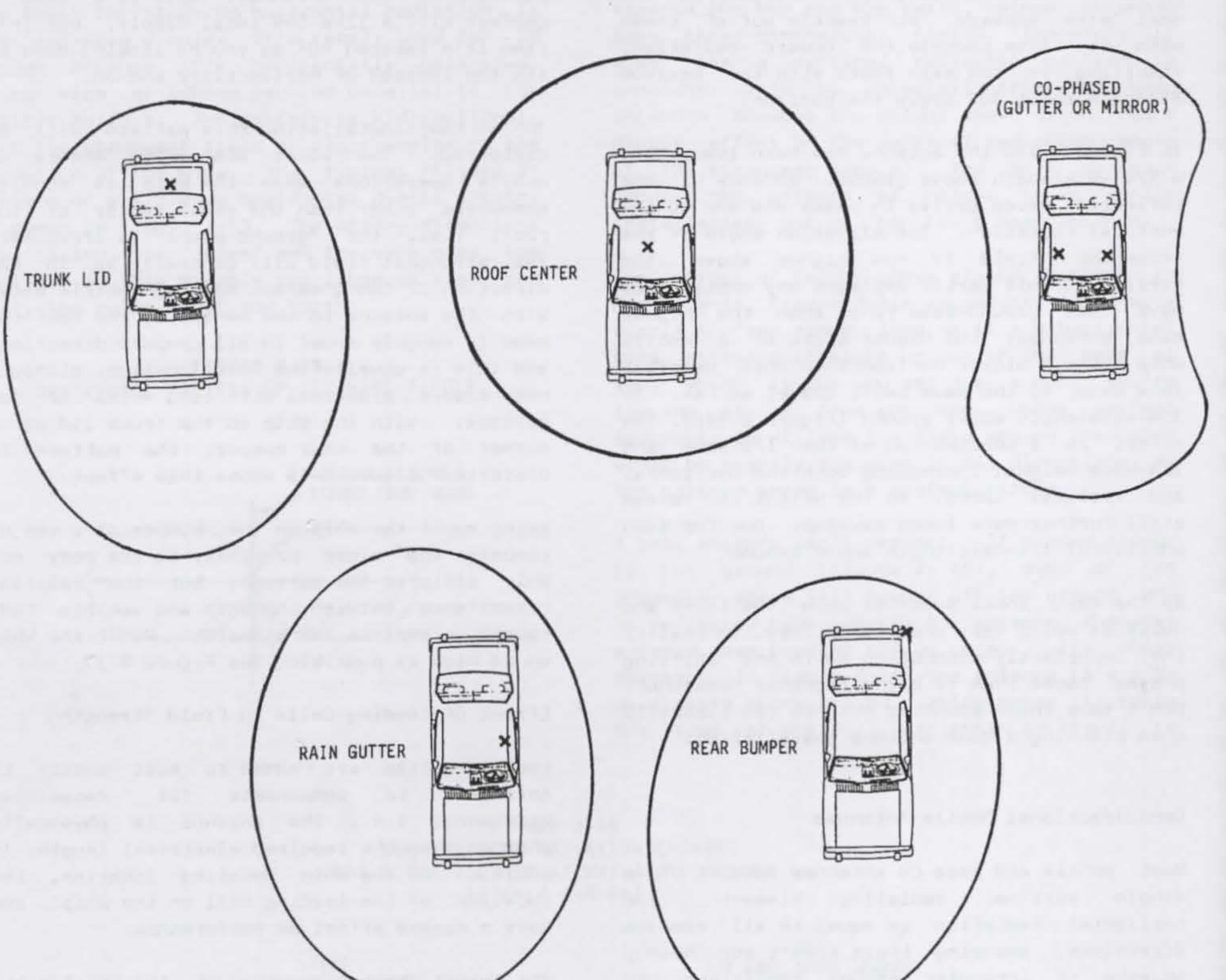
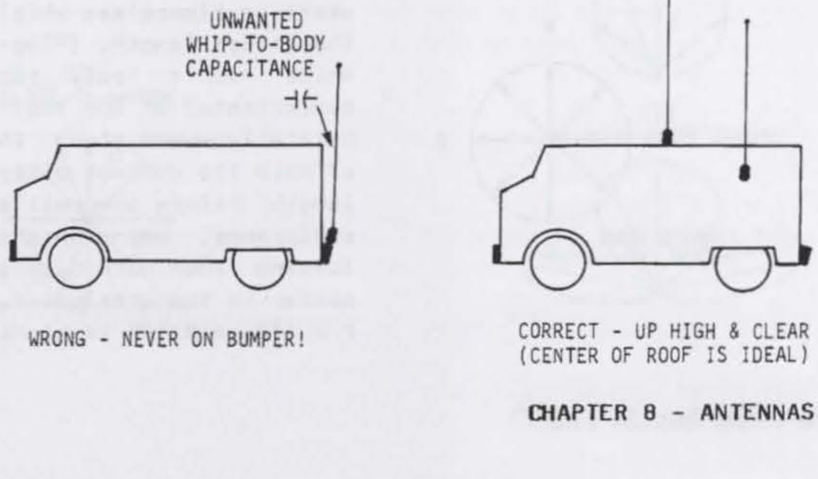


FIGURE 8-19
WHIP MOUNTING ON A VAN



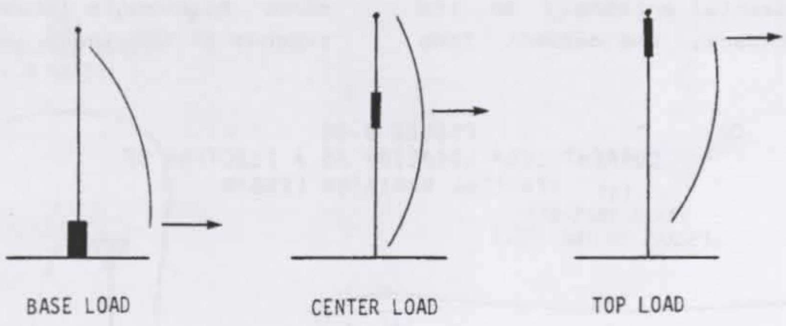
All other things being equal, top loading would have the best range of loaded whips, since the main lobe is highest above ground and therefore sees the furthest horizon. This is like seeing further from the roof of a building than from the ground floor. Figure 8-20 illustrates this effect. Of course the full-size 102" whip has the advantages of full radiation and no coil losses. But these advantages are offset by wind loading at high speeds, bending the whip away from pure vertical polarization.

Before dismissing base-loaded antennas as poor performers, consider this: in loaded whips, the capacitance of just that section above the loading coil appears across its coil. With base loading, the capacitive reactance is a function of the entire whip length. As the loading coil is raised though, the amount of whip remaining above the coil is shorter, increasing the capacitive reactance. This means more inductive reactance will be needed to resonate it, and that means a bigger coil. A bigger coil means more turns and thinner wire, increasing the DC resistance and therefore losing some of its advantage. You could always make the coil physically bigger to offset these losses, but then there's the problem of increased wind drag! Antenna Specialists makes at least one center-loaded whip model using oversize "beer can" loading coils to minimize such losses.

Selecting a good mobile antenna is therefore a compromise between available mounting location and hardware, physical size, type of loading, wind drag, looks, and of course price. For every guy who says his K-40 works best, there's another guy claiming the same for his PAL Firestik. As a general rule, I recommend mobile antennas at least 40" or longer. Any of the better brands like A/S, Francis, Hustler, K-40, PAL Firestik, and Shakespeare will meet this criterion and give excellent and comparable results. Avoid antenna "bargains" when you buy!

The cover of this book shows me adjusting a Hustler HQ-27 center-loaded whip on my car. Except for the mounting hardware, this is the very same whip that's used in the Hustler "Twin Huskies" popular with truckers. I use a bayonet type 3/8" x 24 quick-disconnect with a special two-piece hideaway mount. Unlike standard trunk lid mounts, everything shown in the picture can be removed and thrown in the trunk when not needed, leaving no exposed mounting base visible to would-be thieves. The HQ-27 is sold with many types of mounts. It's 55" long and works quite well. (For example, I've worked Alaska from Phoenix on 4 W when the skip's in!)

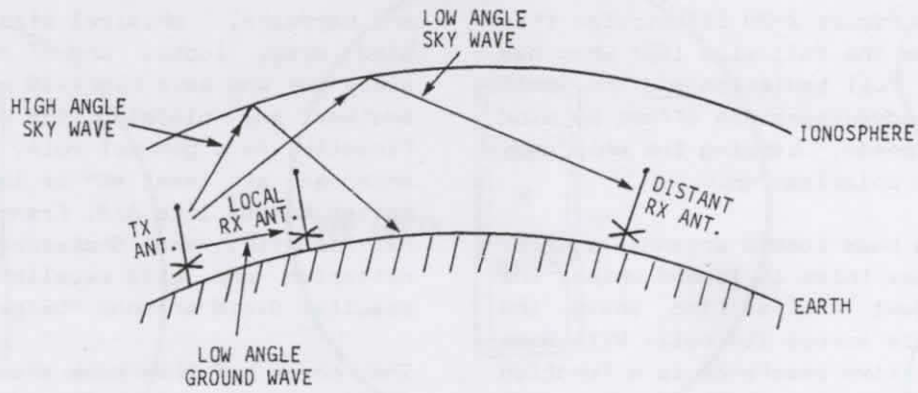
FIGURE 8-20
RF CURRENT DISTRIBUTION AS A FUNCTION
OF LOADING COIL LOCATION



Omnidirectional Base Antennas

CB communication involves both ground-wave and sky-wave or skip propagation. Both give the best range when the vertical radiation angle is low; i.e., close to the earth. The lower this elevation angle, the better the range. With ground waves the lower angle causes them to hug the ground so they cover more distance before fading out. The same is true for skip waves; but instead of hugging the ground, the wave travels further towards the horizon before striking the earth's atmosphere and bouncing back to earth. The effect of both types is shown in Figure 8-21. Note that the sky waves are reflected at the same angle they originally struck the atmosphere, which means the lower angles result in the greatest skip range.

FIGURE 8-21
EFFECT OF VERTICAL RADIATION ANGLE ON COMMUNICATIONS DISTANCE



We've seen how the location of whip loading coils affects their vertical radiation angles. Similar effects occur on vertical base antennas. The location of the current loop still depends on the radiator length, which can be controlled to change the vertical radiation angle. But losses are much smaller on base antennas, since it's physically practical to use full-size radiators with no loading needed.

Omnidirectional base antennas come in three popular heights: the 1/4-wave, the 1/2-wave, and the 5/8-wave, corresponding to about 9', 18', and 22' respectively. Figure 8-22 shows the current distribution pattern for each. ("Height" in a vertical antenna means the same as "length" in a horizontal antenna.) As the radiator height increases, the current loop moves up the antenna, always reaching a peak a 1/4-wavelength below the top.

Raising the current loop lowers the vertical radiation angle, so the 5/8-wave antenna has the lowest angle and the 1/4-wave the highest. The lower the angle, the less radiation lost towards the sky. See Figure 8-23. Visualize this in three dimensions by starting with a perfectly round balloon; squeezing it from the top spreads it out further horizontally while maintaining the same volume or "field."

Up to about 5/8-wavelength, the main lobe angle is low and theoretically has about 2 dBd gain over a 1/4-wave radiator. Beyond this height, minor high-angle lobes begin to appear at the expense of the lower lobes. Thus the 1/2-wave

FIGURE 8-22
CURRENT LOOP LOCATION AS A FUNCTION OF
VERTICAL RADIATOR LENGTH

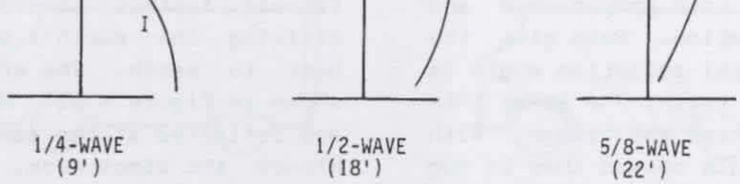
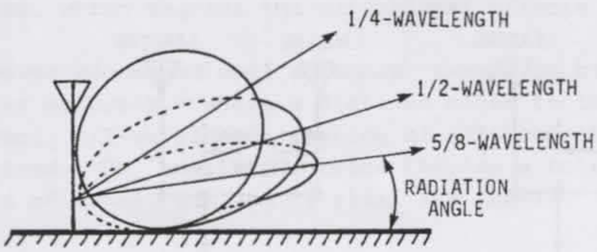


FIGURE 8-23
VERTICAL RADIATION ANGLE AS A FUNCTION OF VERTICAL ANTENNA LENGTH



and 5/8-wave antennas are the most effective omnidirectional types; 5/8-wave is the best you can do with just a single vertical element.

Since verticals are base-fed but the base isn't always the low impedance point, the 1/2-wave and 5/8-wave antennas generally need matching circuits to compensate for their higher base impedances. The 1/4-wave vertical can be fed directly by 50Ω coax with no special matching.

Directional Mobile Antennas

The most popular directional mobile antennas are the dual "trucker" mirror-mount whips. These come under the general category of driven arrays, where both whips are directly driven by the transmitter. The pattern is bidirectional like a dipole. This system was developed to solve the problem of field distortion caused by the large metal trailer, and the fact that truckers are most interested in communications up and down the road they're traveling. The field is usually strongest towards the front and back, although it's just as easy to make it perpendicular to the vehicle. Figure 8-24 shows both possible patterns.

These antennas work on the phasing principle. See Figure 8-25. If two vertical antennas are spaced a 1/2-wavelength apart and fed equal currents in phase, the radiation will be perpendicular to the line of the antennas. This is called a "broadside array" and is the usual case with truck installations. When the same whips are fed 180° out of phase, the radiation will be in line with the antennas and is known as an "end fire" array. Theoretically dual antennas have 3 dB gain over a single vertical radiator. The phasing is accomplished by controlling the whip spacing, and by feeding them with a special coax "phasing harness."

