HIGH GAIN BACKFIRE ANTENNAS

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In the past few weeks there has been considerable interest stimulated in ham activities in the u.h.f. bands. The years 1964, 65, 66 will long be remembered by u.h.f. enthusiasts because such previously difficult things as moonbounce are now a rather common occurrence within ham circles. The obstacles to long distance u.h.f. communications are rapidly being overcome by improved u.h.f. techniques including converters and antennas. The costly converters of yesterday can be equalled or surpassed by relatively inexpensive transistorized units.

This trend toward increased u.h.f. interest has created the need for antennas which yield very high gain and have excellent side lobe and front to back characteristics. It is the purpose of this article to give the general background and describe such a high gain antenna for the 144, 220, 432, and 1296 mc bands. The antenna however, can be scaled to any desired frequency.

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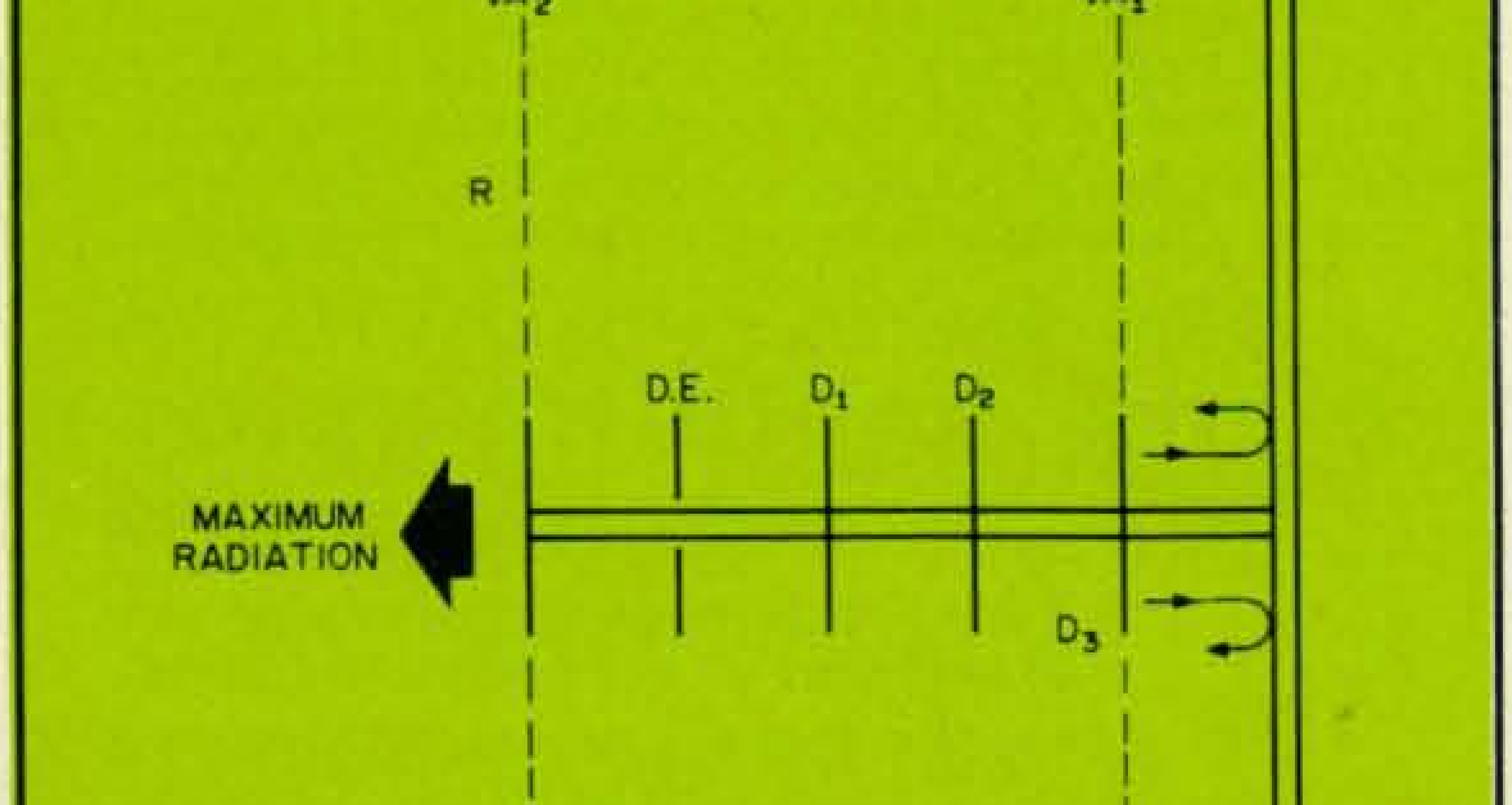


