A Panel-Reflector Antenna for 70 cm

Want a small antenna with gain on 440 MHz? This may be your answer—over 10 dBi in a compact package only 2 feet square!

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This article presents the design and construction of a panel-reflector antenna for the 70 cm (420-450 MHz) amateur band. This antenna design uses a very different design approach than the more commonly known Yagi-Uda beam. While Yagi-based designs use a single driven element with parasitic reflector and director elements, this antenna has four driven elements and a single planar reflector. This approach yields an antenna that is very compact. With its flat reflector, it can be attached directly to a metal mast or cross-boom, eliminating the need for fiberglass or other non-conducting mounting materials. The photo demonstrates just how small this antenna really is.

The panel-reflector antenna provides over 10 dBi of gain and is right-hand circularly polarized. It was designed primarily for satellite work and it has sufficient gain to easily receive any of the current LEO (low earth orbit) satellites with 70 cm downlinks.

Although it was primarily built for satellite work, the antenna has a very wide bandwidth and provides a low standing wave ratio (SWR) across the entire 70 cm ham band. The panel-reflector antenna's circular polarization is compatible with, and works quite well with FM repeaters, and it can even be used for casual SSB/CW work.

Theory of Operation

The panel-reflector antenna consists of four radiating dipole elements over a flat reflector—see Figure 1. The two horizontal dipoles are fed in-phase so that they operate as a two-element, phased array. Similarly, the two vertical dipoles are also fed in-phase and operate as a two-element, phased array. The horizontal and vertical pairs are fed 90° out of phase, however, to produce the right-hand circular polarization.

The flat reflector under the dipoles reflects the radiation from the back side of the dipoles to the forward direction, and significantly increases the overall gain. This reflector is 24×24 inches—less than 1 wavelength at this frequency. Though this small size reduces the gain over the maximum possible, it represents a reasonable compromise between gain and size—a nice, compact package.

In order to make up for some of the gain lost because of the small reflector size, the dipole pairs are spaced beyond the usual half-wavelength spacing found in textbook descriptions of phased arrays. This increases the gain by nearly 1 dB, although it also decreases the front-to-side ratio. On 70 cm, the decreased front-to-side ratio tends not to be an important consideration, and the additional gain is helpful when conditions are difficult. With the increased spacing, the calculated gain of this antenna is 10.88 dB over a circularly polarized isotropic radiator.[1] Since there are some losses in the feed cables, connectors and power splitter, the actual gain will be a little less than this calculated value.

Unlike a Yagi, the location of the phase-center of the radiating elements has only a minor effect on the overall gain of the panel-reflector antenna. This is due to the fact that flat reflectors do not have a specific focal point. As a result, there is no need to use balanced-to-unbalanced (balun) transformers to feed the dipoles, and that significantly simplifies the construction and reduces the cost and complexity of the antenna.

The height of the dipoles from the reflector surface affects the radiation

[1]Notes appear on page 39.

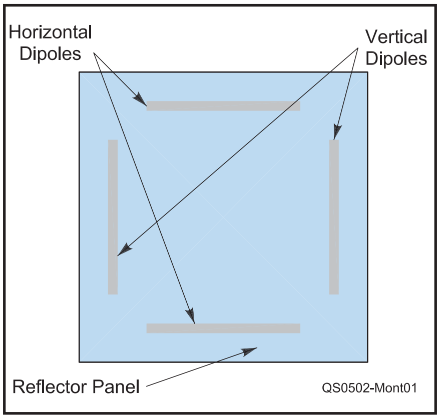

Figure 1—The basic panel reflector antenna consists of four dipoles above a planar reflector.

