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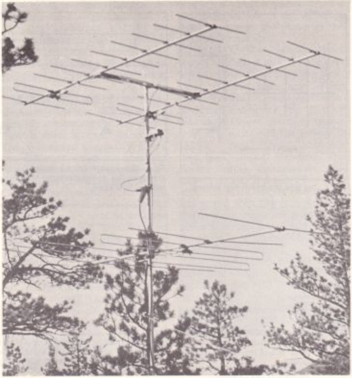
Stacking TV Antennas

By James E. Kluge*

The improved directivity achieved by stacking antennas can significantly reduce or eliminate many types of television interference



■ Multiple TV-antenna arrays, reminiscent of the '50s, are making a reappearance around the country. Today, however, the principal reason for stacking antennas is not only to achieve increased gain out in the fringe areas, but also to solve interference problems through the use of highly directional antenna arrays.

Many urban areas today are plagued with multiple high-rise buildings and heavy users of electrical power, both of which cause television interference (TVI) problems. Typical TVI problems include ghosts, electrical noise and interfering radio signals which usually arrive from a direction slightly off axis from that in which the antenna is pointed. Ground reflections, ignition noise and reflections off moving ground or airborne reflectors, such as trucks and large aircraft, arrive from above or below and cause picture breakup.

Proper stacking of today's highly sophisticated TV antennas can significantly improve directivity and selectivity, as well as gain.

OPERATION OF A SINGLE YAGI

The Yagi antenna, the most commonly used type for TV, "sees" electromagnetic radio waves in a manner similar to the way we see. Our eyes see in the general direction in which our head is pointed. Similarly, the Yagi antenna "sees" in the general direction in which its boom is pointed. When viewed from above (Fig. 1), the Yagi antenna's outline more or less resembles an arrowhead because it tapers out from front to rear. The taper is more pronounced in broad-band antennas than in single-channel antennas. The arrowhead formed by the antenna should, generally speaking, point in the direction from which the desired signal is arriving; i.e., toward the TV transmitter.

Ideally, a TV receiving antenna should "look" in a straight-line path toward the transmitting antenna and "see" nothing above, below or to either side. Not being ideal, of course, even the best TV antennas "see" a considerable amount of undesirable signals arriving from an angle off the axis of the antenna, just as our eyes have some side vision. These signals can cause ghosts and other interference patterns on the TV screen.

A Yagi antenna is made up of many parallel elements arranged along a common axis in a horizontal plane and all oriented toward the signal source. The length, spacing and phasing of each element relative to that of the others determines how the voltages induced in individual elements reinforce (add) at the antenna terminals. The elements are arranged and spaced so that the signal wavefront arrives at each element *sequentially* and so that the voltage induced in each antenna element combines at the antenna terminals with voltages from the other elements, to yield an optimized voltage which produces maximum gain over the desired bandwidth.

If the signal arrives from a source *above or below* the horizontal plane of the antenna, it will arrive at *all* of the Yagi elements simultaneously instead of sequentially. Under these conditions, the combined voltage at the antenna terminals will be something less than the optimum for which the antenna was designed.

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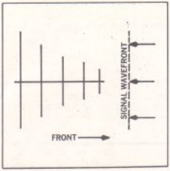

Fig. 1—Top view of a typical Yagi antenna.

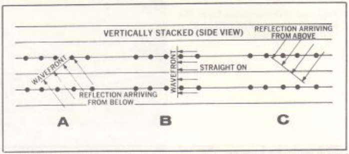

Fig. 2—Side views of vertically stacked Yagi antennas showing relationship of antenna elements and arriving signals. A) Signal reflected from below. B) Signal received straight from source. C) Signal reflected from above.

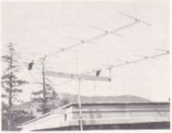

Fig. 3—Horizontal stack consisting of two Winegard Model SCX-10 ten-element, Channel 10 Yagi antennas.