Fig. 1—The simple backfire array shown above consists of a Yagi antenna terminated into a plane reflector.

Backfire Antenna

The backfire antenna is no longer anything new and its operation has been described as far back as the January 1960 *Proceedings of the IRE.*[1] Since this 1960 correspondence in *IRE* a considerable amount of work has been done on the backfire array, including actual working models built by hams for the v.h.f. bands.[2,3] After discussing a few backfire principles, I shall comment on some of the more recent developments in backfire antennas.

There are several types of backfire arrays in existence. Perhaps the simplest is a yagi terminated into a plane reflector as shown in fig. 1.

Here we have an ordinary yagi with reflector, driven element, and three directors. The signal is fed to driven element *DE* and a slow wave propagates down the array and is radiated through virtual aperature VA_1. It continues to travel to the right until it reaches plane reflector *M*. Here it is reflected back and will traverse the yagi a second time. The wave is now radiated from virtual aperature VA_2, and hence we have a backfire array. This antenna acts as a yagi of double length because the wave must

1 Erenspeck, H. W., "The Backfire Antenna, A New Type of Directional Line Source," *Proceedings of the IRE,* January, 1960, p. 109-110.

2 Technical Topics, "The Backfire Antenna," *QST*, February 1961, page 50.

3 Technical Topics, "The Backfire Antenna," *QST,* October 1961, page 50.

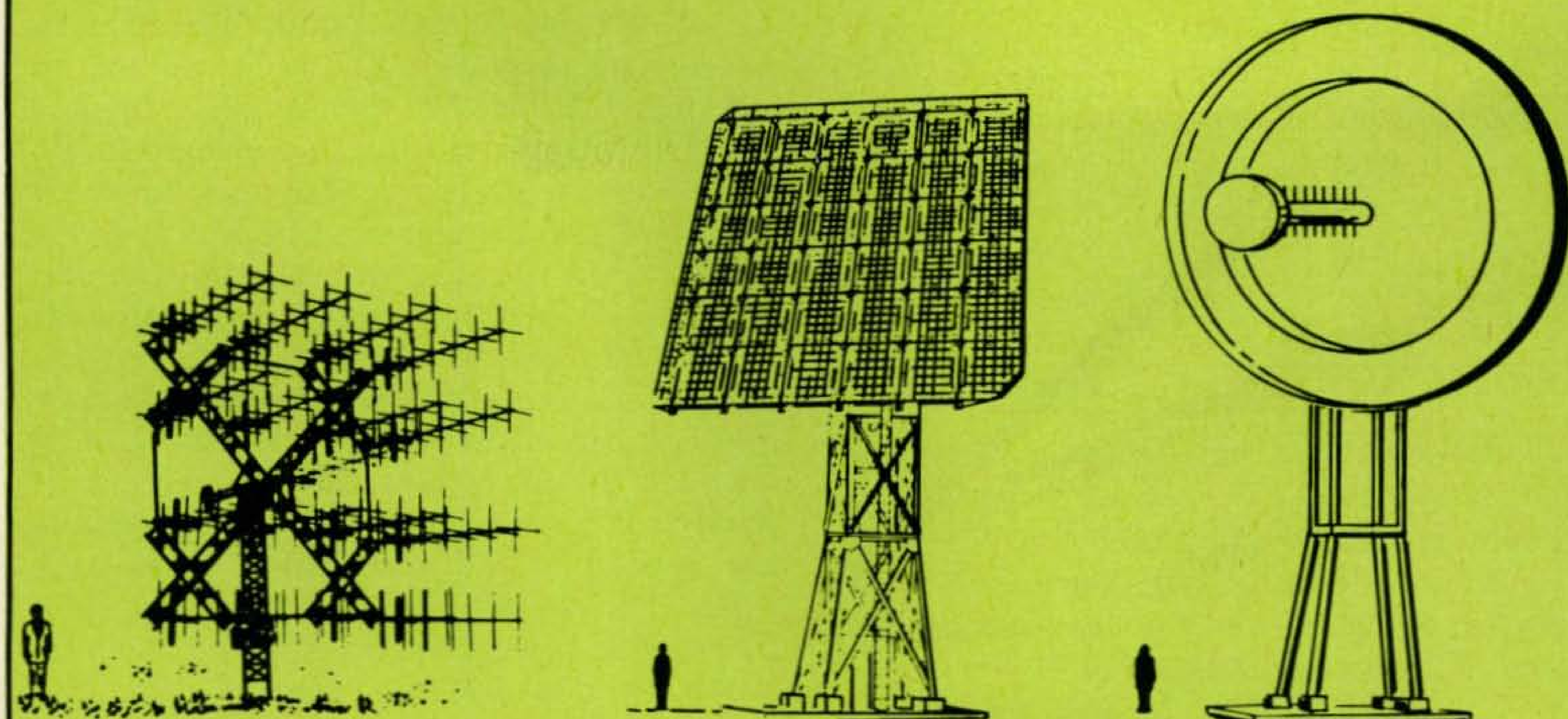


Fig. 2 (A)—Array of sixteen 2 λ Yagis built by NASA. It provides 22.4 db gain over an isotropic source. (B)—Thirty-six cavity backed slots produce a gain of 21.2 db over an isotropic source. (C)—A 4 λ backfire antenna produces a 23.5 db gain over an isotropic source.

traverse the structure twice. The reflector M is plane and should be large enough to intercept the bulk of the wave being propagated through virtual aperture VA_1. Placing the plane reflector M in front of the yagi requires retuning the yagi elements.

The initial backfire antenna was described by Ehrenspeck as listed above. Based on these principles, ham band backfire antennas were built and reported upon in