For the end-fire pattern, a 1/2-wave "phase delay" section using an extra 12' of coax could

FIGURE 8-24
HORIZONTAL RADIATION PATTERN OF CO-PHASED MOBILE WHIPS

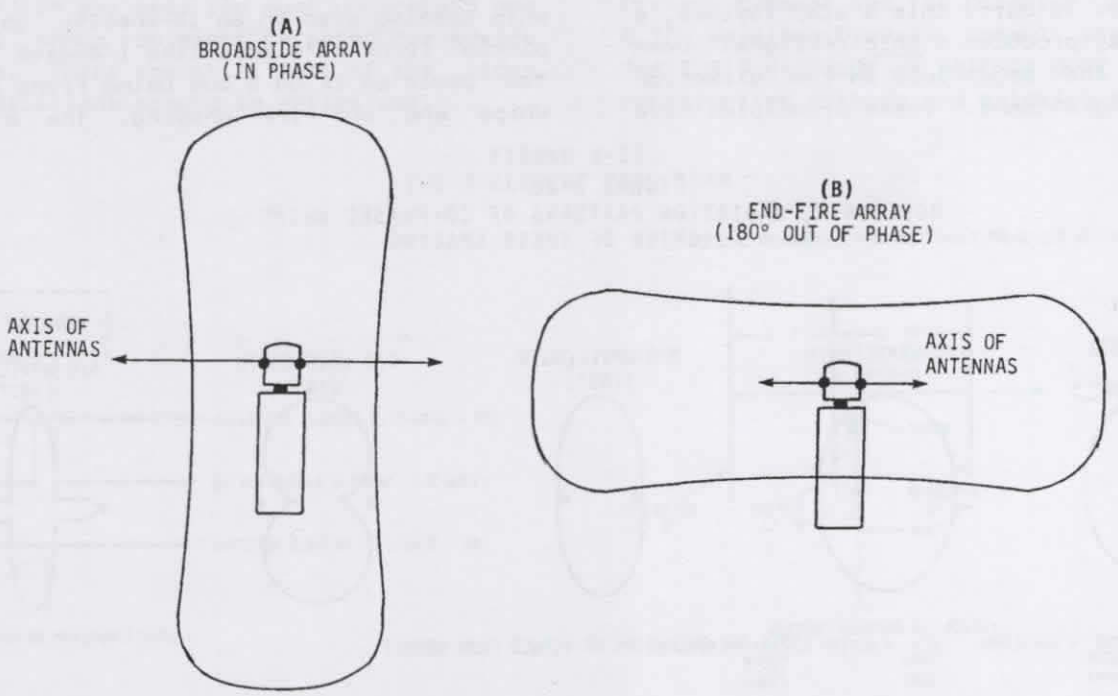
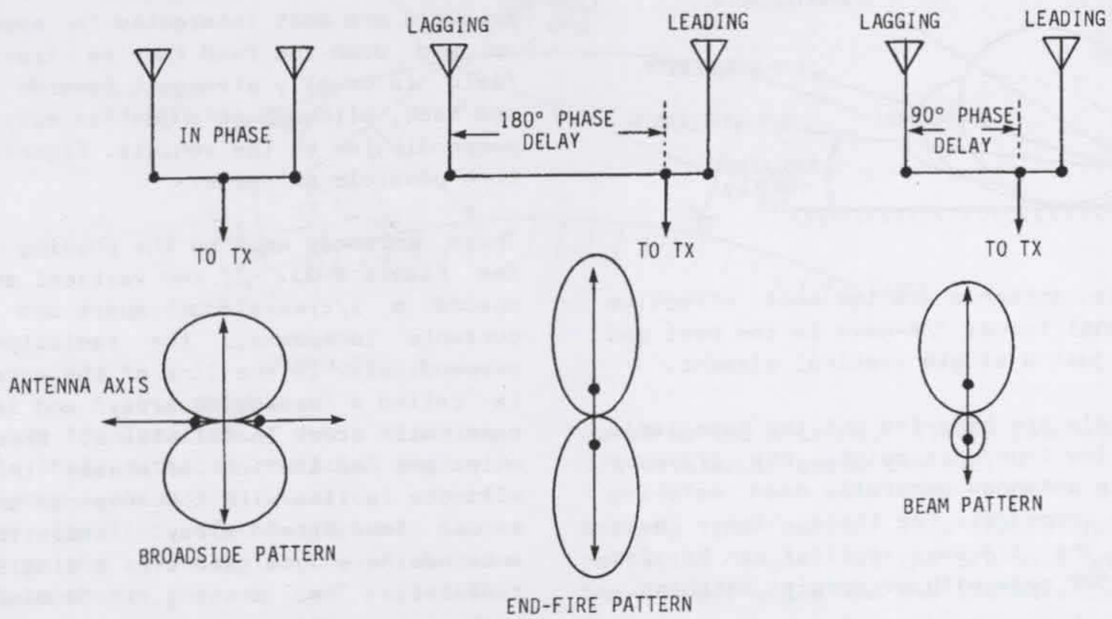


FIGURE 8-25

USE OF PHASING TO CONTROL RADIATION PATTERN



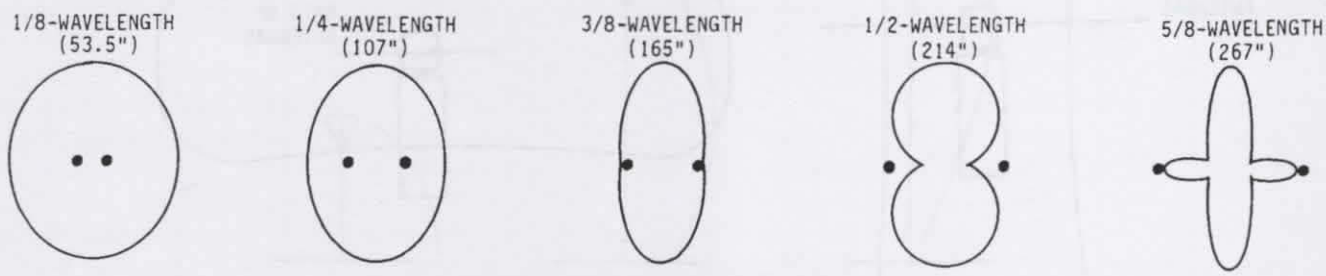
(THE DOTS ARE THE TWO VERTICALS AS VIEWED FROM ABOVE, SPACED 1/2-WAVELENGTH APART)

be added to one side of the balanced feedpoint, as shown. (12' is a 1/2-wavelength including the coax Velocity Factor.) This means the whip with the extra coax lags the leading whip by 180°, since its signal is delayed by that amount of time. To carry this a step further, a 90° phase delay produces a unidirectional beam antenna with the major lobe in the direction of the leading antenna. These principles have been applied for years in most directional AM broadcasting towers, and were simply copied for use in CB antennas.

In practice it's nearly impossible to get a 17' whip spacing even on an 18-wheeler. On a car or pickup trunk it's more like 1/4-wave spacing! You could do it on a bus using front and rear whips and end-fire phasing. The effect of

FIGURE 8-26

HORIZONTAL RADIATION PATTERNS OF CO-PHASED WHIPS AS A FUNCTION OF THEIR SPACING



(DOTS ARE THE WHIPS AS VIEWED FROM ABOVE) the different whip spacings is to distort the horizontal signal patterns. See Figure 8-26. Notice the 1/4-wavelength spacing adds only a tiny improvement ov∍r that of a single whip, and by 5/8-wavelength minor side lobes begin to appear, which degrade the directional effects.

I never recommend dual antennas except on big trucks or buses, where a distance close to the correct 1/2-wavelength spacing of 17' can be realized. On smaller vehicles they're a total waste of money. But you'll still see them!

DIRECTIONAL BASE ANTENNAS

Base beam antennas come under the general category of "parasitic" arrays, where only the "driven" element gets RF directly from the transmitter. The parasitic elements operate by induction of the radiated field from the driven element. CB parasitic beams commonly used are the Yagi (named after its Japanese inventor) and the Quad or Cubical Quad.

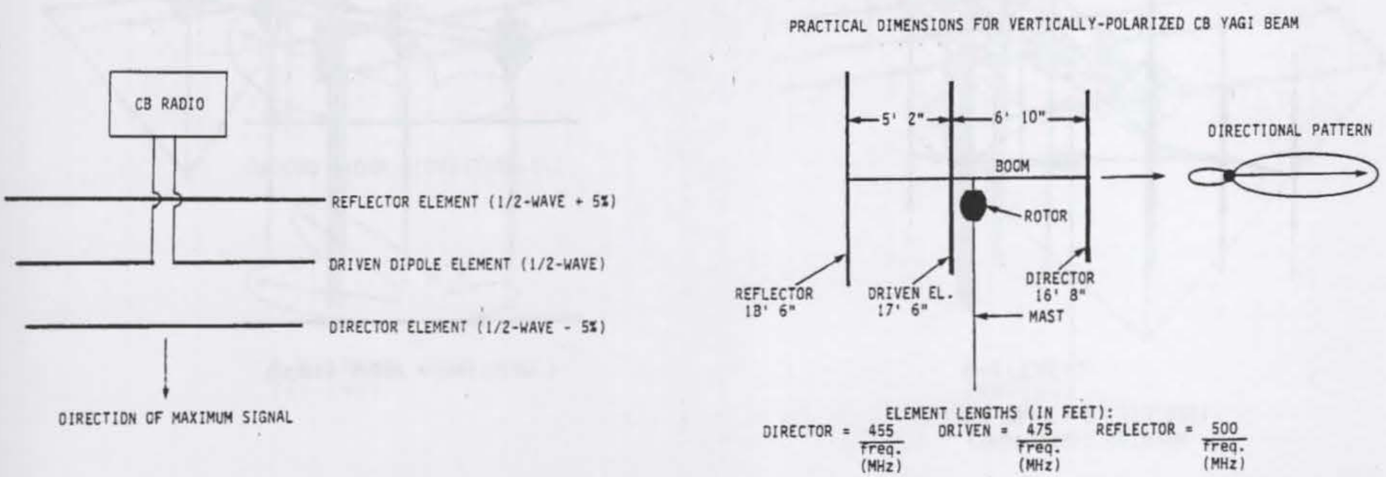
There are few American CB antenna companies still selling beams. Some brainless morons got fried by installing them next to high-voltage power lines, so the government naturally passed a law requiring manufacturers to add special insulation. Most companies decided the extra expense and hassle wasn't worth it, so they simply quit making them. You may find it challenging and educational to build your own; the design and mechanical construction tips are readily available from the antenna books in CHAPTER 1. In any case you must understand how they work, since you might be asked for advice or service. There are still lots of the older beam installations around in active use.

The Yagi Beam

The most common Yagi antenna is the 3-element beam, Figure 8-27. The elements consist of a driven element or 1/2-wave dipole fed by the transmitter, a parastic 1/2-wave element about 5% longer called the "reflector," and a parasitic element about 5% shorter called the "director." Maximum radiation is in the direction shown. When the parasitic elements are located within a 1/4-wavelength of the driven element (the usual case), the current phasing either subtracts from or adds to the field from the driven element. With reflectors the waves are reflected back towards the driven element, and with directors they're absorbed and re-radiated in the forward direction.

The beam has about 7.5 dBd forward gain, a six-fold power increase. (A 4-watt CB sounds like 24 watts using a dipole!) The F/B ratio is typically 20-25 dB, which will greatly improve reception from the power gain in the desired direction and the rejection from the unwanted directions. This drawing shows the beam vertically polarized for CB use, but in Ham or TV applications it's horizontally polarized. In any case, the signal is so concentrated that a remotely-controlled electric motor (rotator) is needed to aim it in the desired direction. Some practical dimensions are shown for builders, as well as the most practical formulas for calculating the element lengths. Generally the best overall performance occurs with the Reflector spaced about 0.15 wavelength from the Driven Element and the Director spaced about 0.20 wavelength away. Consult the ARRL RADIO AMATEUR'S HANDBOOK or ANTENNA BOOK for detailed construction methods and matching networks.

FIGURE 8-27
THE 3-ELEMENT YAGI BEAM



The gain and F/B can be further improved by adding more directors, but eventually you reach a point of diminishing returns and mechanical support problems. Commercial CB Yagis are generally limited to 5 elements, which gives almost 10 dBd gain. The Hustler Co. still sells a 4-element Yagi (Model #11-MB4) which has a power gain of 9.4 dBd and a 28 dB F/B ratio.

A pair of Yagis can be stacked on a common boom and fed with a phasing line for even more gain and directivity. See Figure 8-28. (And also Figure 8-43.) By doubling the number of Yagis a theoretical extra gain of 3 dB is possible, assuming the same number of elements in both. The spacing between Yagis is important, and must be at least a 1/2-wavelength for good gain. Under a 1/2-wavelength the gain falls off but the Front-to-Side ratio improves. At 27 MHz the physical support, wind drag, and required rotator torque make them too impractical and expensive for most CB operators.

The most important design considerations for the Yagi include forward gain, F/B ratio, bandwidth, and input impedance. Unfortunately the best of each characteristic rarely occurs at the same physical spacing and dimensions! The spacing for maximum gain is different than the spacing for maximum F/B, and so forth. Suffice to say that with commercial CB beams, the engineers already made the best overall compromise when they designed it. Figure 8-27 indicated the most practical dimensions.

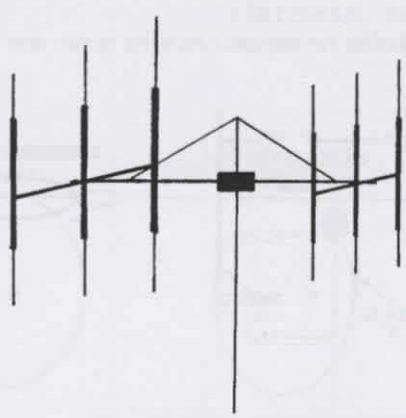
The same height-above-ground patterns for dipoles also apply to Yagi and Quad beams. Figure 8-29 shows the vertical patterns for a 3-element Yagi at a 1/2-wavelength and one wavelength above an ideal ground, viewed from one side. At a 1/2-wavelength there's one major lobe concentrated about 30° above the horizon. Increasing the height to one wavelength yields two lobes at about 15° and 45° elevation. The lower lobe can improve the DX and ground-wave propagation, while the higher lobe is sometimes useful during short skip conditions.

The Cubical Quad Beam

The other major parasitic beam is the Quad. Figure 8-30 summarizes its main characteristics and design dimensions. It consists of two or more closed one-wavelength wire loops in a diamond or square shape. The first parasitic element is generally chosen to be a reflector; additional elements will be directors. Each full-wave loop has four 1/4-wavelength sides, hence the name. Like the Yagi, only one loop is driven; the reflector is about 3% longer than one wavelength and the director(s) about 3% shorter. Polarization is determined by the feedpoint location. Constructional details and matching methods are found in the antenna books described in CHAPTER 1.