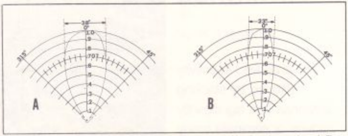

Fig. 4—Polar patterns which illustrate the effect of horizontally stacking the antennas shown in Fig. 3. A) This is the pattern for a single Winegard Model SCX-10 Yagi. B) Narrower pattern produced by horizontally stacking two Winegard SCX-10 Yagis one wavelength apart.

VERTICAL STACKING

Stacking two identical antennas on a common vertical mast significantly narrows the *vertical* beam-width angle. That is, vertically stacked antennas more effectively reject those interfering signals arriving from *above or below* their horizontal plane than does a single antenna. It's as though they were looking through a horizontal venetian blind. Because there's nothing mounted to the side of either antenna, their side-to-side vision is virtually uneffected. In the process, gain increases about 2.5 dB over that of a single antenna.

Vertical stacking improves both gain and vertical directivity. This helps reduce airplane flutter and attendant picture roll, and certain types of ground noise and ground reflections.

The basic principle of stacked antennas involves the difference in the time of arrival, and therefore the phase, of signals intercepted by the antenna combination. If a pair of identical Yagi antennas are mounted one above the other, a wavelength apart, on a common vertical mast and are oriented identically (pointed) toward the signal source, any TV signals traveling horizontally and arriving from any direction will be intercepted simultaneously by both antennas.

Those signals arriving on axis from the direction in which the antenna is pointed (Fig. 2B) will be strongest.

Because the antennas are identical, the generated signal voltages arriving at the output terminals shared by the antennas will be in phase, causing them to add directly. Theoretically, there should be a 3 dB increase (double) in signal power over that of a single antenna, but, because of losses in the coupler and cable, the actual gain increase will be somewhat less than 3 dB.

An important point to remember is that, regardless of the azimuth angle between the antenna orientation and the signal source, the arriving signal will strike any given identical points on the two antennas simultaneously. However, if the signal is arriving from a source *above or below* the horizontal plane of the antenna, the previous statement is no longer true. For example, if the wavefront is from a source *below* the plane of the antenna (Fig. 2A), the signal will arrive first at the lower antenna and the signal voltage from the top antenna will lag the signal from the lower antenna. The signal voltages at the antenna output terminals will no longer be in phase, and partial cancellation will take place. The opposite is true if the signal arrives from above (Fig. 2C).

The angle of arrival and the resultant difference in arrival time causes a phase difference which reduces the magnitude of the combined voltages. You should begin to see now why two vertically stacked, identical antennas have a more restricted "vision" to signals arriving from a point above or below the horizontal plane than does a single antenna.

HORIZONTAL STACKING

Stacking two identical antennas side by side in a horizontal plane (Fig. 3) significantly narrows the *horizontal* beam-width angle, as shown in Fig. 4. That is, the antenna combination, like a horse wearing blinders, "sees" fewer interfering signals arriving from the sides while its vision up and down (in a vertical plane) is virtually unaffected. In the process, gain increases approximately 1.2 dB over that of a single antenna.

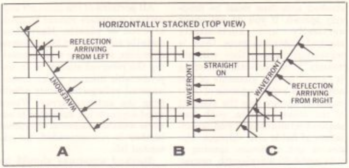

Fig. 5—Top views of horizontally stacked Yagi antennas showing relationships of antenna elements and arriving signals. A) Signal arriving from left side. B) Signal received straight from source. C) Signal arriving from right side.

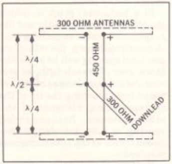

Fig. 6—Harness arrangement for vertical stacking. Using a phasing harness to couple 300-ohm stacked antennas eliminates a coupler and avoids losses but can only be optimized for one channel. A harness is also susceptible to noise and is more time consuming to install. Phasing harnesses, made from balanced transmission line, must be precisely dimensioned, properly phased and carefully positioned to achieve satisfactory performance. Vertically stacked single-channel 300-ohm antennas are connected in parallel using two quarter-wave lengths or 450-ohm transmission line. Phasing polarities must be strictly observed. In absence of polarity marking on antenna, consider corresponding right and left terminals on identical antennas as same polarity.