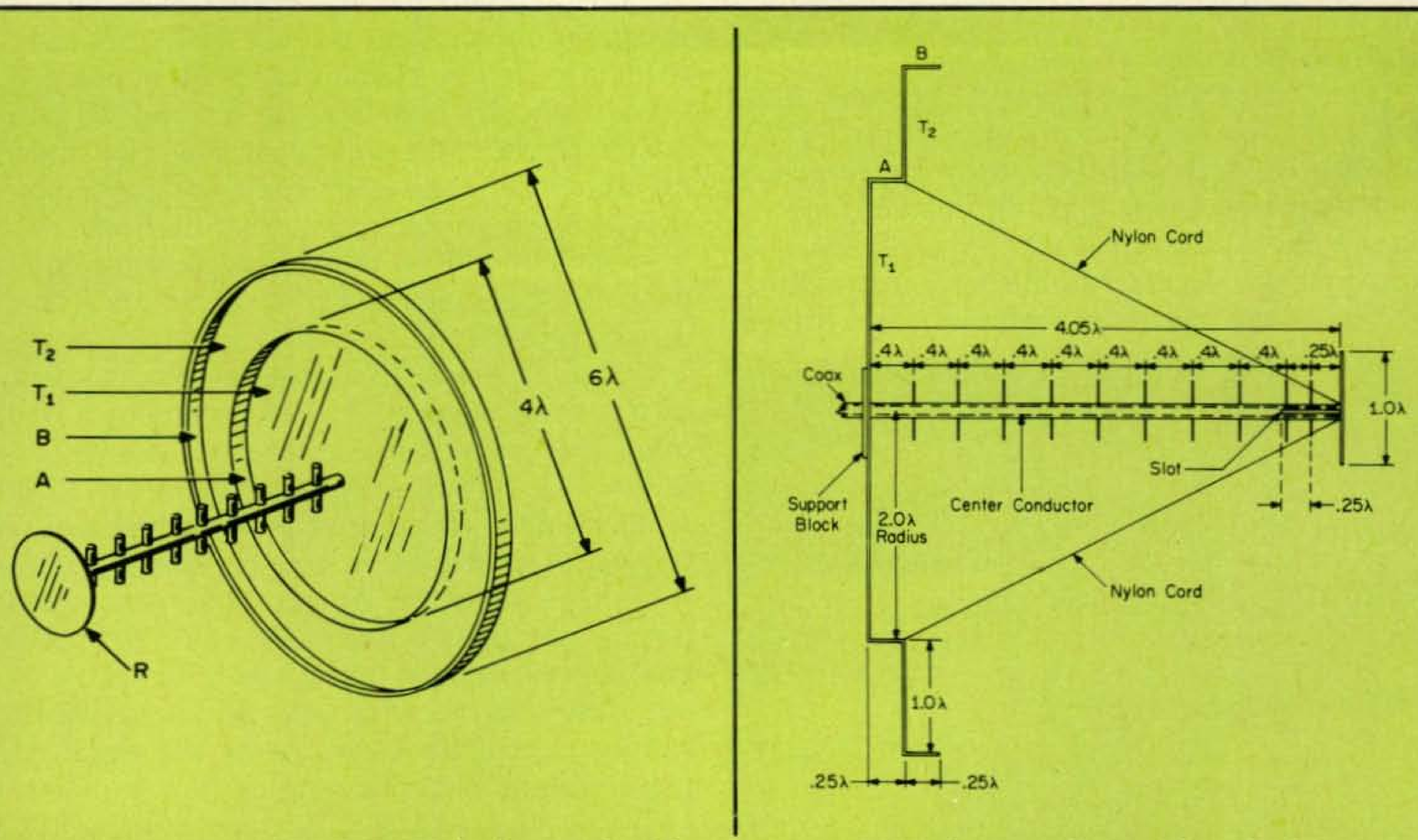


Fig. 3 (A)—Isometric view of a high gain backfire antenna. (B)—Side view showing lengths for construction. The details for the slot, driven element and center conductor are shown in fig. 6(B), the shortened version of this antenna. Reflector R is 1/16" thick.

PART	144mc	220mc	432mc	1296mc
B	20.5"	13.42"	6.83"	2.28"
d	20.5"	13.42"	6.83"	2.28"
T_1 DIAM.	328.0"	214.69"	109.32"	36.44"
T_2 DIAM.	492.0"	322.04"	163.99"	54.67"
DE to D_1	16.40"	10.73"	5.46"	1.82"
DE to R	16.40"	10.73"	5.46"	1.82"
D_N to D_{N+1}	32.8"	21.47"	10.93"	3.64"
L	328.0"	214.69"	109.32"	36.44"
λ"	82.0"	53.67"	27.33"	9.11"

Chart I—High gain backfire array dimensions.