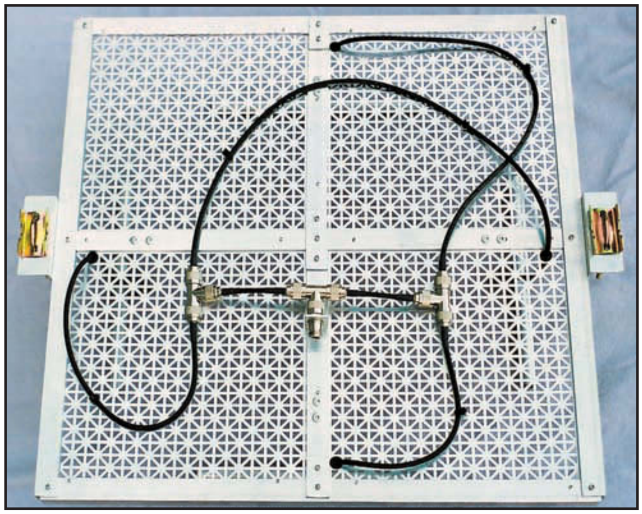

Figure 2—The power splitter for the four dipole radiators can be seen in this rear view of the antenna.

resistance and this spacing was designed so that the dipoles each present a 50 Ω load. Since no balun is needed, the dipoles can be fed directly, with common, 50 Ω, coaxial cable. Note that you cannot measure each dipole's impedance separately. Only when all are fed in proper phase do they present 50 Ω loads.

The phasing of the dipole elements is accomplished by using specific lengths of the coaxial feed cables. Although it is more common to feed pairs of a phased array, using same-length cables, this approach was not used, as it would require an untidy cable arrangement. Instead, pairs of dipoles are fed with cables that differ by 180° of electrical length and the wires are then reversed at the dipoles to restore the required in-phase feed. Since the horizontal and vertical pairs are fed 90° out-of-phase, this means that each feed cable is a different length. This adds slightly to the construction complexity but results in a much nicer wiring arrangement.

The dipole feed cables are each connected to one port of a 4-way, 0° power-splitter. The power-splitter is very simple and easy to construct as it is assembled from ordinary 50 Ω coaxial cable and standard type N coaxial connectors. The power splitter is shown in Figure 2, behind the antenna.

The operation of the power-splitter is as follows: Each dipole presents a 50 Ω load and is connected to one of the feed ports (numbered 1 to 4), using 50 Ω coaxial cable. Each feed port is thus terminated in a 50 Ω load and each of the ports is a leg of a standard N-type T-connector. At the center of the T-connector that joins ports 1 and 2, the impedance is 25 Ω—the result of the two 50 Ω loads in parallel. This 25 Ω load is transformed into 100 Ω via an electrical quarter-wavelength section of 50 Ω coaxial cable. The same thing occurs with ports 3 and 4. At the center of the T-connector of the input port, the two 100 Ω loads are joined in parallel to provide the desired 50 Ω antenna impedance.

This antenna design employs thick dipoles; and with its feed method and power splitter, it has a wide bandwidth. It covers the entire 70 cm band and does not require any tuning or adjustments. This simplifies the construction and eliminates the need for any special UHF test equipment.

Construction

The panel-reflector antenna, while not exactly a beginner's project, is relatively straightforward in construction. Except for the coaxial cable and connectors, all of the materials were obtained from a local hardware store, and the prototype was built using only ordinary hand tools. Experienced builders should feel free to substitute their own favorite construction techniques. Additionally, the antenna was designed to be insensitive to small dimensional deviations. A complete list of materials that were used to construct the prototype is shown in Table 1. Complete construction details, including frame and panel details, dipole feed details, power splitter design and radiation and SWR plots can be found on the ARRL Web site.[2]

This list of materials is generally not critical with only a few exceptions: the reflector panel must be at least 2×2 feet in size, and the tubing used to construct the dipoles must be 3/4 inch in outside dimension. The other materials were selected because they were readily available locally.

LMR-240 cable was selected because it is thin and easy to work with, yet it has relatively low loss at 440 MHz for its size. It can handle over 350 W at this frequency, even at +40°C. Other thin 50 Ω cables, such as RG-58/U, could be substituted, but the maximum power rating and gain of the antenna would be lower because of the increased losses.