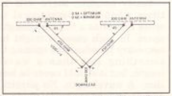

Fig. 7—Harness arrangement for horizontal stacking. Two horizontally stacked, 300-ohm, single-channel antennas require two equal lengths of 450-ohm balanced transmission line cut to an odd multiple of a quarter wavelength at the center frequency of the channel to be received and positioned at 45 degrees to the horizontal. Phasing polarity must be strictly observed. (For the purpose of connecting a phasing harness, a quad stack (2 x 2) can be envisioned as two separate vertical stacks, each preconnected and arranged in a horizontal-stacking pattern. Connect the output of each vertical stack as you would each output of identical antennas in a horizontal stacking arrangement.

If two identical antennas are arranged side by side in a horizontal plane and the signal wavefront arrives directly from the front (Fig. 5B), each antenna "sees" the same wave or field at the same time. If the wavefront arrives from a source above or below, the same is still true, except that the individual antennas are not operating as efficiently. However, if the wavefront arrives from *one side or the other* (Fig. 5A and C), the antenna on the side from which the signal is arriving will "feel" the signal first, causing the voltages induced in each antenna to be out of phase. This, in turn, causes partial cancellation of the antenna voltages when they are combined.

The up and down (vertical) "vision" of a horizontal stack is comparable to that of a single antenna, but its side-to-side "vision" is more restricted.

QUAD STACKS

Stacking four identical antennas, two vertically and two horizontally in a rectangular or diamond pattern, restricts the vision of this combination in all directions off the axis. Called a *quad stack*, it "sees" as though it were looking through a tube pointed in the direction of the transmitting antenna. Gain is increased approximately 4 to 5 dB over that of a single antenna.

GENERAL TECHNIQUES

Before you start putting up an array, you should be aware of the following basic considerations which apply to dual and quad stacking of antennas:

1) Stack only identical antennas
2) Maintain approximately one wavelength spacing (at lowest channel frequency) between antennas
3) Cut phasing lines or connecting cables to *equal* lengths
4) Length and phase of twinlead interconnecting harnesses is critical
5) Horizontal supports should be nonmetallic
6) Avoid running interconnecting cables horizontally.

Vertical stacking is easier than horizontal stacking simply because in vertical stacks the antennas mount on a common vertical mast and spacing is easily adjusted.

However, with the excellent gain and high directivity of most Yagis today, vertical stacking is seldom necessary. If additional gain is needed, two vertically stacked identical antennas spaced more than ½ wavelength apart will increase signal power by 3dB compared to that of one antenna. However, part of the increased gain will be lost in the connecting cables and the coupler.

Horizontally stacked antennas also must be spaced so that their booms are separated by a distance equal to more than ½ wavelength of the lowest channel frequency. This spacing is needed to prevent the tips of the longest reflector elements from touching. Also, the horizontal supports must be *nonmetallic;* redwood or cedar 2' x 4's are commonly used.

The severe ghosts caused by high-rise buildings, water towers and mountains can be reduced or eliminated by horizontally stacking two Yagis. However, the wavelength of a channel 2 signal exceeds 17 feet, making such an array for channel 2 unwieldly, heavy and subject to damage from ice and/or high wind. Fortunately, ghosting is more of a problem at high-band channels, and high-band antenna dimensions are significantly smaller. For these reasons, usually only high-band Yagis are stacked horizontally.

Spacing

For optimum performance,

stacked antennas must be properly spaced. If you do not space vertically and horizontally stacked antennas more than ½ wavelength apart, they will adversely "load" each other. Loading is caused by the elements of one antenna re-radiating some of their received energy into the element of the other antenna, with consequent reinforcement and cancellation of fields and voltages. *Optimum* and *minimum* spacing is *0.94* and *0.60* wavelength, respectively, at the lowest frequency received. Spacing exceeding one wavelength reduces the performance of the stack.

In a horizontal stack in which the elements are tip-to-tip and the longest element is something over .6 wavelength long, the minimum practical spacing will be some distance over .6 wavelength, to prevent the *longest* element of one antenna from touching the tip of the corresponding element of the other antenna. Recommended spacing is 0.94 wavelength between booms at the lowest channel involved.