Radiation patterns are like the Yagi. However the Quad has several advantages which make it extremely popular with DXers, and that's why

FIGURE 8-28
"STACKING" TWO 3-ELEMENT YAGIS FOR INCREASED GAIN & DIRECTIVITY



(SEE FIG. 8-43 FOR COAX HARNESS DIMENSIONS)

FIGURE 8-29
VERTICAL BEAM RADIATION PATTERNS (SIDE VIEW)

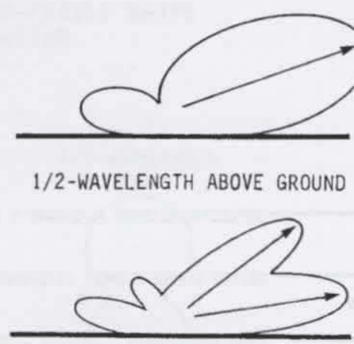
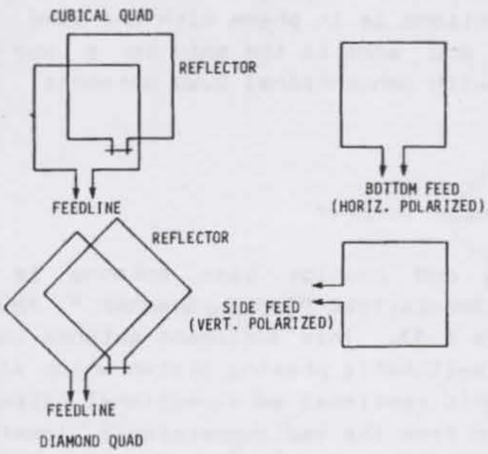
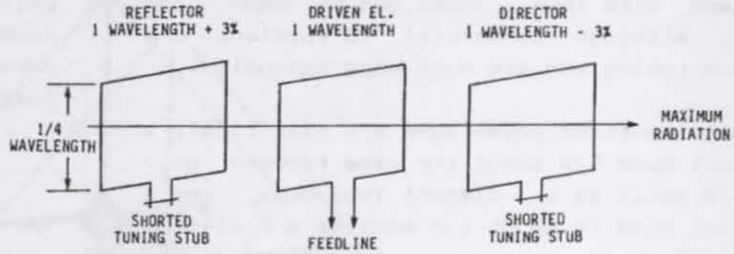


FIGURE 8-30
THE QUAD BEAM ANTENNA





PHYSICAL DIMENSIONS (IN FEET):

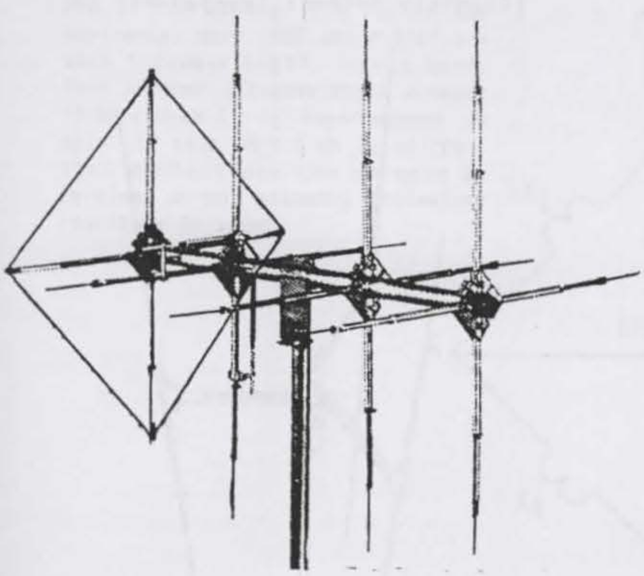
$$\text{DRIVEN EL.} = \frac{1005}{\text{FREQ. (MHz)}}$$

$$\text{REFLECTOR} = \frac{1030}{\text{FREQ. (MHz)}}$$

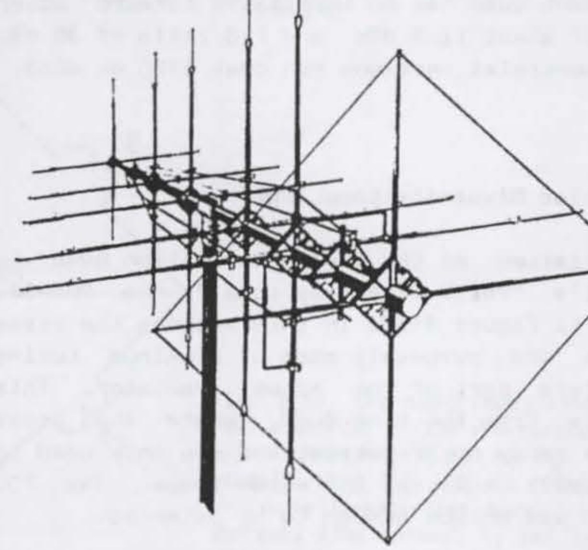
$$\text{DIRECTOR} = \frac{975}{\text{FREQ. (MHz)}}$$

ELEMENT SPACING: 0.15 TO 0.20 WAVELENGTH

FIGURE 8-31
MOONRAKER 4- & 6-ELEMENT HYBRID BEAMS
(Courtesy Antenna Specialists Co.)



4-ELEMENT
(AV-140)



6-ELEMENT
(AV-146)

they're still being made for CB use. From a constructional standpoint it's much simpler, needing only one short boom and an "X" frame for each wire loop. These can be made from bamboo, although commercial CB versions use aluminum tubing and are much more expensive.

The most important advantages are electrical: a 2-element Quad has about the same forward gain and F/B ratio as a 3-element Yagi beam, and a 3-element Quad is about the same as a 4-element Yagi, and so on. This saves on costs. A dipole or Yagi is practically useless as a DX antenna when less than a 1/2-wavelength above ground, but a Quad has a low radiation angle even at very low mounting heights. This means big, expensive towers aren't needed to make it effective. Finally, the Quad has much higher radiation resistance than a Yagi, simplifying RF power transfer from a 50Ω transceiver.

The best-known CB Quads are the Avanti PDL-II and Moonraker 4-element and 6-element, shown in Figure 8-31. (Avanti is now part of the Antenna Specialists Co. and is still sold through A/S distributors.) The Moonraker-4 and Moonraker-6 are actually Quad/Yagi hybrids. Only the driven element is a loop; the parasitic elements are crossed Yagis which allow both vertical and horizontal polarization by suitable feed switching of the driven loop. The reflector is designed around the "PDL" principle. (See the following description.) True Quads are still being made by the Signal Engineering Co. A CB 6-element Quad has an impressive forward power gain of about 11.5 dBd and F/B ratio of 30 dB. The commercial versions can cost $300 or more.

The Polar Diversity Loop (PDL)

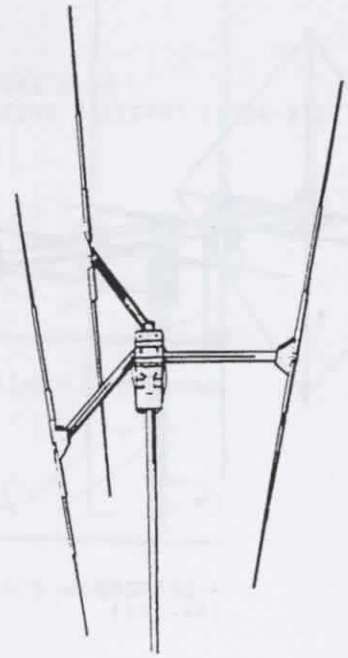
A variation on the dual-polarization Quad is Avanti's "Polar Diversity Loop," the PDL-II. Refer to Figure 8-32. In this antenna the cross braces are purposely made of aluminum tubing and form part of the actual radiator. This differs from the true Quad, where the cross braces carry no RF current and are only used to physically support the wire loops. The PDL design was unique enough to be patented.

Electrically the PDL resembles a Wheatstone bridge circuit; the tubing across each "V" adds another 1/2-wavelength such that horizontal and vertical signals are isolated from each other by the balancing effect of the bridge. This balance is remotely controlled at the radio location so the operator can choose the desired polarization. RF flowing in the extra 1/2-wave cross sections is in phase with the Quad loop currents and adds to the gain in a way not possible with conventional Quad antennas.

The A/S Super Scanner

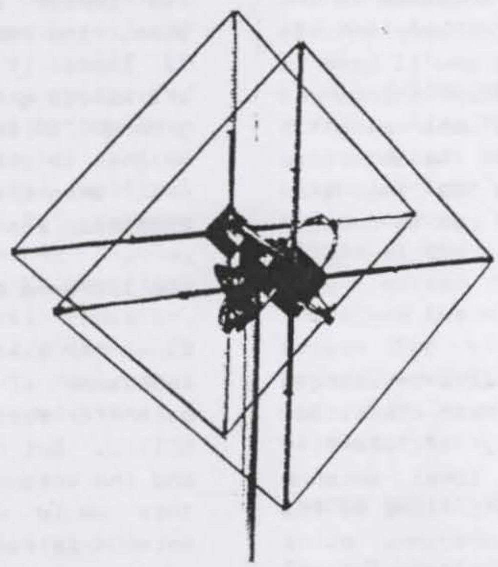
A unique and popular base antenna is the Antenna Specialists "Super Scanner," #MS119. See Figure 8-33. This 3-element antenna uses a special switchable phasing system which allows either omnidirectional or directional patterns, controlled from the radio operator's location. In the "Omni" mode all three elements are active, with some gain in all directions. In the "Beam" mode one compass direction is chosen which activates the appropriate two elements in the same vertical plane, like a Yagi beam. The main disadvantage is its limit of only three main lobe directions for a given mounting orientation. But it eliminates the need for an expensive rotator, and represents a very clever compromise for the standard Yagi antenna.

FIGURE 8-33
THE A/S "SUPER SCANNER"
(Courtesy Antenna Specialists Co.)



MS-119

FIGURE 8-32
THE POLAR DIVERSITY LOOP (PDL) BEAM ANTENNA
(Courtesy Antenna Specialists Co.)



PDL-II
(AV-122)

FIG. 1

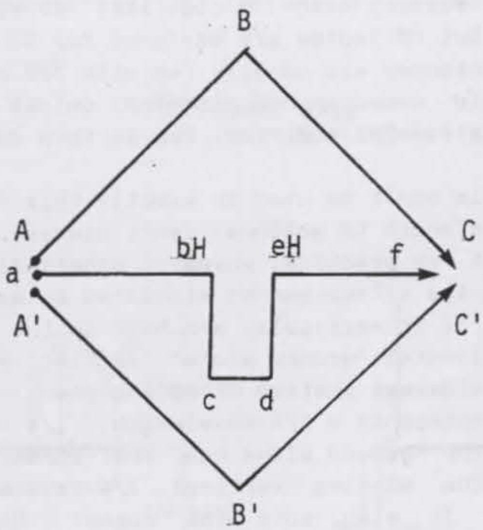


FIG. 1 represents the PDL in the horizontal mode. ABC and A'B'C' are each 1/2-wavelength, like a Quad. Then another 1/2-wavelength element (a-bH-c-d-eH-f) is superimposed on this. If stub bH-c-d-eH is omitted, then connections can be made at terminal bH-eH, assuming equivalent reactance is added.

FIG. 2

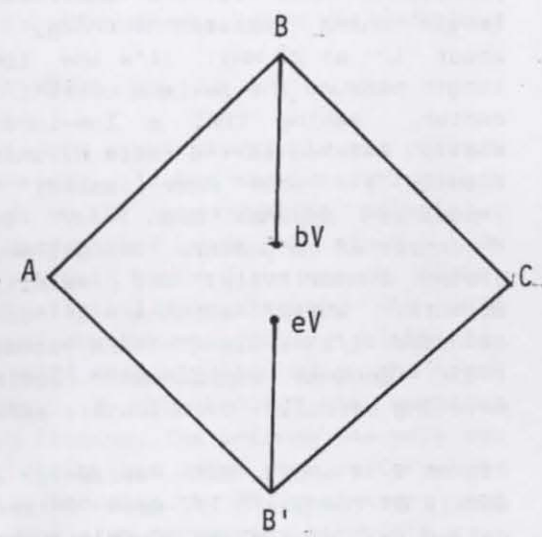


FIG. 2 shows the same loop connected for vertical polarity. Terminals are bV and eV.

FIG. 3

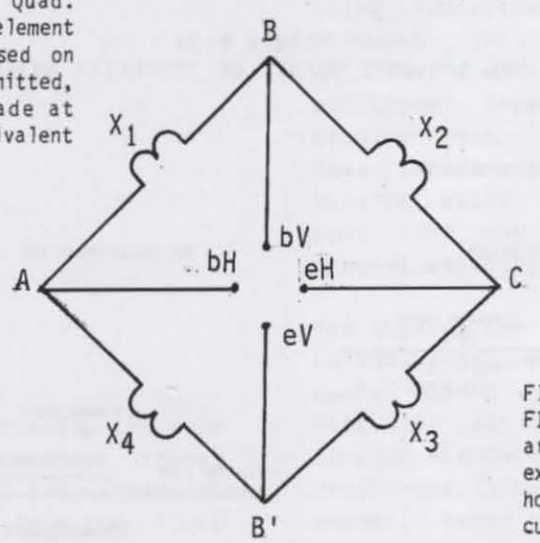


FIG. 3 is the superimposition of FIG. 1 on FIG. 2. The arm reactances are represented by X_1-X_4. For example, when the PDL is receiving horizontally-polarized waves, equal currents flow through X_1 and X_2 as well as X_3 and X_4; the bridge is balanced so that no voltage exists at B to B', thereby isolating the horizontal and vertical signals.

In this section we'll examine various methods for matching the most common CB antennas to the transmitter and coax cable. It's important to understand these principles so you'll have a better idea of where to look when things go wrong. Each basic antenna type uses slightly different matching circuits, but the objective is always the same: to create a 50Ω impedance at the antenna so maximum power can be coupled with minimum VSWR.

The 1/2-Wave Dipole Reference

Most CB antennas operate on the 1/2-wavelength principle. This is the shortest electrical length which radiates RF energy efficiently, about 17' at 27 MHz. It's the ideal antenna length because the maximum current flows at the center, making that a low-impedance point easily matched to the radio by inexpensive and readily available coax cables. The actual impedance depends upon many factors like thickness of conductors, height above ground, ground conductivity, and proximity to nearby objects. While antennas of other than a standard 1/2-wavelength are sometimes used, their unusual impedances require special matching circuits. Examples are covered later.

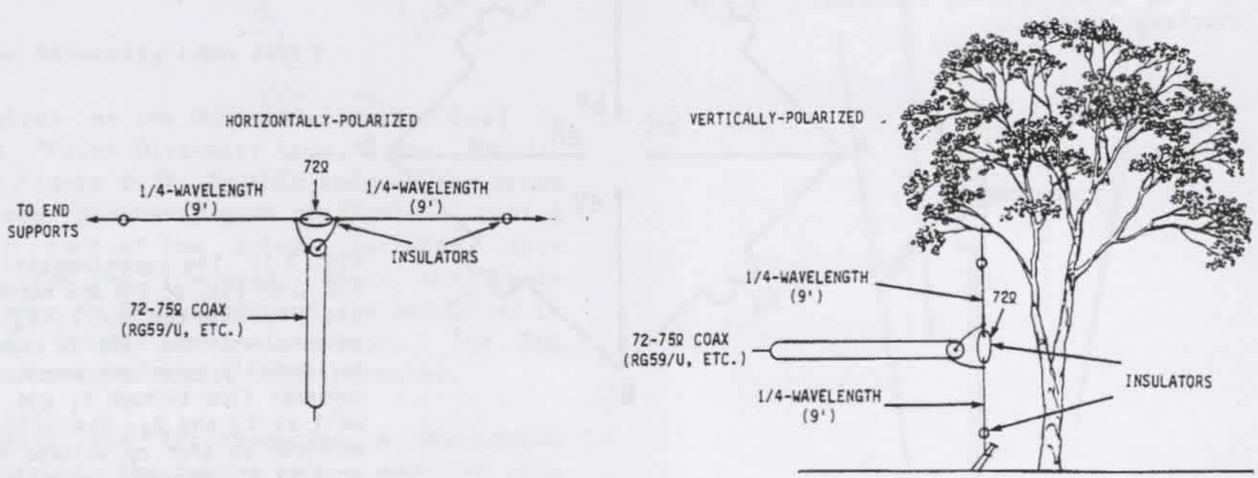
Figure 8-34 shows both horizontal and vertical models of the basic 1/2-wave antenna, usually called a "dipole" or "doublet" because it's split in half. Each half is a 1/4-wavelength long, or about 8.5'. When a dipole is opened at its center and connected to a transmission line, the nominal feedpoint impedance is about 72 ohms, <u>if</u> the antenna's mounted at least a 1/2-wavelength above a perfectly conducting ground. For base installations this 17' minimum height is easily achieved, but not in mobile use. When the height is closer to ground, the radiation resistance decreases considerably.

The 1/4-Wave Ground-Plane Antenna

Since the basic 1/2-wave dipole antenna has an impedance of 72 ohms, it makes an excellent match for feeding with 73Ω coax like RG59/U or RG11/U. But CB radios are designed for 50 ohms and the antennas are usually fed with 50Ω coax. This would cause an SWR mismatch unless the antenna is somehow modified. How is this done?