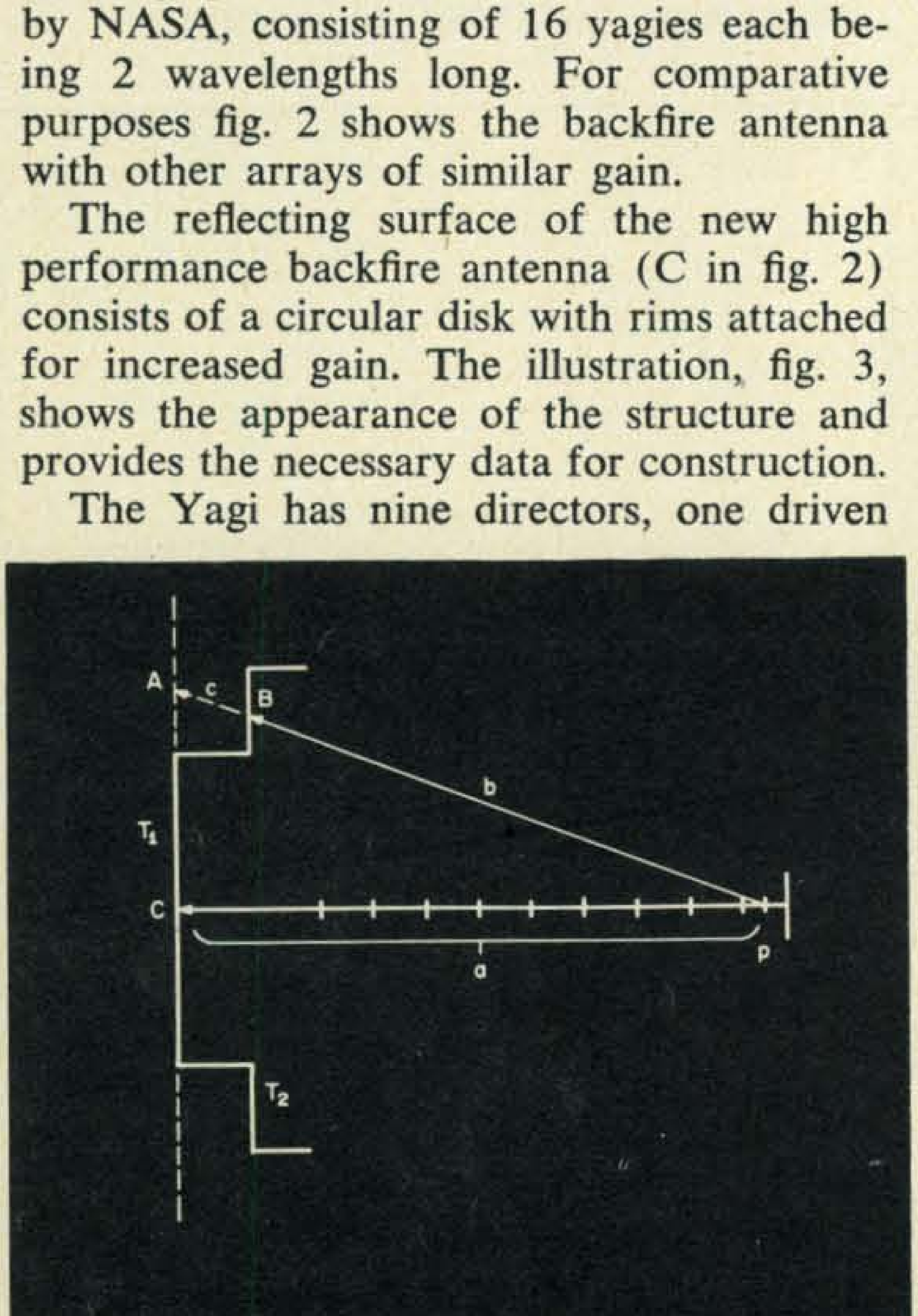
February, 1961, and October, 1961, *QST*. Here it was pointed out that a gain of 4.5 db was obtained over a one wavelength long yagi with front to back up to 19 db.

High Gain Backfire Antenna

.Recent work has resulted in greatly improved pattern control. This is a result of the improved backfire antenna as found in the March, 1965, *Proceedings of IEEE,* by Dr. Ehrenspeck. Working models have been built which yield gains greater than 8 db over an equal length yagi, with side lobes 22 db down and front to back near 30 db down from maximum signal lobe. An array yielding gain of this order has been built by NASA, consisting of 16 yagies each being 2 wavelengths long. For comparative purposes fig. 2 shows the backfire antenna with other arrays of similar gain.

The reflecting surface of the new high performance backfire antenna (C in fig. 2) consists of a circular disk with rims attached for increased gain. The illustration, fig. 3, shows the appearance of the structure and provides the necessary data for construction.

The Yagi has nine directors, one driven element, *DE,* and a circular plane reflector, *R,* of 0.5 wavelength radius spaced 0.20 wavelength from *DE.* The radius of the inner plane T_1 is 2.0 wavelengths. T_2 is a plane reflector ring of 1 wavelength width and 3 wavelength radius. The plane in which T_1 and T_2 lie are separated by a distance *A* as shown in the side view sketch. The rim *A* is about 0.25 wavelength and surrounds T_1, whose depth is *d* (the distance between T_1 and T_2). *B* is a rim surrounding T_2, whose width is also about 0.25 wavelength. Spacing between the feed point and first director is fixed at 0.20 wavelength. All other directors are spaced at 0.4 wavelength from each other. The overall length, *L*, measured from T_1 to *R* is 4 wavelengths. Chart I includes calculated dimensions for the 144, 220, 432, and 1296 mc bands. This antenna is somewhat impractical at 144 mc because of phvsical size.