Because of restrictions on space (usually height), there will be times when it is impractical to space antennas a full wavelength apart. In such cases it might be necessary to reduce the spacing to something less than a wavelength, but it should never be less than .6 wavelength. No physical damage will be caused by spacings closer than one wavelength, but as spacing is reduced, performance will deteriorate. At less than .6 wavelength, all of the advantages of multiple-stacked antennas are lost.

All portions of the antenna supporting structure should be made of wood or plastic. Horizontal metallic supports act like antenna elements, absorbing and reradiating the received energy in an unpredictable manner which causes unusual voltage/frequency effects from the antenna array. Where wood supports are subjected to adverse weather, redwood or cypress lumber is recommended, for extended life.

Stacked antennas should be identical. They can be broad-band, single-band or single-channel antennas, but they must be *identical*. If not, the phase of the voltages from the two antennas, when combined, will not produce the optimum signal level.

Interconnections

Connecting the antennas properly is as important as spacing and orienting them. Getting the individual voltages from each antenna to the point where they are combined without 1) combining them out of phase and 2) without adding extraneous signals and noise requires careful positioning, dimensioning and coupling of the antennas, the harness and/or the connecting cables.

Antennas may be coupled by a phasing harness made from balanced transmission line (Figs. 6 and 7) or they may be coupled with a hybrid antenna coupler (Figs. 8, 9 and 10). Antenna couplers are simpler to hook up and are less critical and more durable than phasing harnesses. Harnesses must be cut to the precise length for a single channel frequency, must be kept straight and untwisted and, for horizontal stack-

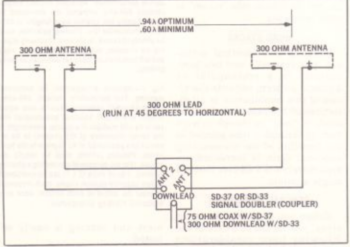

Fig. 8—Method of using SD signal doublers to couple horizontally stacked antennas.

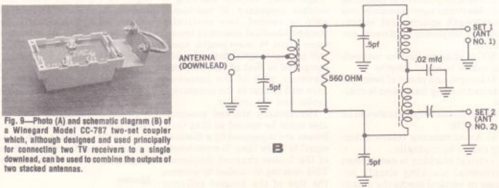

Fig. 9—Photo (A) and schematic diagram (B) of a Winegard Model CC-787 two-set coupler which, although designed and used principally for connecting two TV receivers to a single downlead, can be used to combine the outputs of two stacked antennas.

ing, must be installed and maintained at a 45-degree angle to the horizontal. Also, the harness connections at the antenna and the combining point must be phased properly or the performance will be less than that from only a single antenna.

Along the length of any transmission line there will be voltage maximums and minimums. If the lines are to be interconnected, cut and connect them at points at which the voltages are maximum, or at odd multiples of a quarter wavelength. If the transmission lines are of different lengths, connect them at a point where their signals are in phase (multiples of a whole wavelength, longer or shorter) so that the voltages will add.

Because wavelength changes with frequency, wiring harnesses are only practical for single-channel antennas. Multiple-band and wide-band antennas should always be connected with *broadband hybrid couplers.*

Antenna couplers simplify the interconnection of stacked antennas with 75-ohm coaxial cable, as shown in Fig. 10. Because of cable loss, the cables should be kept as short as possible and of equal lengths. They can be taped to the metal boom or mast. However, because cable is a metallic conductor, horizontal lengths parallel to antenna elements should be avoided; the cable shield might act as an antenna element, re-radiating energy into the antenna and thereby causing cancellation and ghosts.

Most MATV companies manufacture a variety of couplers to simplify combining the individual signals from stacked antennas. The Winegard Company offers two different series for stacking applications: the SD signal doubler and the CC multiset couplers. CC multiset couplers, although designed and sold principally for coupling two TV sets to a single antenna downlead, also function well as antenna couplers.

As shown in Fig. 8, SD signal doublers combine signals from any two identical 300-ohm antennas and provide either a balanced 300-ohm output (the SD-33) or a coaxial 75-ohm output (the SD-37).