The dipole won't be used in exactly this form. A 1/2-wavelength CB antenna isn't always very convenient or practical anyway, especially on cars. But its effect can be simulated by making only half of it vertical, and half in the form of a horizontal "ground plane" section which goes off sideways instead of up and down. Each section represents a 1/4-wavelength; 1/4 + 1/4 = 1/2. The ground plane has the effect of adding the missing vertical 1/4-wavelength section. It also cuts the normal dipole impedance of 72Ω in half, or 72Ω ÷ 2 = 36 ohms. This makes a much closer match for 50Ω coax.

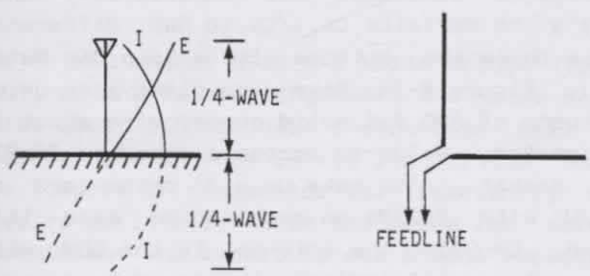
FIGURE 8-34
THE 1/2-WAVE DIPOLE OR "DOUBLET" ANTENNA



A ground plane can be formed using any large conducting surface at least a 1/4-wavelength long, although in practice it can be smaller. See Figure 8-35A. The 1/4-wavelength vertical radiator produces a mirror image of itself in the ground plane. Visualize it as a center-fed dipole which instead of being straight has been bent into an "L" shape; the horizontal part of the "L" is the ground plane and the vertical part is the radiator. A simple "L" antenna would be bidirectional like any other dipole, but by adding several horizontal "L" sections spaced equally around the vertical radiator, the pattern becomes omnidirectional instead. CB base antennas use three or four horizontal spokes or "radials" to form the ground plane.

FIGURE 8-35
THE 1/4-WAVE GROUND PLANE ANTENNA

(A)



(B)

Another example that works on exactly the same principle is the 1/4-wave AM broadcast tower; the ground plane is formed using 1/4-wavelength copper wires fanning out evenly from the tower base. Usually at least 120 radials are used; that's a lot of copper! And even though they're laying on the ground, it's these wires and not the soil which form the ground plane. Another name for a ground plane is a "counterpoise," since it electrically balances the antenna. The counterpoise is often used for marine antennas when the boat's fiberglass; a copper sheet in the hull forms the needed ground plane.

Figure 8-35B shows a typical 1/4-wave CB base antenna using three 1/4-wavelength radials. In some compact models the radials are shortened with loading coils, which like all loading coils reduce efficiency. The ground plane exists at the mounting height, not the ground. This raises the radiation resistance and therefore the efficiency. The ground plane also raises the electrical height above actual ground, resulting in lower radiation angles. And when mounted well above ground, it can eliminate stray RF currents below the radials.

LOADED MOBILE WHIPS

The 1/4-wavelength vertical whip is the primary mobile CB antenna. It has many variations but always works on the ground-plane principle. Instead of horizontal rods or wires, the vehicle body itself becomes the ground plane. While electrically a 1/4-wavelength, the whip is often much shorter physically, since few people want a 9' whip sticking up on the roof of their car. By shortening the vertical radiator with loading, the antenna has more eye appeal and rigidity but loses some performance; loading coils increase the DC resistance and heat losses, and also narrow the bandwidth.

There are still a few mobile fiberglass whips being advertised as "1/2-wave" or "5/8-wave" antennas. This is simply not true! Any single whip that's more than a 1/4-wavelength requires additional impedance matching circuits, since true antennas of those dimensions will have base impedances much higher than 50 ohms. But they're still connected directly to 50Ω coax just like any other mobile whip, with no special matching circuits. I wonder why...

The shorter the antenna, the more critical and narrow-banded the tuning. As a general rule, don't use a whip less than about 40" long. Virtually all base-loaded types will meet this minimum standard. However there are still some very short (like 18") center-loaded clip-on or magnetic types available, and they're extremely poor antennas. At least a few manufacturers now sell an on-glass CB whip made to look like a cellular mobile telephone antenna! Besides being far too short, you won't even get the benefit of a metal-to-metal ground contact.

Avoid these antennas like the plague, unless you're on some ego trip and need to feel like a VIP when talking to the car next door; that's probably all the range you'll get anyway. Besides potential SWR problems, transmitter damage, and very narrow bandwidth, the reduced capture area of such short antennas also kills the receiver sensitivity. Not recommended!

Tuning The Mobile Whip

Mobile whips are tuned by changing the physical length so the VSWR is lowest over the desired frequency range. The full-size whips don't need any adjustment, since they're already correct electrically. The whips that do need adjustment are those with base, center, or top loading.

The general tuning procedure begins by checking the SWR at Ch.1 and Ch.40. When higher on Ch.40 than Ch.1, the rod is too long and must be shortened. If higher on Ch.1 than Ch.40, the rod must be lengthened. All the better quality base- and center-loaded whips have a metal sleeve/set-screw arrangement which adjusts the length. If the whip needs shortening more than it will drop down into the holder, you must cut it. Use a hacksaw and never cut more than ½" at a time, rechecking the SWR after each cut.

With any 3/8" x 24 loaded whip using a bayonet type quick-disconnect, the extra few inches of this adapter can affect the SWR and must be considered when adjusting the antenna length. This is also true when adding a shock spring.

If the rod needs lengthening more than it can be raised out of the holder, you have a problem! Recheck the grounding and cable connections and whip location first. I've never seen this problem with name brand hardware, but I have with the "economy" brands; you get what you pay for. If you have some extra rods laying around, you can try a slightly longer one and sometimes succeed, but the best solution is to use a good quality antenna in the first place. Replacement rods are available from sources like GC Electronics (#19-112, 36", and #19-114, 40"). They also have the loading coil (#19-110) and the spring hardware (#19-100) to match. A/S also sells these standard replacement parts.

Never play "mix and match" with different brands of coils and whips even though they often look the same; each was designed for a very specific inductance-to-whip length ratio. For instance, a Radio Shack coil may require a completely different whip length than an A/S base coil. A couple inches either way and it'll never tune. If you suspect this may have been done in a problem situation, get a history from the customer or try the methods described next.

Shortened fiberglass whips are top-loaded. The better ones have an adjustable tip whose length can be changed like those on the base-loaded types. If not, peel off some of the shrink wrap and remove some wire, ½" at a time while rechecking the Ch.1/Ch.40 SWR after each cut. Once it tunes correctly, replace the cap. If it needs lengthening, there's little you can do without experimenting: since fiberglass rods use standard 3/8" x 24 threaded mounts with lugs for the coax, try removing the center coax wire lug and adding a small series RF choke, less than 1.0 µH (Mouser 43LQ type), to start. Eventually you'll hit the right inductance for resonance, and the SWR will drop to normal.

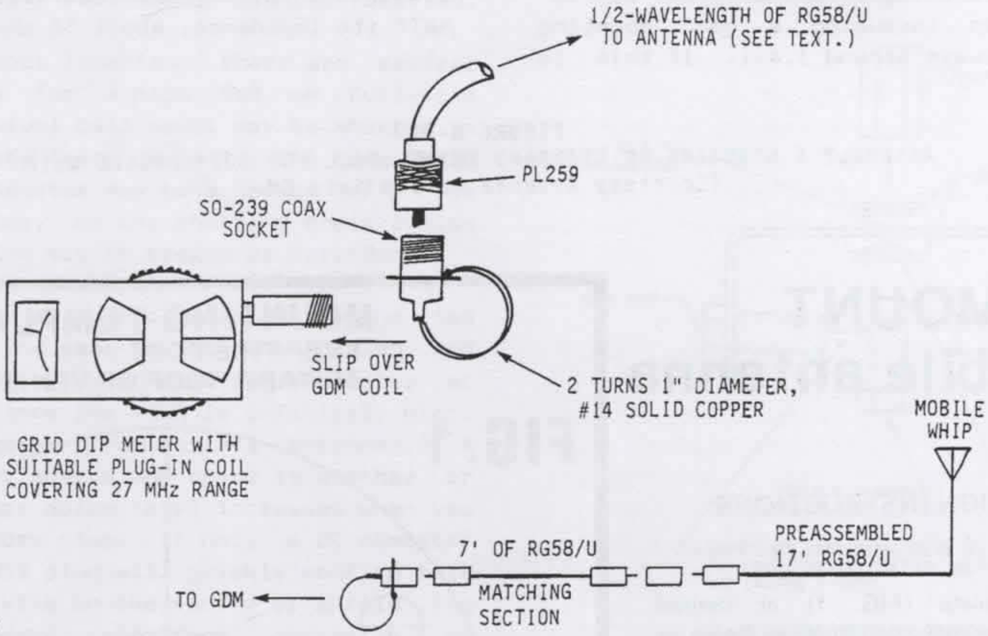
Tuning With The GDM Or Noise Bridge

A trick I sometimes use successfully when there's no definite Ch.1/Ch.40 SWR difference is to check the antenna with a Grip Dip Meter (GDM), Figure 8-36. Make a coupling loop using two turns of AWG #14 solid copper wire about 1" in diameter, soldered across a standard SO-239 coax socket. Also make up a 7' patch cord of RG58/U with PL259s on each end in case it's needed. Coupling the antenna to the GDM with this set-up will indicate the general resonant frequency, so you know whether to shorten or lengthen the whip.

There are two precautions when using this method: first, check the dial accuracy of your GDM, since readings tend to be very broad. Turn up its output level and couple it into your frequency counter, comparing the readings. Second, make sure you're using a true electrical 1/2-wavelength coax line or its multiple; a 1/4-wavelength is an impedance transformer and will probably indicate a false resonant frequency. A convenient true length would be 12' or 24' of coax, assuming the standard 66% Velocity Factor. For mobile whips having the usual 17' of preassembled coax, add an extra 7' patch cord in series using a PL258 double-female barrel connector. This makes a full-wave impedance repeater line.

Another method when working with unknown antennas is to use a special impedance bridge, like the MFJ Model 204B Antenna Bridge (about

FIGURE 8-36
USING GRID DIP METER TO DETERMINE RESONANT FREQUENCY
OF AN UNKNOWN MOBILE WHIP



$80), MFJ Model 202B R-X Noise Bridge (about $60), or the Palomar Engineers R-X Noise Bridge (also about $60). These instruments tell you whether the antenna is too long or too short, the degree of resistance vs. reactance, etc. They're definitely worth the price for serious technicians who expect to see a wide variety of drive-in antenna repairs! These bridges are sold in the better Ham radio stores, or look for the ads in any Ham magazine like "CQ," "73," "QST," "HAM RADIO," or "WORLDRADIO."

THE FULL-SIZE MOBILE WHIP

The most efficient mobile antenna is the true 1/4-wavelength vertical whip. Ideally it would be mounted in the center of the vehicle roof for an omnidirectional pattern. It has no loading coils to waste power and lower the current loop. The disadvantages are obvious: it's ugly, clumsy, and requires a much stronger physical support than the shorter loaded whips.

Some recent evidence by Antenna Specialists Co. suggests that a 1/4-wavelength antenna shows an incredible 2.5 dB gain improvement by simply moving it from the usual trunk lid location to the center of the roof. And a 5/8-wavelength has a 1 dB gain location improvement. There are no 5/8-wave mobile CB whips; these figures are based upon unloaded VHF antennas, which are physically practical to install here. Loaded CB whips would offer reduced improvement. But this gives you some idea of the potential range increase if you're willing to mount a full-size CB whip at roof center. Just convince the wife you really need that big hole in the roof!

The length of a full-size whip depends upon its material. Steel whips are about 102" and fiberglass 96". Ever wonder why? Fiberglass is shorter because its radiating element is a copper wire buried in the fiberglass; copper is a better conductor than steel, so RF propagates through it faster. Same idea as the coax Velocity Factor. Shakespeare does sell a 102" fiberglass whip that's 3/8-wavelength in copper with a very slight gain (1 dBd) over a standard whip, resulting from its lower radiation angle.

Troubleshooting The Full-Size Whip

There's no tuning with a full-size whip when correctly installed. "Correctly" means never on the bumper of a van or camper! Otherwise you've got several feet of the vehicle body being capacitively coupled to the whip, totally detuning it. Nothing will correct the problem except relocation. Acceptable locations are high up along one side of the body, or on the roof. Bumpers are OK for cars though, since the body is lower and relatively far away. In any case the radiation pattern is distorted and will be much stronger in the forward direction, towards the greatest mass of vehicle metal.

The normal SWR reading of a 102" steel or 96" fiberglass whip (assuming a good mounting location) is always around 1.4:1. If this is the ideal mobile antenna, why shouldn't it match perfectly when loaded whips often do? The reason is radiation resistance. The 1/2-wave dipole has an impedance of about 72 ohms but a 1/4-wave whip, which is half its size, has only half its impedance, about 36 ohms. Since SWR is

FIGURE 8-37
ASSEMBLY & MOUNTING OF STANDARD SWIVEL BALL FOR 102" MOBILE WHIP
(Courtesy Antenna Specialists Co.)

BALL MOUNT for mobile antenna

INSTALLATION INSTRUCTIONS

1) Place template (FIG. 1) at desired mounting location, drill holes as shown on the template. CAUTION: Attach to flat portion of body.
2) Assemble mount as shown in FIG. 2.
3) After the mounting screws have been tightened securely, the antenna receptacle in the upper hemisphere can be adjusted to a vertical position by loosening the angle bolt and angle nut. Tighten both after adjustment.
4) Tighten the grounding screw (FIG. 3) securely into the car body for a good ground. Attach the center conductor of the coax to the center stud and attach the shield braid to the grounding screw.
5) Fasten antenna and tighten.