To build the antenna, start by constructing a frame for the reflector. The outside of the frame was made from 1×1×1/8 inch angle stock. The interior cross supports are made of sections of 1×1/8 inch rectangular

Table 1
Bill of Materials for the Panel-Reflector Antenna

Quantity	*Description*
4'	1"×1"×1/8" aluminum angle stock
2'×2'	Perforated aluminum sheet
8'	1"×1/8" aluminum rectangular bar stock
2'	1 1/2"×1 1/2"×1/8" aluminum angle stock
4'	3/4" OD aluminum tubing
(4)	1/2" black PVC insert coupling (for lawn sprinkler systems)
(4)	1/4" ID rubber grommet
(8)	1/2" nylon spacer
(8)	1/16" nylon bushing
(8)	Mylar washer
(8)	8-32×2" stainless steel screw
(8)	#8 stainless steel flat washer
(8)	#8 stainless steel lock washer
(8)	8-32 stainless steel nut
(8)	1/4" aluminum screw post fastener
Various	1/8" and 3/16" aluminum pop rivets
Tube	OX-GARD electrical grease
(2)	1 1/4" stainless steel U-bolt assembly
(8)	Type N male connector for LMR-240 cable
(2)	Type N female/female/female T-connector
(1)	Type N female/male/female T-connector
(1)	Type N female/female bulkhead connector
10"	LMR-240 50-Ω coaxial cable

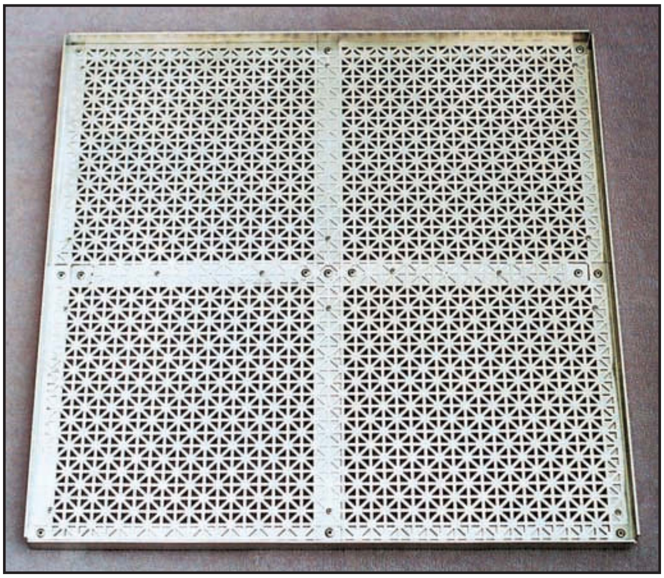

Figure 3—The completed planar reflector—before the dipoles are mounted.

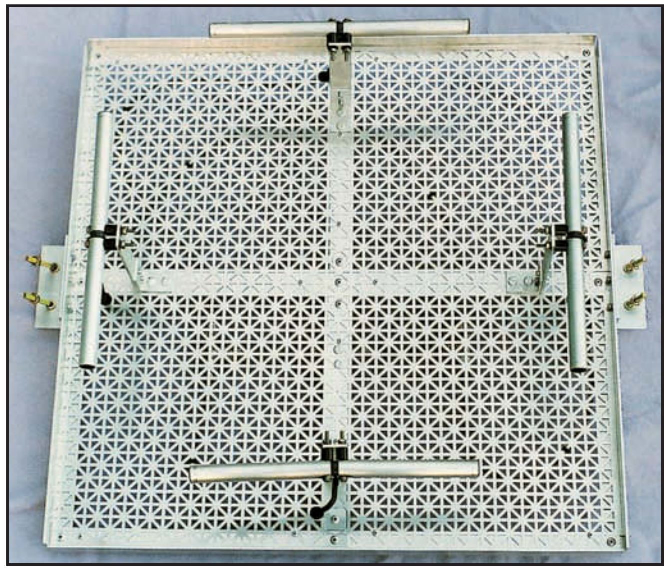

Figure 4—The completed antenna assembly.

bar stock. The assembly is held together with aluminum pop rivets. Note that the corners are not mitered—the top and bottom supports are mounted beneath the side supports. The center supports are offset so they are at the same height as the side sections in order that the reflector can be mounted flat. The techniques used here are not critical; the idea is only to provide a rigid, flat support structure for the 2×2 foot reflector panel. When the frame is complete, the reflector panel is attached to the frame with pop rivets. The completed planar reflector panel is shown in Figure 3.