Because SD's have only 300-ohm inputs, they are not recommended as highly for horizontal stacking as the CC's, which have 75-ohm inputs.

When connecting stacked antennas, correct phasing must be achieved or a null signal (no picture) will be produced at the coupler. If a null is observed, put a half twist in *one* of the 300-ohm lines to reverse the phase at the coupler terminals.

Series-CC 82-channel multiset couplers (Figs. 9 and 10) are preferred over SD's for coupling identical, stacked antennas. When used as antenna couplers, the individual antennas are coupled into the "TV-set" (output) terminals of the CC and the output is taken from the "antenna downlead" (input) terminal. The device simply separates or combines signals. It doesn't know its input from its output and is only concerned with the *impedance* of the devices connected to its terminals. It doesn't know and doesn't care in which direction the signal is passing through it.

CC couplers have an 82-channel bandpass and are available with both 300-ohm and 75-ohm input/outputs. CC couplers also have two or four inputs, for both dual and quad stacks, and are enclosed in a weatherproof housing equipped with universal mast-mounting brackets.

Because 75-ohm coaxial cable is recommended for interconnecting stacked antennas, and for downlead as well, the logical coupler choices are the CC-787 two-set coupler, for dual stacks, and the CC-997 four-set coupler, for quad stacks.

Cautions to be observed when coupling stacked antennas include cutting the coaxial interconnecting cables into equal lengths, observing the correct phase, and dressing cables away from the antenna elements.

If 300-ohm antennas are used, impedance-matching transformers, such as the T-28M (Fig. 10), are recommended to adapt the an-

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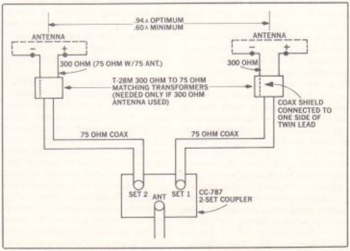

Fig. 10—Method of using the Model CC-787 two-set coupler to combine the outputs of two horizontally stacked antennas. Coupling stacked antennas with a hybrid coupler and 75-ohm coaxial cable simplifies the installation. Coaxial cable routed along the boom and metal supports causes no adverse effects. Phasing need not be considered except to insure that the coax shield be directly connected through the matching transformer to corresponding antenna terminals. A simple ohmmeter check on the matching transformer will disclose which side of the 300-ohm output lead is directly connected to the coax shield. Connecting antennas to a coupler using 300-ohm transmission line (alternate method) does require careful attention to phasing.

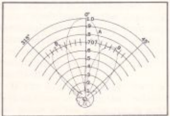

Fig. 11—Composite polar graph showing the difference between the polar pattern (A) of two in-phase horizontally stacked Yagi high-band TV antennas and the polar pattern (B) of the same two antennas out of phase.

STACKING TV ANTENNAS

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tenna output to the 75-ohm coaxial cable.

If you choose to use the T-28M or some other matching transformer, correct *phasing* on the *300-ohm* side must be observed. The easiest way to do this is to measure for continuity between the threaded (shield) portion of the coaxial connector and one conductor on the 300-ohm side. The conductor thus determined should then always be connected to a corresponding, right or left, screw terminal on each of the identical antennas for in-phase connections, or reversed for out-of-phase connections.

The effect of incorrectly phased horizontally stacked antennas is illustrated in Fig. 11.

BEYOND DUAL OR QUAD STACKS

Not much improvement in eliminating ghosting or man-made noise is gained by stacking more than two antennas horizontally or two vertically. If more than two in either direction seems to be required, then the advice of an experienced TV antenna installer or antenna engineer should be sought.

There are techniques other than conventional stacking that can reduce TVI. Stagger stacking, tri-stacking, and phasing harnesses can be useful, but all require a high level of knowledge and experience.

One source of such help or advice is the technical staff of an antenna manufacturer such as the Winegard Company. They might have a special antenna design (called an *area special*) which will overcome the particular problems in your area and, if not, they might be willing to help you or a Winegard dealer/installer in your area "design" a special antenna array which will solve the problem. ■