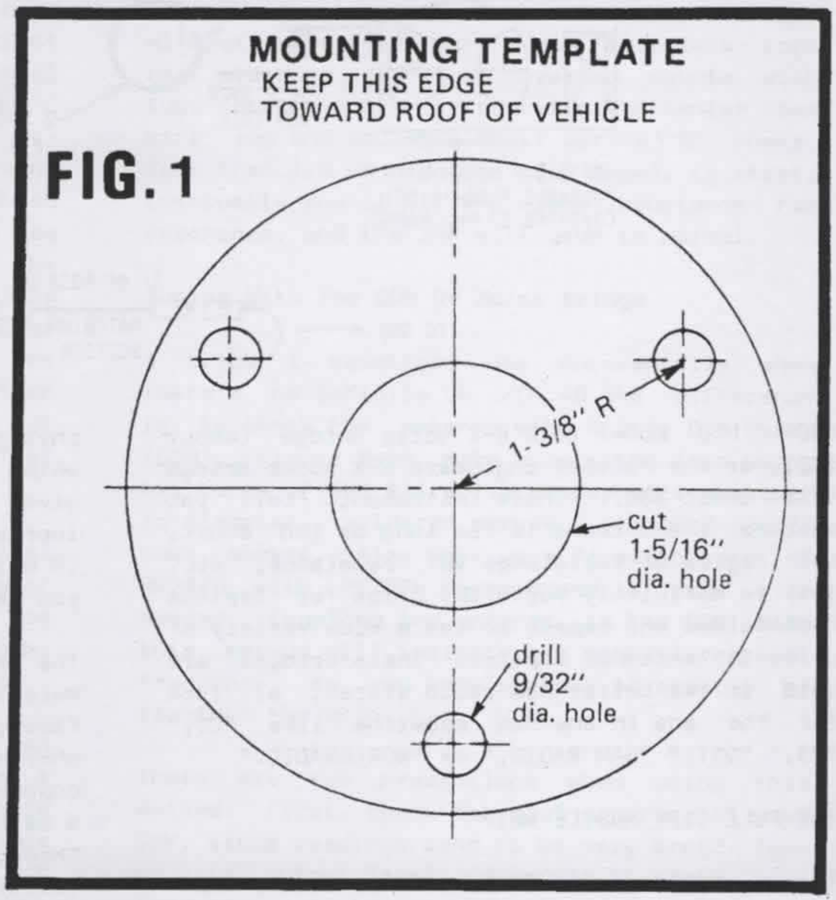


FIG. 1

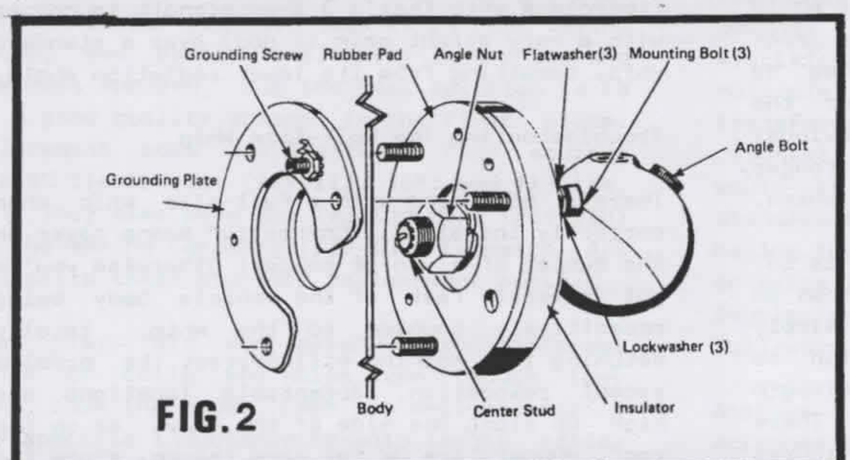


FIG. 2

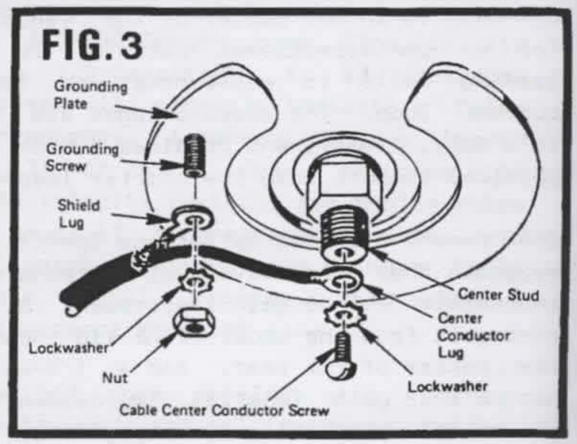


FIG. 3

the ratio of one impedance to another, this makes it 50 ÷ 36 = 1.389, which is a perfectly acceptable figure. Loaded whips are adjustable, and the feedpoint impedance can be raised above 36 ohms by proper coil design and tap location.

Besides improper location, there are several other reasons for a high SWR on full-size whips: the swivel ball mount may be shorted to the vehicle body (very common!), the coax braid or center conductor may have broken off from its mounting lug, or the shorting braid inside the shock spring may be broken or corroded.

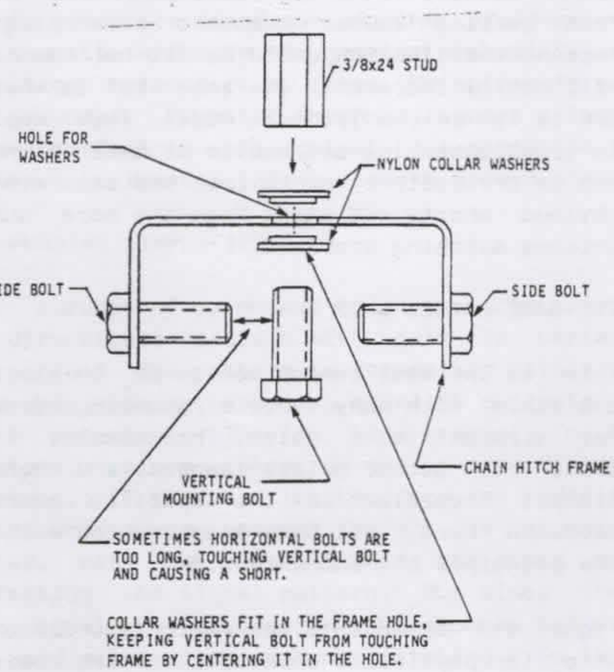
With a shorted or open coax conductor the SWR will measure the same on both the FORWARD and REFLECTED scales, and will peg the meter at full scale, since the VSWR is infinitely high. (Such readings are true for all antennas.) A quick test for shorts and opens is whether or not the receiver noise level increases when you connect the coax plug. If not, a DC ohmmeter across the PL259 plug will quickly confirm this problem. The wire on the center or shield lug sometimes breaks off from corrosion or vibration. Jumper a clip-lead across the whip and one of the swivel ball mounting bolts; an ohmmeter across the PL259 plug should then indicate a short, unless one conductor is open.

In the case of a short, you'll very often find the swivel ball/shock spring assembly shorted directly to the vehicle body; many amateurs install these wrong! The whip and spring are supposed to be supported only by the plastic mounting plate, which means a hole at least 1¼" in diameter. Many people drill this hole out just big enough to pass the threaded stud of the ball mount, effectively bolting the ball directly to the vehicle body! See Figure 8-37 for the correct installation technique.

When installing a chain or strap bumper hitch, make sure the horizontal bolts of the mounting plate don't protrude far enough inside to short to the vertical mounting stud. Also make sure that the nylon collar washers are properly seated; these must insulate the 3/8" x 24 stud and the whip from the vehicle body. People have been known to replace lost bolts with longer ones, or to forget the insulating plastic collar washers. Figure 8-38 shows this idea.

All the same tests for shorts and opens apply equally to center-loaded steel whips and loaded fiberglass rods. If standard 3/8" x 24 mounting

FIGURE 8-38
ASSEMBLY OF 3/8" x 24 WHIP STUD FOR CHAIN BUMPER HITCH



threads are used, these antennas can be checked just like the full-size threaded whips.

Don't overlook the possibility of a shorted or open PL259 plug either. The factory crimp-on plugs occasionally go bad. Even more common is improper installation of the standard PL259 and the associated UG175/U or UG176/U reducing adapter. When installing a preassembled cable, plan the cable run so you won't have to cut off the factory plug; thread the plain end through the vehicle first. If you must install the plug yourself, I highly recommend using the Amphenol 83-58FCP solderless coax plug instead. Other solderless PL259s include the GC Electronics #18-415 and Radio Shack #278-196. Review the correct plug/cable installations on Page 318.

When the SWR is about 3:1 in an otherwise good installation (or known to be good previously), the problem is usually a broken shorting braid inside the shock spring. Most people don't realize there is one! If you bend the whip over far enough to stretch the spring, you'll see it inside. Without this shorting braid, the spring acts like a base loading coil; this adds inductance to an already resonant antenna and detunes it. A broken braid isn't repairable and the spring should be replaced. The smaller springs on base-loaded whips also have shorting braids. Replacement parts are sold by A/S, Radio Shack, Dick Smith, and GC Electronics.

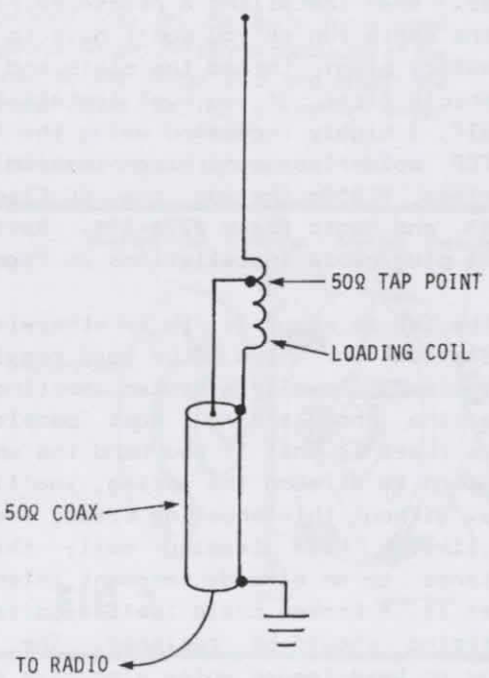
Any problem besides an outright short or open won't usually stop the receiver noise level from getting louder when the coax plug is reconnected. The SWR could be 3:1 but the noise will still increase. The true test is whether SWR is low in the Transmit mode. This applies to troubleshooting all mobile or base antennas, and is the fastest way to test and separate the obvious shorts and opens from the more subtle antenna matching problems.

THE BASE-LOADED WHIP

This is the most common mobile CB whip. It's available with many types of mounting hardware for straight roof holes, hatchbacks, trunk lids, rain gutter clips, campers, and magnetic clamps. Regardless of the specific mounting hardware used, all base-loaded whips work on the principle of "shunt feed."

Figure 8-39 shows this schematically. Since the whip is physically shorter than the correct electrical length, it has capacitive reactance. This is balanced out with an equal amount of inductive reactance shunted across its base terminals. At the same time, the proper 50Ω impedance point must be found. This point is located somewhere along the coil, which is tapped at that point. In commercial CB antennas the 50Ω point is permanently sealed inside the coil shell and connects to its center pin. Thus shunt feed works just like the tapping down of any other parallel-resonant circuit, where the higher tapped impedance is matched to the lower impedance of the total coil winding. Every installation is slightly different and the exact capacitive reactance can't be predicted, so the whip length must always be adjustable.

FIGURE 8-39
THE SHUNT-FED MOBILE WHIP USING BASE LOADING



The main advantage of shunt feed is that the antenna operates at DC ground potential and can be fed with unbalanced coaxial cable. Because of this, it provides a safety factor against lighting when used in base installations, and reduction of road static when used in mobile installations. The ball tip included on the end of the whip rod helps discharge road static too, since that end is a voltage loop and high voltage is usually attracted to sharp points.

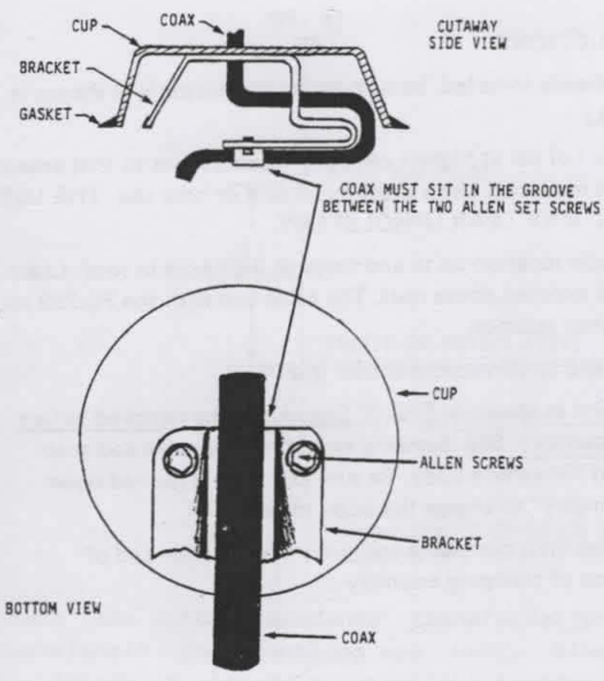
Troubleshooting The Base-Loaded Whip

Note from Figure 8-39 that your ohmmeter will always show a DC short between the coax center and shield when connected to any base-loaded CB antenna. This has misled countless amateurs who thought they had found a shorted antenna. DC resistance and RF impedance are <u>not</u> the same! An ohmmeter will show DC continuity from the whip to the center pin of the coil and center pin of the coax plug, <u>and</u> to the outer coil threads which are the vehicle ground. The better antennas rarely have coil problems, but there's still some junk around that actually uses conductive plastic; couple those with a 200-watt linear and high SWR, and the coil is guaranteed to burn open!

Poor grounding is a common cause of high SWR in trunk-lid mounts. Make sure there's always some metal-to-metal contact between mounting cup and vehicle body. The little Allen screws on the cup are supposed to break the paint, so make sure they do. When the mount itself isn't preassembled, make sure you route the coax correctly; it's supposed to fit in the groove between the Allen screws so there's some strain relief. Many installers incorrectly let it drop straight down, which strains the cable and may eventually pull it completely out of the cup. Figure 8-40 shows the proper cup assembly.

Most base-loaded antennas that are permanently installed on the roof or elsewhere use a

FIGURE 8-40
PROPER COAX ROUTING OF TRUNK LID MOUNT



standard 3/8" mounting hole for the 5/8" threaded base assembly which mates with the coil. (Hustler is one exception, having its own unique mounting method. The XBL-4 uses a 3/4" hole and the threaded base is preassembled, a good idea!) In such installations, make sure the center coax wire folds over into the groove of the center pin; people have been known to leave it sticking straight up, causing an intermittent or open circuit. Personally, I always solder the wire to the pin afterwards to prevent any possible corrosion or resistive connection to develop. Figure 8-41 shows the correct assembly procedure.

Magnetic Antennas

These are very convenient for people who don't want holes in their car, or who use one antenna on several vehicles. And it allows the superior rooftop location to be chosen. Any loaded antenna (base, center, or top) can be used with a magnetic base. You can buy either the base itself with 3/8" x 24 or 5/8" threads to mate with most popular whips, or complete magnetic antennas with oversize coils, like the K-40 or A/S Formula 1.

This antenna type is only capacitively coupled to the vehicle body via the magnet base, so its efficiency is less than a metal-to-metal ground. This weakness can sometimes be offset by rooftop mounting and its higher radiation pattern. Make sure the coax doesn't get mashed passing through the door or trunk lid, which would upset its impedance. Another disadvantage of magnetic whips is the greater probability of ignition noise pickup, since the antenna's not DC grounded. Magnetic antennas require a large steel surface to work against, so <u>never</u> use it without at least a 1/4-wavelength ground plane.

CO-PHASING SIMPLIFIED

The purpose of co-phased antennas is to create a directional pattern with gain in certain directions. The pattern is determined mainly by the whip spacing, assuming equal RF currents in both antennas. (They're always equal in CB systems, since there's no power divider circuit.) If the coax lengths from the radio to each whip were unequal there'd be a phase delay, with one signal leading the other and effecting the signal pattern. But since they are equal, we can assume the co-phase harness is used mainly for impedance matching. So it's more accurately called a "matching" harness than a "phasing" harness.

Since the transmitter has a standard 50Ω output impedance which must equal the load impedance for maximum power transfer, paralleling two antennas directly would yield 50 ÷ 2 = 25 ohms impedance. To end up with a <u>net</u> parallel impedance of 50 ohms at the PL259 plug, each antenna impedance must be raised to 100 ohms; 100 ÷ 2 = 50 ohms. Unlike a single whip that's already 50 ohms and connected to 50Ω coax, we now need two 50Ω whips stepped up to 100 ohms; when paralleled the result is 50 ohms. The coax that connects these unequal impedances together must have some intermediate value between 50 and 100 ohms. That can be calculated by,

$$Z_{avg} = \sqrt{Z_1 \times Z_2}$$
$$= \sqrt{50 \times 100}$$
$$= \sqrt{5000}$$
$$= 70.7\Omega$$

This value is conveniently close to the nominal impedance of RG59/U or RG11/U coax cable, which are 73 and 75 ohms respectively. That's exactly what <u>is</u> used for the co-phase harness.