Construct the four dipoles using the $^3/_4$ inch aluminum tubing and the PVC insert couplings. The tubing pieces are each $5^1/_2$ inches long and they are spaced $^1/_4$ inch apart at the center, giving an overall length of $11^3/_4$ inches. The PVC insert couplings, used as the center insulators, will need to be filed or sanded to fit inside the tubing. The fit should be snug. After assembling the tubing sections over the insulator, drill two holes, each $^{11}/_{64}$ inch, all the way through the tubing and the center insulator. These holes will be used to mount the dipoles and provide the electrical connections.

The dipoles are held in place by dipole support brackets. These are fabricated from a 1 inch wide section of the $1^1/_2 \times 1^1/_2 \times {}^1/_8$ inch angle stock and a length of $1 \times {}^1/_8$ inch bar stock; fastened together with pop-rivets. The centers of the dipoles need to be mounted $5^5/_{16}$ inches from the reflector surface and $9^3/_4$ inches from the center of the reflector (the dipole pairs are spaced $19^1/_2$ inches apart). The dipole mounting holes are $^5/_8$ inch apart to mate with the holes on the dipoles. The brackets are fastened to the reflector panel using aluminum "screw-posts," allowing them to be easily removed. This can be helpful in transporting the antenna for portable uses.

The dipoles are fastened to the support brackets with the 8-32×2 inch screws and associated 8-32 hardware. The nylon bushings and mylar washers are used to insulate the screws from the dipole brackets. The nylon spacers hold the dipole assembly $^1/_2$ inch away from the support bracket. All of the nylon and mylar hardware was painted black to mitigate the effects of the ultraviolet radiation from the sun.

Dipole feed-cables are connected to the 4-way power splitter. Dipole construction and power splitter details are given on the ARRL Web site.[3] The power splitter is made from standard type N connectors and two short lengths of LMR-240 cable. The two female/female/female Ts are used at the output ports. The female/male/female T is used at the input port. Each output T is connected to one leg of the input T with a short male-to- male jumper cable made with enough cable so that the distance from the center of the output T to the center of the input T is a quarter wavelength. LMR-240 cable has a velocity factor of 0.84 and the T-connectors were assumed to also have a 0.84 velocity factor, so this requires a total length of 5.7 inches between the centers of the T-connectors. The LMR-240 cable should be cut to 4.5 inches in total length before stripping. With standard crimp male N connectors, there will be 3.1 inches of the coax jacket showing between the two connectors on the completed jumper. A bulkhead connector is mounted on a bracket made from a 1 inch wide section of $1^1/_2 \times 1^1/_2 \times {}^1/_8$ inch angle stock. The male part of the input T is connected to the bulkhead connector.

The front view of the completed panel-reflector antenna is shown in Figure 4. Note that mounting brackets, made from $1^1/_2 \times 1^1/_2 \times {}^1/_8$ inch angle stock, have been riveted to the sides of the reflector frame and fitted with U-bolts to accommodate a standard $1^1/_4$ inch mast.

Polarization Switching

At the time this article was written, all of the operational satellites used either linear or right-hand circular polarization, so no provision was made in the prototype to allow switching to left-hand polarization. This is easy to add, if desired, however. Just make one leg of the power splitter cable an extra half-wavelength (11.4 inches) longer to change to left-hand polarization. An antenna-transfer relay could then be used to add in yet another half-wavelength to switch back to right-hand polarization. Make sure to include the path length through your transfer relay. The total cable plus relay path lengths, as measured between the T-connector centers, should be 17.1 inches for left-hand polarization and 28.5 inches for right-hand polarization.

Design Testing

The return loss of the completed antenna was tested using an HP 8640B signal generator, a Narda 3020A directional coupler, an HP 423A detector and an HP 415E SWR meter. The directional coupler was attached directly at the antenna input connector. Spot frequencies were checked over the range from 410 to

Figure 5—On the air! Using the panel-reflector antenna during Field Day 2003.

460 MHz. The return loss was converted to the more familiar standing wave ratio (SWR) and the result plotted. The SWR is well below 1.5:1 (needed by modern transceivers) across the entire 70 cm band (420-450 MHz).