The maximum gain for the backfire antenna is closely related to its length and phase velocity. It has been shown that the phase velocity of the wave traveling along a yagi can be used as the design criterion for maximum gain. This stems from work done by Ehrenspeck and Poehler.[4] For each length of yagi there is an optimum gain and phase velocity. Adjustment of phase velocity will be discussed later.

The radiation pattern of the backfire array is the vector sum of the field E_1, radiated from the driven element and E_2 (reflected wave from T_1 and T_2). If E_1 and E_2 are out of phase, the resultant field will be their difference. If, however, they are in phase, they will reinforce each other and the resultant field will be their sum. It is the purpose of T_2, as seen in fig. 4, to maintain this proper phase relationship.

Consider point *P* at the driven element as the signal source. A wave traveling from point *P* to point *C* must travel a distance (a) before it is reflected. Another wave traveling from point *P* to point *A* must travel a distance (b+c) which is greater than (a) before it is reflected. Hence the two waves leaving the same point at the same time will not be reflected at the same time. This is not desirable because one of these waves cannot contribute as much as the other to the resultant backfire pattern. As a matter

[4] Ehrenspeck & Poehler, "A New Method for Obtaining Maximum Gain From Yagi Antennas," *IRE Transactions on Antennas and Propagation,* October, 1959, p. 379-386.

of fact, the wave arriving out of phase will *subtract* from the total field strength. If, however, we add plane reflector ring T_2 and properly space it from T_1, the in phase relation may be restored with the resultant gain of more than 2 db over that of T_1 alone. The waves are now reflected at points *C* and *B* at the same instant in time. Therefore T_2 serves a very useful purpose. In a sense one can think of points *B* and *C* as points lying on a parabolic reflector. The radiation pattern of the antenna described in this article has a half power beam width of 11.5° in the *H* plane. Beam widths in other planes were nearly the same and hence yielded a gain of about 23.5 db over an isotropic source. A typical pattern is shown in fig. 5.