FIGURE 8-41
INSTALLATION OF STANDARD 3/8" SNAP-IN ROOF MOUNT
(Courtesy Antenna Specialists Co.)

FIG. 1

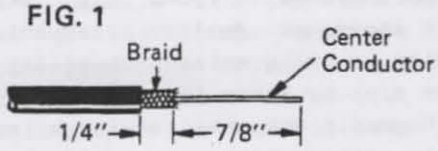


FIG. 2

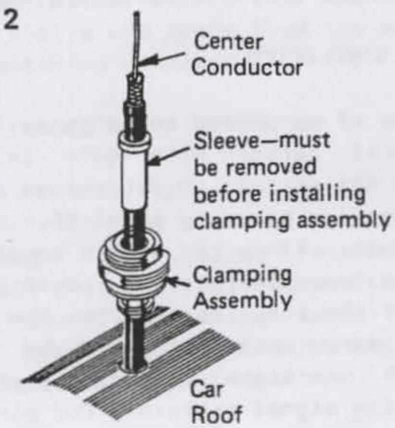


FIG. 3

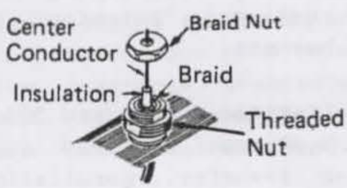
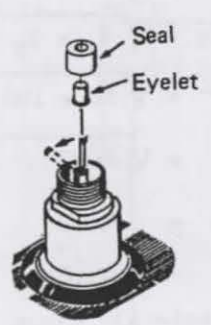


FIG. 4

FIG. 5

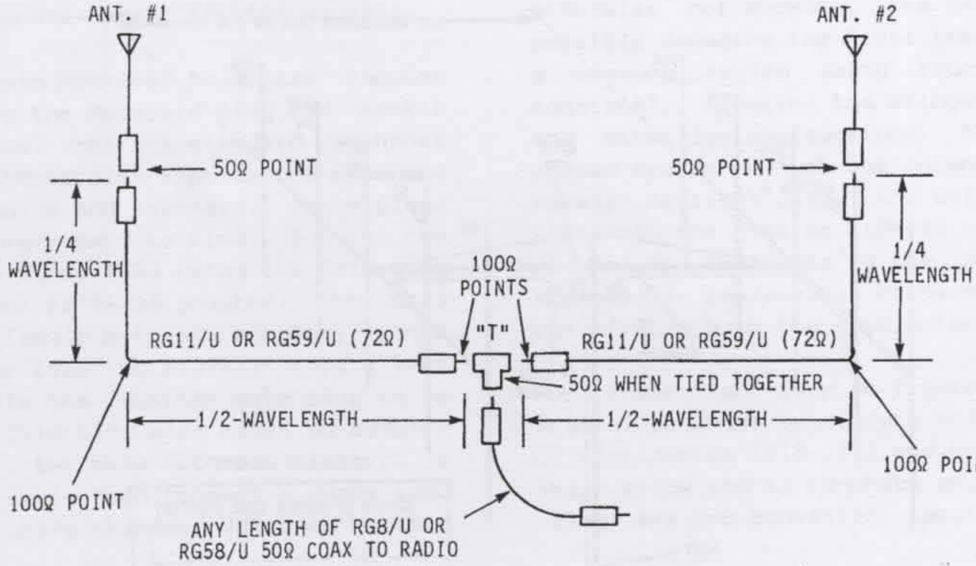


INSTALLATION INSTRUCTIONS

(If clamping assembly is already installed, be sure center conductor is as shown in FIG. 4 and begin at step 9.)

1. Drill 3/8" hole in roof of car at highest centrally located point so that antenna will be vertical when mounted. Use a sheet metal drill or hole saw. THE USE OF A TWIST DRILL MAY TEAR UPHOLSTERY.
2. Route cable from radio location up to and through 3/8" hole in roof. Leave a few inches of cable exposed above roof. The cable end with the PL-259 remains at the transmitter location.
3. Strip exposed cable end to dimensions shown in FIG. 1.
4. Disassemble the mount as shown in FIG. 2. Sleeve must be removed before installing clamping assembly. Slip clamping assembly over cable and snap "fingers" into hole in the vehicle body. Be sure assembly is pushed down far enough for all "fingers" to engage the body metal.
5. Insert sleeve, plain end first, over cable and press in until wide end of sleeve is flush with top of clamping assembly.
6. Holding clamping assembly on 1/2" flats, tighten threaded nut (with 3/4" flats) until clamping assembly is rigidly fastened to mounting surface. (FIG. 3).
7. Fan out 1/4" of exposed braid and push cable into clamping assembly until braid rests on top of clamping assembly (FIG. 3).
8. Extend insulation (1/4" long) through braid nut and thread it on clamping assembly until braid is securely clamped.
9. Place rubber pad over clamping assembly and flat against mounting surface (FIG. 4).
10. Screw mounting adapter snugly on clamping assembly (FIG. 5), threading center conductor through hole in adapter pin. DO NOT USE WRENCH LONGER THAN 6" to tighten mounting adapter.
11. **NOTE! →** Bend exposed center conductor back along slot in side of adapter pin (FIG. 5). Center conductor must lay completely in slot.
12. Press eyelet into seal then press seal and eyelet assembly over adapter pin (FIG. 5).
13. Complete installation by following original instructions supplied with antenna.

FIGURE 8-42
IMPEDANCE MATCHING OF DUAL WHIPS USING TUNED CO-PHASE HARNESS
(Courtesy Antenna Specialists Co.)



To make the actual impedance transformation, 1/4-wavelength coax sections are used, since such a length is already a convenient impedance transformer; if high at one end it's low at the other, and vice-versa. In this case it's a 2:1 step-down transformer. A 1/4-wavelength will be about 6' using standard 66% Velocity Factor coax. Any odd multiple of a 1/4-wavelength can also be used, such as 1/4, 3/4, 5/4, etc. (Even multiples result in 1/2-wavelengths, which are impedance repeaters.) If the physical whip spacing exceeds the 12' of the two coax lines, 3/4-wavelength (or longer) cables must be used. This is the usual situation in an 18-wheeler and the excess cable is bundled up out of the way. Figure 8-42 shows the net result of using two phasing cables with 3/4-wavelength (17') coax transformers to feed each antenna.

Co-Phasing Base Antennas

The same principle can be used when feeding or stacking two base antennas. The antenna types really don't matter as long as they're normally 50 ohms at the feedpoints. For example, they could be two 1/4-wavelength ground planes, two 5-element Yagi beams, etc. Figure 8-43 shows the 1/2-wave stacking of two multi-element Yagi beams with a suitable phasing harness. Note this harness is virtually identical to the dual trucker phasing harness, except here the heavier low-loss RG8/U and RG11/U cables are used for the base installation.

Co-Phase Matching Tips

Matching phased arrays involves adjustment of two antennas rather than one, which complicates tuning. If you happen to get a reasonably low SWR right away, you can probably do the fine tuning with both antennas connected. When there's any significant reactance though, both antennas will interact with each other. You could spend all day running up and down ladders trying to match them.

Instead, try terminating one antenna plug in a 50Ω dummy load while tuning the other whip for lowest SWR. Then reverse the process, replacing the tuned antenna with the dummy load while tuning the second antenna. This way you've eliminated any secondary reactance before it affects the SWR readings. Figure 8-44 shows the general idea.

The same principle that's used on mirror-mount whips also applies to stacked beams or base verticals. Tune one antenna and then the other using suitable dummy loads. The disconnected antenna will probably have a small inductive effect on the hot antenna because of its close proximity, so some retuning afterwards may still be needed.

Never cut the coax cable of a commercially-made CB harness; they already figured out the correct lengths! If you do make your own

FIGURE 8-43
HOW TO STACK TWO (OR MORE) YAGI BEAMS USING CO-PHASE HARNESS
(Courtesy Antenna Specialists Co.)

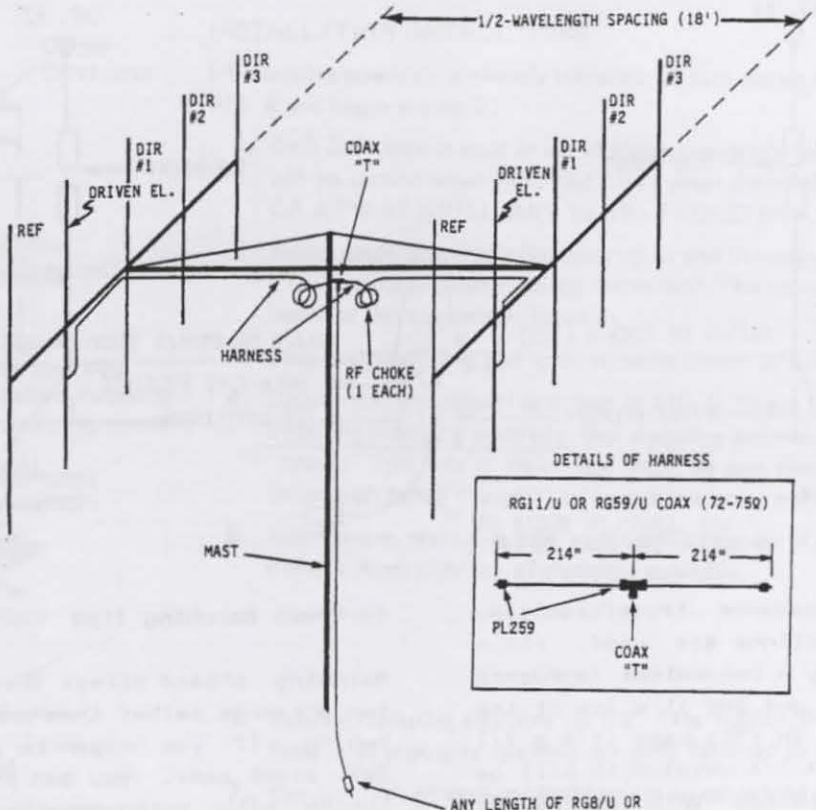
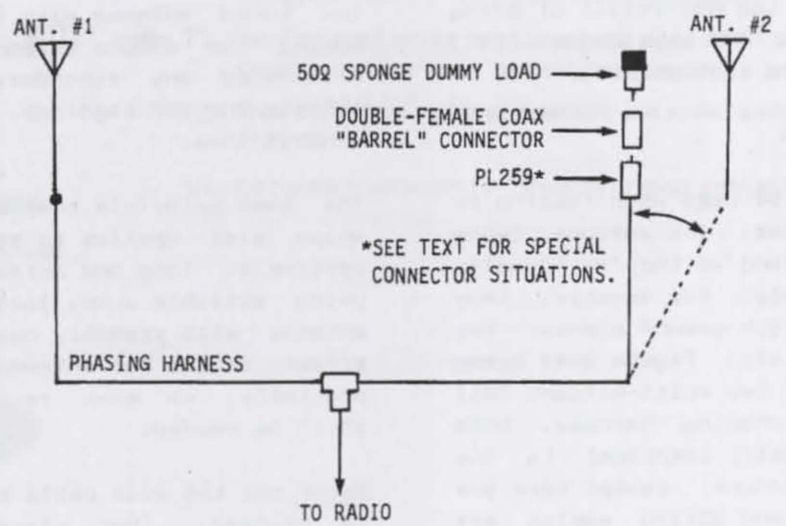


FIGURE 8-44
USE OF ALTERNATING DUMMY LOAD FOR TUNING CO-PHASED SYSTEM

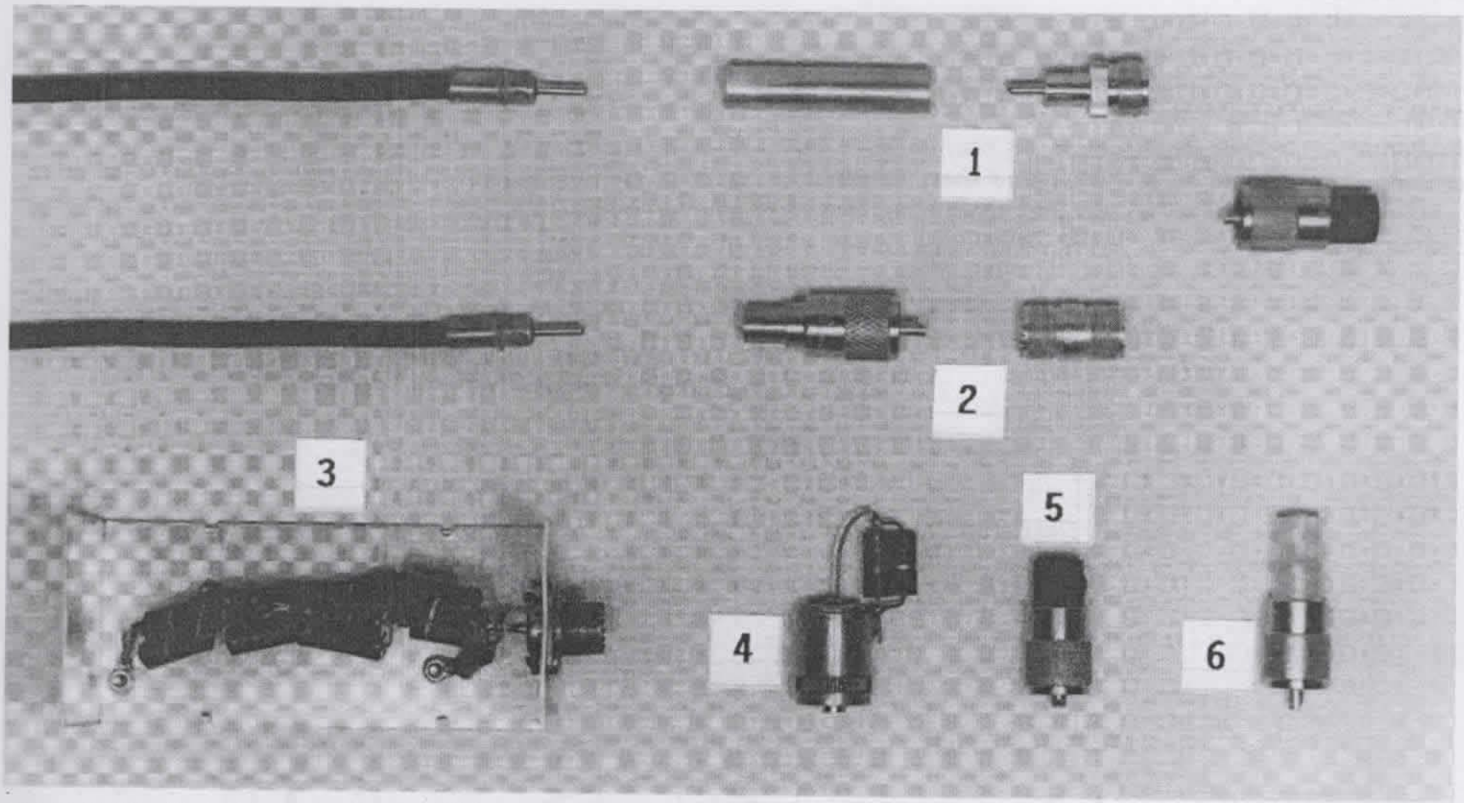


phasing harness, pre-test it by terminating both antenna ends with 50Ω dummy loads before connecting the actual antennas. In most cases this is very easy, since the antenna ends use PL259 plugs; you can connect a 50Ω sponge dummy load through a double-female (PL258) coupler.