The author did not attempt to precisely measure the antenna circularity but an on-the-air check was performed by listening to the carrier of a distant FM repeater using a transceiver set to SSB mode. The antenna was rotated through 0°, 45° and 90° while observing the S-meter and listening to the received carrier level. It was not possible to discern any difference in the received signal strength either audibly or on the S meter as the angle was changed, indicating very good circularity.

Another check of antenna circularity was made by keying up a distant FM repeater using just 0.5 W of power into the antenna. As before, the antenna was rotated through 0°, 45° and 90° to see if any differences could be found in either the ability to bring up the repeater or in the received signal strength. There were no cases where any differences could be detected.

Field Day 2003

The compact size of this antenna makes it very handy for setting up portable operations and the author used it for an OSCAR 40 satellite station in the 2003 ARRL Field Day exercise. This station was part of the North Shore Radio Association, NS1RA, effort, and the intent of the station was to generate exposure to satellite operating and to give club members who had never operated through a satellite a chance to try out OSCAR 40.

Due to the contest nature of this event, the unusually high number of stations operating, and the corresponding automatic gain control (AGC) action of the OSCAR 40 UHF receiver, Field Day presents an unusually difficult set of conditions for generating a reliable uplink signal. This made it a good test of the capability of the panel-reflector antenna.

The station used a Yaesu FT-847 transceiver with a maximum output power of 50 W. To complement the panel-reflector transmitting antenna, a pyramidal-horn receiving antenna was made from some cardboard boxes and aluminum-foil, as shown in Figure 5.[4] As can be seen from the figure, the panel-reflector antenna was just propped up on a small folding chair.

In spite of the lack of satellite experience among club members, we had no difficulty making plenty of contacts, not to mention plenty of fun! One of the participants, who had just taken a break from operating an HF station, expressed amazement at how easy it seemed to make contacts compared to how difficult things were on HF that day. The panel-reflector antenna proved both convenient and effective. Sadly, the OSCAR 40 satellite is no longer operational. Even so, the performance benefit demonstrated by this antenna during Field Day 2003 is applicable to other ham satellites today, including the new P3E and Eagle satellites under development.

Summary

I have described the design of panel-reflector antenna for the amateur 70 cm band. The design uses four driven elements and a planar reflector and results in a very compact package. The antenna is circularly polarized and has over 10 dBi of gain, making it ideal for satellite work. Additionally, it has a very wide bandwidth, eliminating the need for tuning or specialized test equipment. Its bandwidth allows it to be used over the entire 70 cm band including the FM repeater and SSB/CW sub-bands.

Notes

[1]The antenna was modeled using *EZNEC* software by W7EL. *EZNEC* is available at **www.eznec.com**.

[2]**www.arrl.org/files/qst-binaries/panel-antenna.zip**.

[3]See Note 2.

[4]A. Monteiro, "Work OSCAR 40 with Cardboard Box Antennas!" *QST*, Mar 2003, pp 57-62.

All photos by the author.

Tony Monteiro, AA2TX, has been a ham since 1973 and is a member of AMSAT, TAPR, ARRL and QCWA. While mostly interested in the technical aspects of Amateur Radio, he can be found operating on the satellites. Tony was a member of the technical staff at Bell Labs and held senior management positions at Cisco Systems and several high-tech start-ups. He can be reached at **aa2tx@amsat.org**.

New Products

LEGAL LIMIT BALANCED ANTENNA TUNER

◊ MFJ has added a high power balanced antenna tuner, the MFJ-976, to their product line. The tuner is said to match from 12 to 2000 Ω over the frequency range of 1.8 to 30 MHz. It is specified to handle 1500 W using SSB or CW. In addition to operating with balanced lines, the T-network based tuner is said to be able to tune coax fed or random wire antennas. An active peak reading lighted cross-needle meter indicates SWR, peak or average forward or reflected power with 300 or 3000 W full scale ranges. The unit is $12 \times 6 \times 15\frac{3}{4}$ inches in size. Price: $499.95.

For more information, contact MFJ Enterprises Inc, 300 Industrial Park Rd, Starkville, MS 39759; tel 800-647-1800; fax 662-323-6551; **www.mfjenterprises.com**.