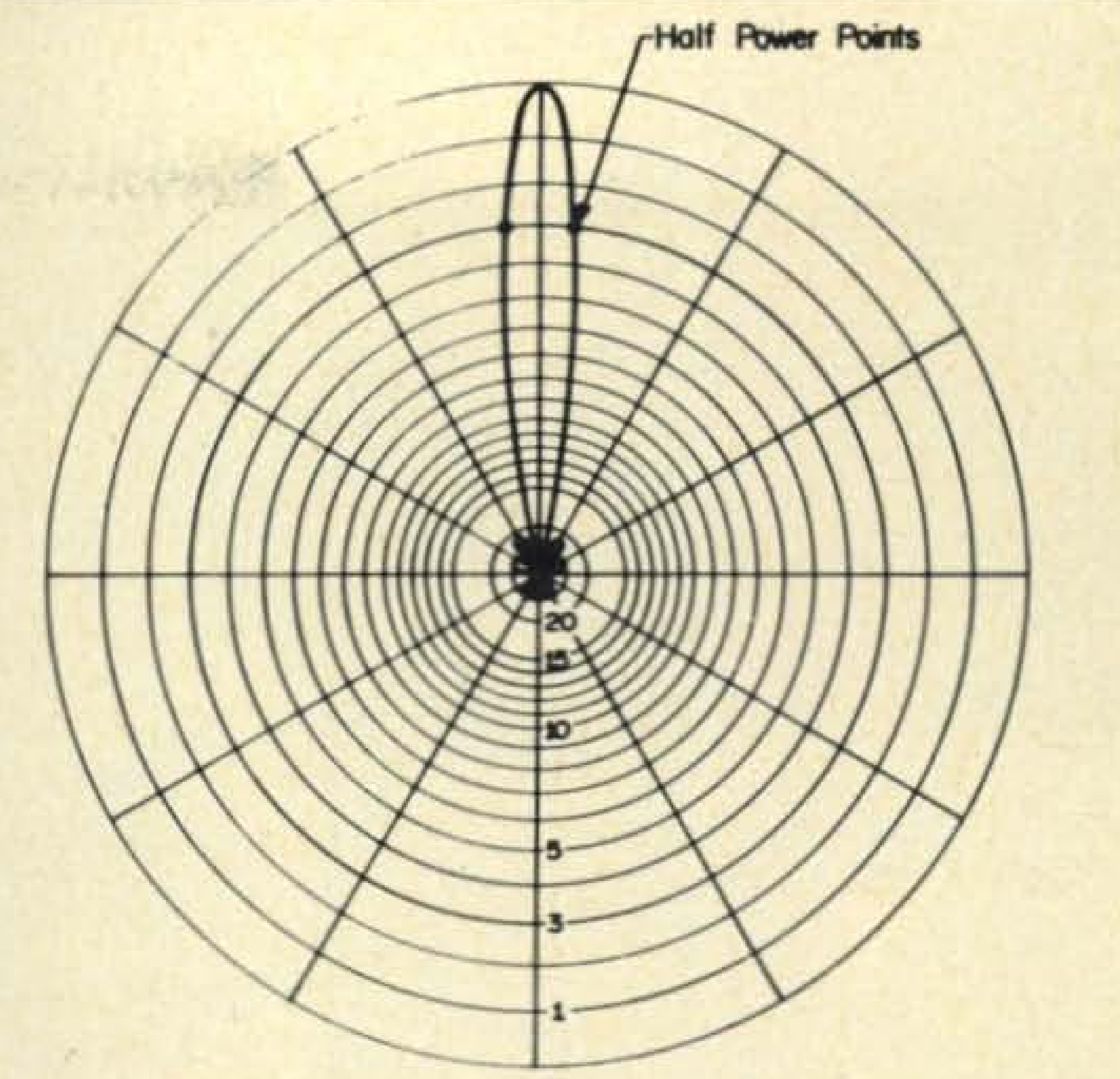


Fig. 5—H plane pattern of the 4 λ backfire antenna. The beam width at the half power points is 11½ degrees.

Medium Gain Backfire Antenna

The backfire antennas discussed thus far will yield high gain, which makes them useful for moonbounce applications. The physical size of this antenna at the lower frequency bands such as 144 mc is quite large. For this reason we shall consider the short backfire antenna. This is an especially interesting and useful antenna because it yields a remarkably high gain for its physical size. The short backfire antenna has been depicted by H. W. Ehrenspeck in the August, 1965, *Proceedings of IEEE.*

A side view sketch of the backfire array is found in fig. 6.

The antenna consists of two circular plane reflectors, *M* and *R*, spaced 0.5 wavelength apart. *M* is a circular disk 2.0 wavelength in diameter. The antenna is fed by the dipole *DE* placed between *M* and *R*. The width, *r*, of the rim around reflector *M* is about 0.25 wavelength. Reflectors *M* and *R* may be made of solid sheet metal or a fine mesh screen to minimize wind loading. This antenna has the unique advantage of being insensitive to feed polarization. Thus it may be linear in any direction, crossed or circular. A typical pattern is shown in fig. 7.

The gain of this short backfire antenna has been measured to be more than 13 db over a dipole. All side lobes are down 20 db or more from the maximum lobe and the front to back ratio is more than 25 db. Fig. 8 shows the comparative size between a short backfire antenna and a long yagi of similar gain.