The Hustler "Twin Huskies" that are popular with truckers use the Motorola plug and socket on their antennas, not the standard Amphenol UHF types. (The "Motorola" type is the same one found on car radios and scanners.) These plugs and sockets are very hard to find. But you can make a suitable dummy load using the Gold Line #95 or Radio Shack #278-208 adapter, the Gold Line #78 double-female Motorola adapter, and a sponge type dummy load (GL #1072); this allows you to terminate the Hustler male plug in a female UHF end. Gold Line also makes an adapter (#85) to convert the male Motorola plug to a PL259 end; you could then connect a dummy load to that PL259 using standard UHF-type mating hardware. (See the following photo.) Otherwise, you'd have to resort to a clip-leaded resistor for a dummy load when testing them.

If one antenna of a phased pair is broken or otherwise not working, the SWR will increase, possibly damaging the Final transistor. This is a common problem among truckers, who are constantly breaking the stinger tips on trees and other low obstructions. Never operate a phased system on just one antenna. If you can't repair it right away, the only options are to terminate the phasing harness with a dummy load at the end that goes to the bad antenna, or temporarily replace the harness with a straight run of RG58/U to the good antenna.

For those too lazy to figure all this out, special co-phase tuners are still being made by GC Electronics (#18-732) and Gold Line (#1098). These allow you to co-phase any two CB antennas using any two convenient lengths of 50Ω coax.



DUMMY LOADS: #1 and #2 show two possible ways to adapt the Hustler type Motorola coax plugs to female UHF ends for use with a dummy load when tuning co-phased whips. #1 uses a double-female Motorola adapter (Gold Line #78) with a Motorola-to-UHF adapter (Gold Line #95, Radio Shack #278-208). #2 uses a Gold Line #85 adapter with a standard PL258 coupler. Both result in a female UHF end for direct connection to a sponge-type dummy load. #3 is a homebrew 30-watt load using a network of seventeen 100Ω, 2-watt resistors, mounted in a Bud box with an SO-239 coax socket. #4 is made from the brass base of a standard 5/8" A/S type loading coil and two 100Ω, 2-watt resistors. #5 is the 4-watt sponge type load (Gold Line #1072), and #6 is the modulation light type (Gold Line #1057).

They're not made for high power though, and they also add some insertion loss. Replacement harnesses are still sold by Shakespeare: the #4048 has the lug terminals, and the #4173 has the PL259s for both common mirror-mount types.

Dummy Loads Aren't So Dumb

The use of dummy loads is a fast way to isolate coax vs. antenna problems in any installation. By replacing the antenna with a non-reactive 50Ω load, you'll know immediately where the problem lies. If you expect to do a lot of drive-in CB repairs, half the problems will be in the antenna and not the radio. Be prepared by having suitable dummy loads to fit all the most common connectors and mounting hardware.

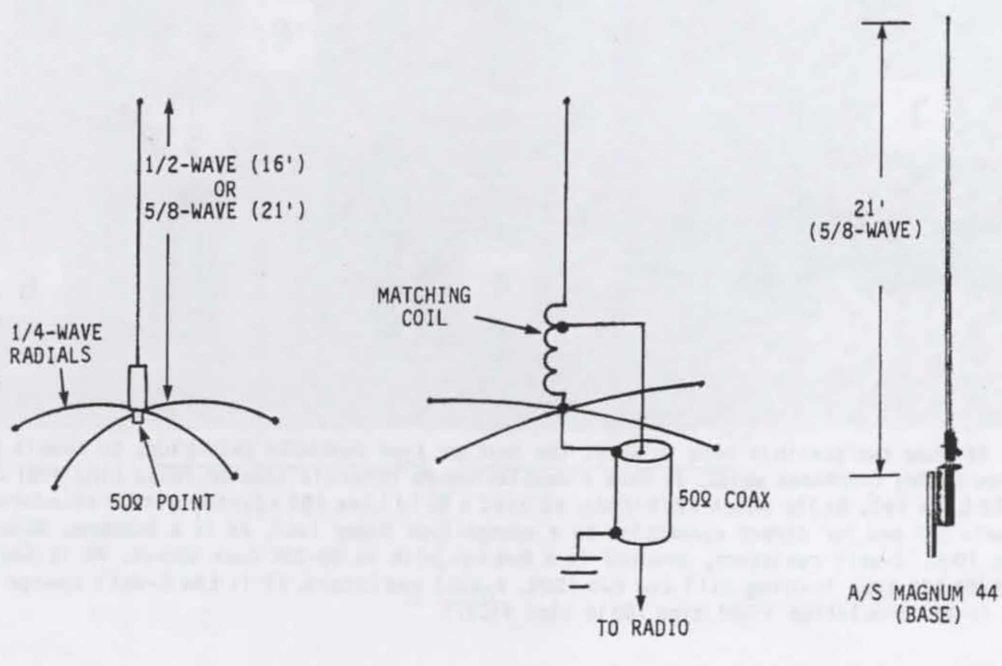
As shown in the photo, you can also make a dummy load to fit all the common 5/8" threaded base-loaded mounts by using a defective loading coil. Break it open and remove the wire, saving the threaded brass base. Then solder two 100Ω, 2-watt carbon resistors across this. Use it on any standard 5/8" base-loaded roof mount or trunk lid mount. You can even clip-lead such resistors directly across the antenna mount to test coax SWR, but keep the leads very short. Clip-leading these resistors is also useful for antennas with lugs on one end of the coax, like those with the 3/8" x 24 threaded stud mounts.

MATCHING HIGH-IMPEDANCE VERTICALS

The popular 1/2-wavelength and 5/8-wavelength omnidirectional CB verticals can't be connected directly to 50Ω coax like a 1/4-wave ground plane without special impedance matching. An example is the A/S Magnum 44, which is a 21' 5/8-wave radiator. Since the current loop or low-impedance point of a 1/2-wave antenna is at the center, a voltage loop or high-impedance point exists at the ends. This impedance can be as high as 2,000 ohms. Since you're feeding it at one of those ends, the high impedance must be transformed to 50 ohms. This is done using the same shunt feed method previously described for the base-loaded mobile whips.

Refer to Figure 8-45. A 1/2-wave radiator is naturally resonant, so adding base inductance would detune it. Therefore the manufacturer purposely shortens the vertical radiator slightly, creating capacitive reactance. Now the additional inductive reactance of the base coil can simultaneously tune it to resonance and transform the impedance. Somewhere along the coil there's a 50Ω point, which can be tapped for matching to 50Ω coax. In practice the 1/2-wave radiator is made about 16' long, slightly shorter than the true 17' electrical size. This antenna sometimes includes 1/4-wave radials, although they're not actually needed.

FIGURE 8-45
MATCHING SHUNT-FED 1/2- & 5/8-WAVE BASE VERTICALS



The 5/8-wave radiator (22') has a slightly lower radiation angle and slightly more gain. It's matched in exactly the same way. The feedpoint impedance will be different than the 1/2-wave vertical, since you've moved another 1/8-wavelength along the voltage loop. Again, ground radials are sometimes included. The shortened length is about 21'. The use of shunt feed in both these antennas simplifies feeding with coax cable, and grounds the antenna for DC which is very helpful for static discharge and lightning protection.

MATCHING YAGI & QUAD BEAMS

Both the Yagi and Quad antennas are matched using a similar technique, called a "Gamma" match for its similarity to that Greek letter. The methods are slightly different because each type is physically different; the Yagi has aluminum tubing and the Quad uses wire for the elements, but the principle is the same.

The impedances of Yagis and Quads are very different. A Yagi may be in the range of about 15Ω depending upon element spacing, where a Quad is typically 95-130Ω. But this makes no difference at all. The Gamma match is based on the fact there will always be two points on the driven element between which the radiation resistance equals 50 ohms. This point can be matched with 50Ω coax cable. See Figure 8-46A.

The coax can't be directly connected between these two points, since they're physically much farther apart than the spacing of the coax conductors, about 18-24" at 27 MHz. Spreading the coax conductors to reach these two points creates inductive reactance, which must be balanced out with an equal amount of capacitive reactance. An air-variable capacitor of about 50-75 pF in series is used, which is sealed in a weatherproof housing. Figure 8-46B shows the Gamma match for the Yagi and Quad antennas.

Either antenna is tuned by adjusting both the capacitor and the Gamma shorting point for lowest SWR. The SWR Meter should be placed at the antenna end, which means at least two people are needed to make the adjustments.

Preventing Coax Radiation

There's one other problem created by feeding a balanced antenna like a Quad or Yagi with unbalanced coax: RF current flows along the outer shield conductor. Normally with balanced feeders like "Twin Lead," whatever current is flowing in one conductor has a current of equal but opposite phase in the other conductor to cancel it. But with coax, the field from the inner wire can't escape the shielding effect of the outer braid for cancellation to occur. The result is radiation from the coax itself. This not only upsets the signal pattern and the impedance match as the coax becomes part of the total radiating system, but can also cause TVI. As shown in Figure 8-47, the RF can flow right back down into the transmitter and from there to the AC power lines. With poor grounding it may even be re-radiated all over the building.

FIGURE 8-46
MATCHING QUADS & YAGIS

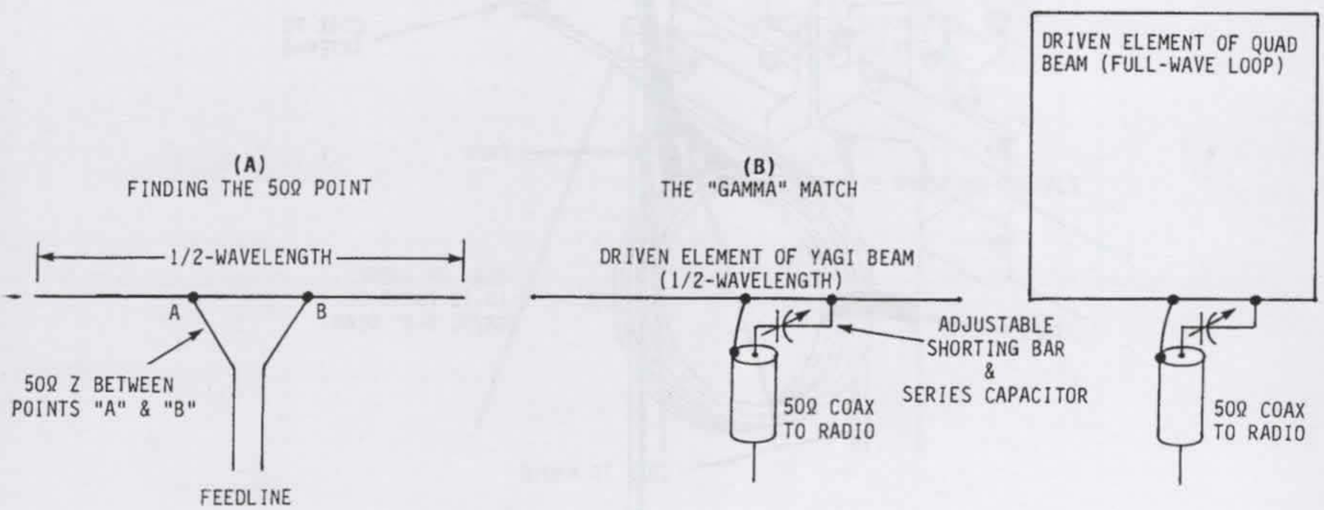
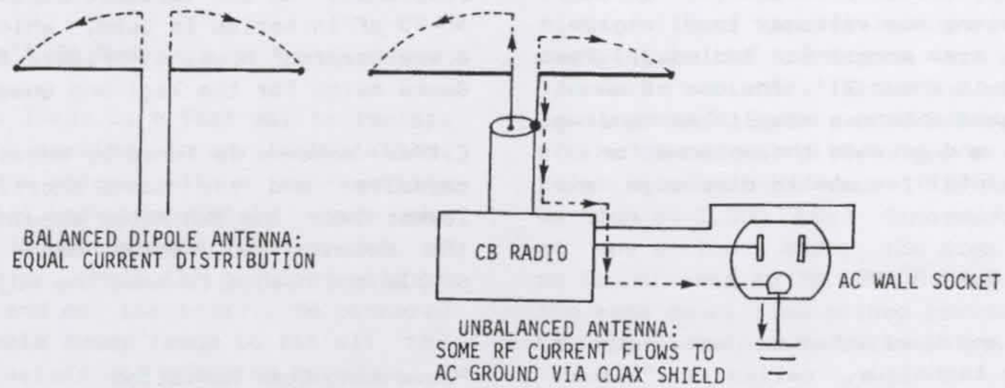


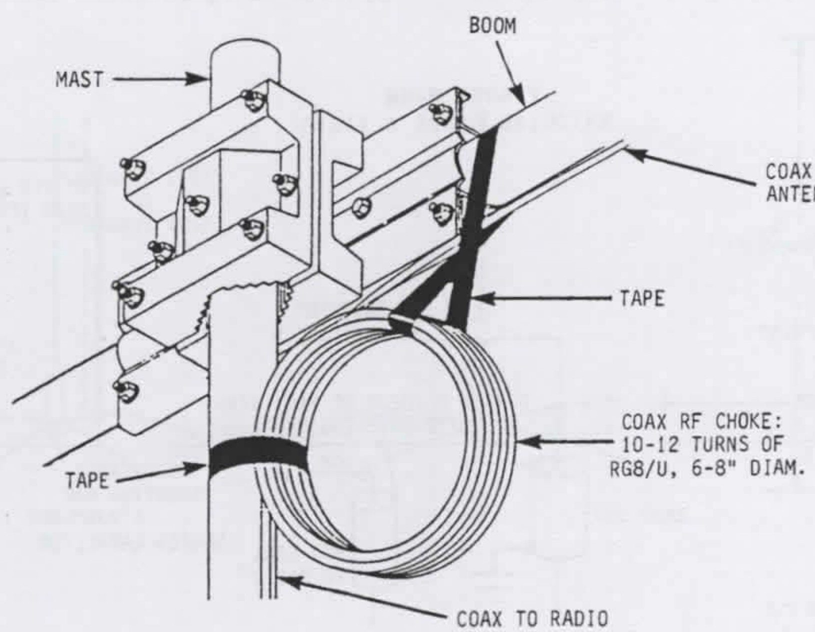
FIGURE 8-47
EFFECT OF USING UNBALANCED COAX FEEDLINE
(Courtesy RSGB RADIO HANDBOOK)



To prevent this, the balance must be restored. A "balun" or balanced-to-unbalanced transformer is one commonly used method. This is basically a tuned parallel stub across the coax at the antenna end. Commercial baluns are weatherproof units having coax sockets, and are sold in Ham equipment stores. Without a balun, you could use a large ferrite core at the antenna end, wrapping about three turns of coax around it.

The simplest and cheapest method is to make an RF choke using the coax feedline itself. Refer to Figure 8-48. (Also Figure 8-43.) Wrap 10-12 turns of the RG8/U at the antenna end into a coil about 6-8" in diameter and tape it to the mast or boom. This creates enough series reactance to minimize the shield current flow. Commercial antennas use similar isolation methods. Consider the RF unbalance possibility if TVI problems exist; the previous installer may have forgotten to include the RF choke, connecting the coax directly to the beam.

FIGURE 8-48
SIMPLE RF CHOKE MADE FROM THE COAX FEEDLINE
(Courtesy Telex/HyGain Communications Inc.)



Guy Wire Effects

When guy wires are used to support the mast on base antennas like a Yagi, Quad, or ground plane vertical, they must be broken up into non-resonant lengths. Otherwise they'll detune the antenna, effecting SWR and the radiation pattern. Effective lengths might be 6' or 12', broken up by some plastic or porcelain egg type insulators. (Available from Dick Smith, Fair Radio Sales, Ham Radio Outlet, etc.) The first set should be placed within a few inches of the guy-wire ring; otherwise the metal-to-metal contact between the mast and the partial wire "radials" might form a capacity hat which loads the antenna. See Figure 8-49.

SPECIAL CB ANTENNAS

There are several popular CB antennas using 1/4-wave or 1/2-wave radiators, but having slightly different matching techniques than those discussed so far. The following is a quick summary of how they work.

FIGURE 8-49
GUY WIRE EFFECTS & PROPER INSTALLATION

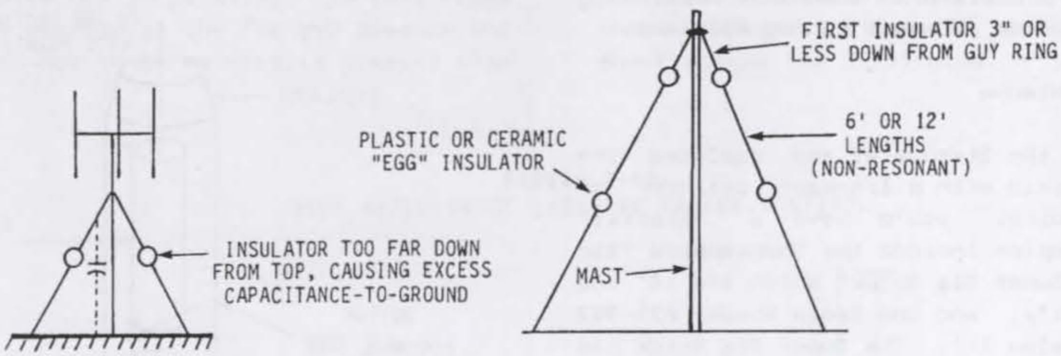
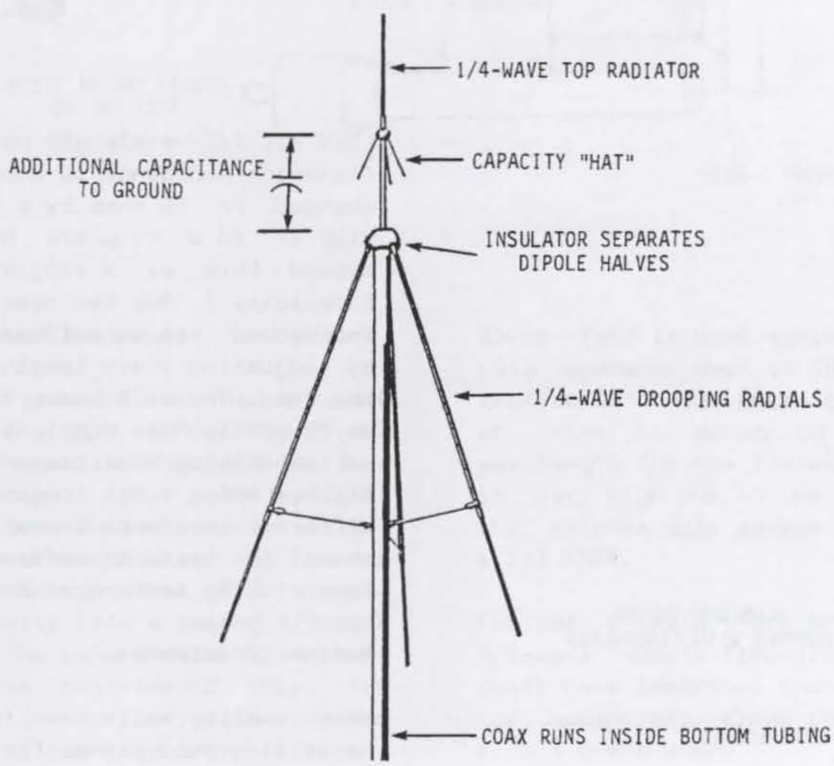


FIGURE 8-50
THE "STARDUSTER" OMNIDIRECTIONAL BASE ANTENNA
(Courtesy Antenna Specialists Co.)



The A/S Starduster

A variation on the common 1/4-wave ground plane vertical is the very popular A/S "Starduster," Figure 8-50. It combines both capacitive top loading and "drooping" radials. The small radials at the top add extra capacitance to ground, which raises the current loop. This lowers the radiation angle. And by allowing the radials to drop at a 45° angle, the radiation resistance is also increased, making it easier to feed RF power. Remember, a normal 1/4-wave ground plane is only about 36 ohms, so raising the impedance improves the match to 50Ω cable. The coax actually runs up inside the larger bottom section; there's an insulator separating the top and bottom 1/4-wave tubing sections.

The Coaxial Antenna

If you took the Starduster and replaced the drooping radials with a 1/4-wave cylinder of aluminum tubing, you'd have a "coaxial" antenna. Examples include the Shakespeare "Big Stick" and "Super Big Stick" which are 16' and 18' respectively, and the Radio Shack #21-967 "Crossbow," also 16'. The Super Big Stick has slightly better performance than the others, because of its lower radiation angle.

FIGURE 8-51
CONSTRUCTION OF THE COAXIAL ANTENNA

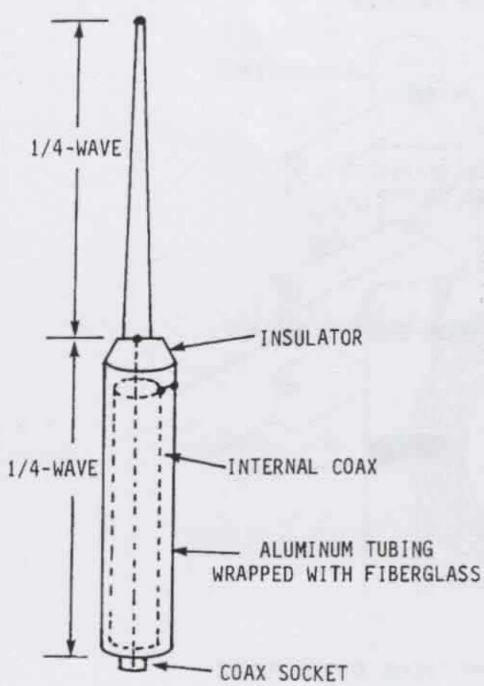
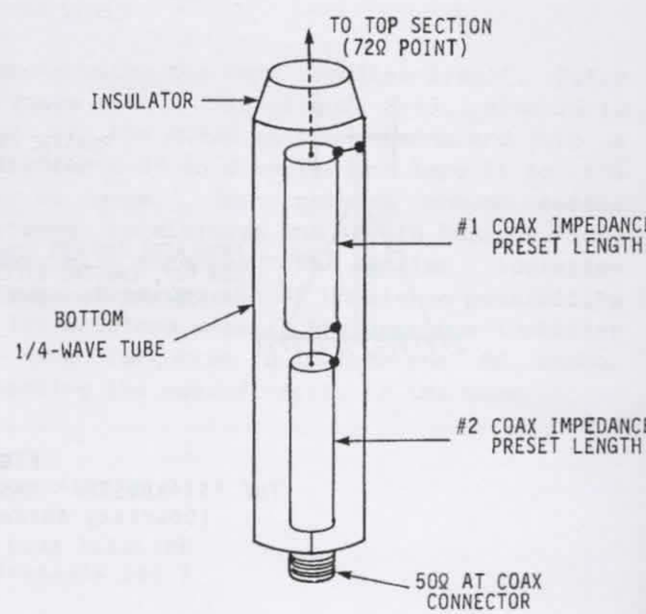


Figure 8-51 shows their construction. Although the coax plugs into the base, it's not actually fed there; there's more coax running up inside the tubing from the base to the center insulator that joins the two 1/4-wave sections. The coax center wire connects internally through the insulator to the top 1/4-wave section, and the coax shield to the bottom 1/4-wave tube. The effect is that of a vertical 1/2-wave dipole. The main advantage at 27 MHz is less wind drag, because it needs no radials.

FIGURE 8-52
SERIES-SECTION COAX IMPEDANCE TRANSFORMER



Like all 1/2-wavelength center-fed dipoles, the feedpoint impedance is about 72 ohms. This is changed to 50 ohms by a coaxial transformer, similar to a co-phase harness. (Figure 8-51 showed this as a single piece of coax for simplicity.) Any two coax cables of different impedances can be spliced together and matched by adjusting their lengths and distances from the load. The well-known "1/4-wave transformer" or "Q section" is simply a special case of the series-section coax transformer. The Super Big Stick, being a bit longer, requires a slightly different impedance transformation. Figure 8-52 shows the basic transformer placed inside the lower tubing section of the coaxial antenna.

Marine CB Antennas

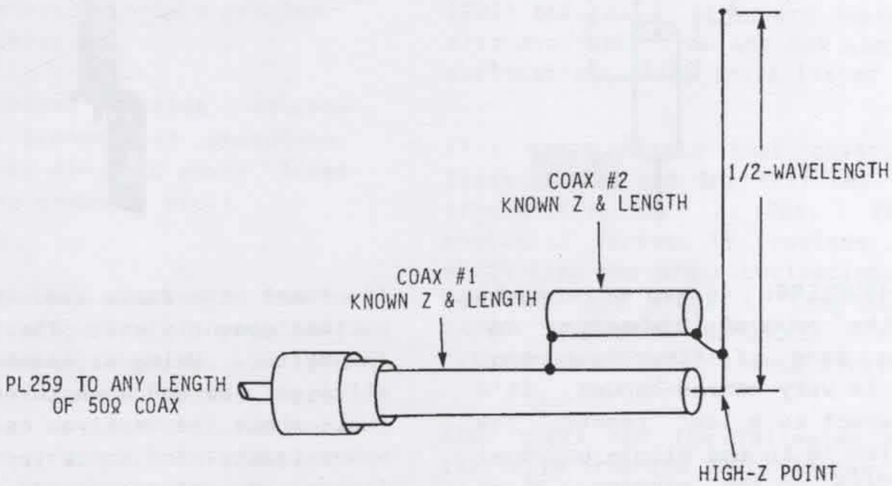
Many smaller boats have fiberglass hulls with no metal ground plane. For such installations a

1/2-wavelength vertical must be used, since it doesn't need a ground plane to work against. True 1/2-wave marine antennas are about 18' long. Shortened models include the Shakespeare 4050-B (3') and 388 (7'), which are both loaded and therefore quite narrow-banded. The problem again is the high base impedance of a 1/2-wave vertical antenna. A shunt-fed transformer could be used, but salt air would quickly corrode the coil and destroy its effectiveness.

Figure 8-53 shows a simpler matching method using a coax "stub" to transform the high base impedance down to 50 ohms. This is similar to the previous series-section coax transformer, with the cables now in parallel. In this case the stub is shorted at the far end because the antenna impedance to be matched is greater than the feedline impedance; when the antenna impedance is lower than the feedline impedance (like the shortened marine whips), the stub would be open at the far end. By using different coax impedances and lengths, a point can eventually be found where the correct impedance transformation occurs. The stub is terminated in a PL259 plug.

The advantage of this method is that the stub connection can be tightly sealed inside a PVC jacket for protection against the sea air. This special coax matching section must never be cut. Any convenient length of RG58/U or RG8/U can be spliced on with coax connectors to reach the radio location. Like shunt-fed antennas, these types will normally show a DC ohmmeter short across the PL259 plug.

FIGURE 8-53
STUB MATCHING OF 1/2-WAVE MARINE VERTICAL

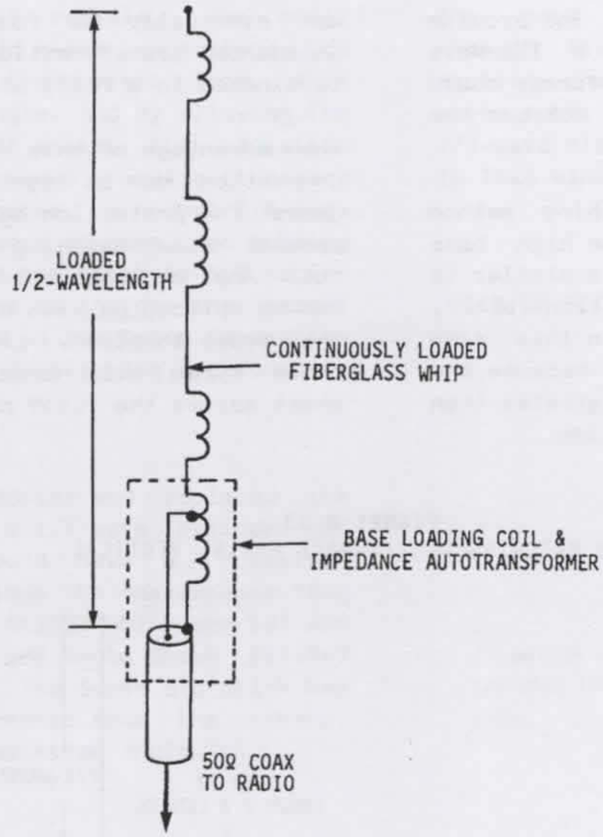


Other "No Ground Plane" Antennas

Working on the same principle as the 1/2-wave marine antenna is the A/S MR306 "No Ground Plane" mobile whip, shown in Figure 8-54. This was designed especially for vehicles like boats, motorcycles, snowmobiles, camper shells, Corvettes, or any other mobile application where there's not enough metal for a good ground plane. Basically it's a loaded 1/2-wave fiberglass whip in the same physical length as the standard 1/4-wave base-loaded whip. The combination of the loaded fiberglass rod and loading coil makes the complete 1/2-wavelength. Shunt feed is used again to transform the high base impedance down to 50Ω. The fiberglass rod section is continuously loaded. It takes a <u>lot</u> of wire to accomplish this, about one wavelength for the 1/2-wave effect. Thus the Q is very high due to the large L/D ratio, and the antenna only covers about 15 channels with a 2:1 VSWR.

Earlier I said there are no true 1/2-wave or 5/8-wave mobile fiberglass whips because they don't have impedance transformers. This one's the exception, since the base loading coil is also a transformer.

FIGURE 8-54
THE A/S MR306 "NO GROUND PLANE" MOBILE WHIP
(Courtesy Antenna Specialists Co.



A SPECIAL NOTE TO TRUCKERS: As you've no doubt already learned, the cabs of 18-wheelers are increasingly being made of fiberglass too. Because the MR306 is very narrow-banded, it's not recommended except as a last resort. The best overall solution is to use single or dual 5' or 7' PAL Firestiks on the mirrors, which do have adjustable tuning tips to compensate somewhat. (Some other brands are also tunable.) At least the doors are still metal to form a partial ground plane. The longer the whip(s), the better. Using at least a 5' whip, you can still get the SWR down to about 1.5:1. This is just about the best you can hope for in these newer trucks. And don't try compensating with a linear amp unless there's a low SWR; chances are you'll fry the Final transistor and/or the linear's power transistor(s)!

NOTES