A yagi antenna needs 15 or more elements with an overall length of at least 4.0 wavelengths to yield a gain of 15 db over an isotropic source. Yagis with optimized gain have quite high side lobes. In order to obtain patterns comparable to the short backfire antenna, the number of reflectors and the overall length of the yagi would need to be significantly increased. The two arrays shown in fig. 8 both yield patterns of nearly

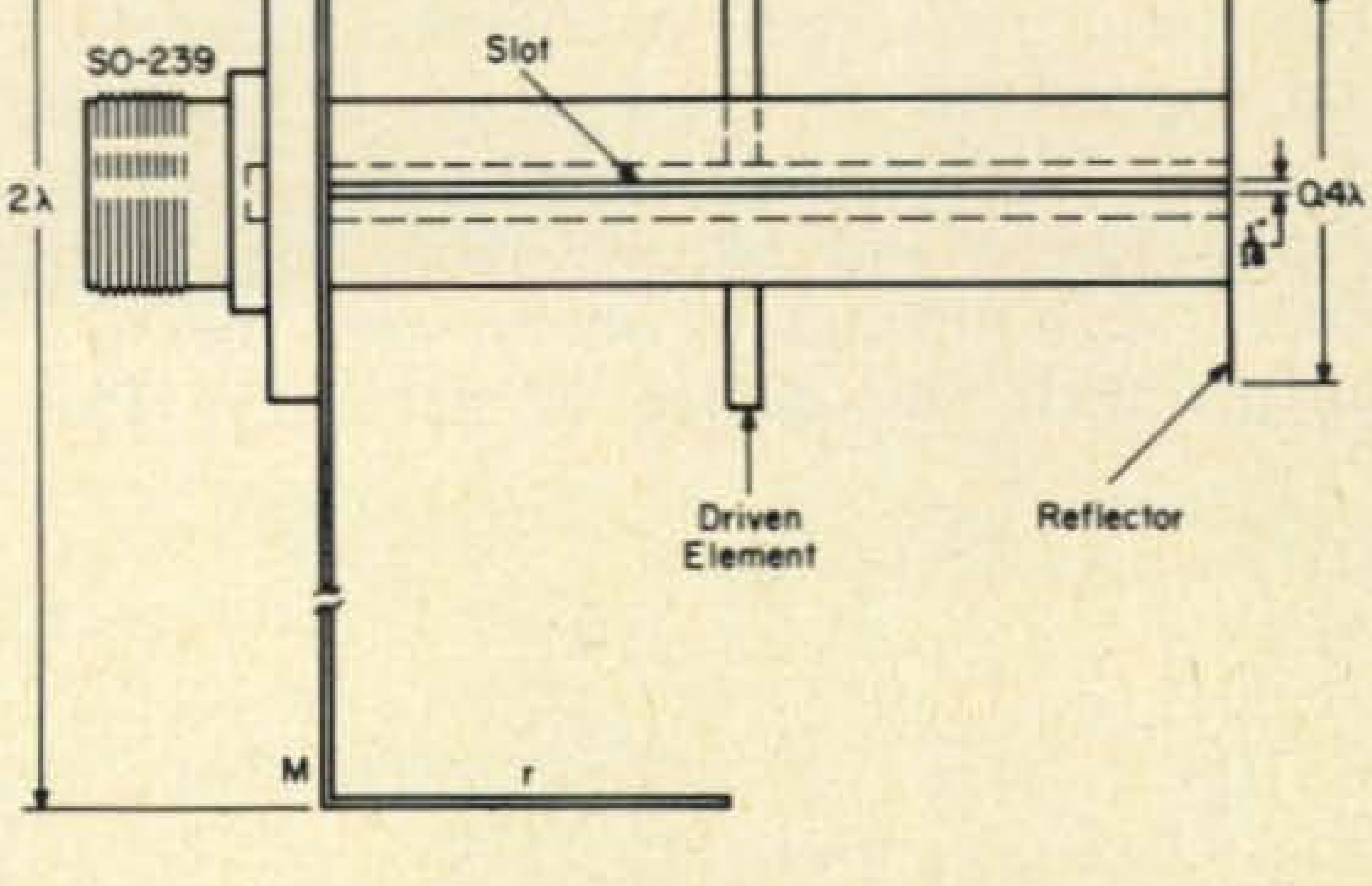


Fig. 6—Side view of the medium gain (short) backfire antenna with dimensions showing details of the balun and driven element. The width of the slot is approximately 1/16" wide. If it is made too wide, it will act as a two wire transmission line. The driven element has one side connected to the wall of the boom. The second side of the driven element is connected to the wall of the wall of the boom *and* the center conductor.

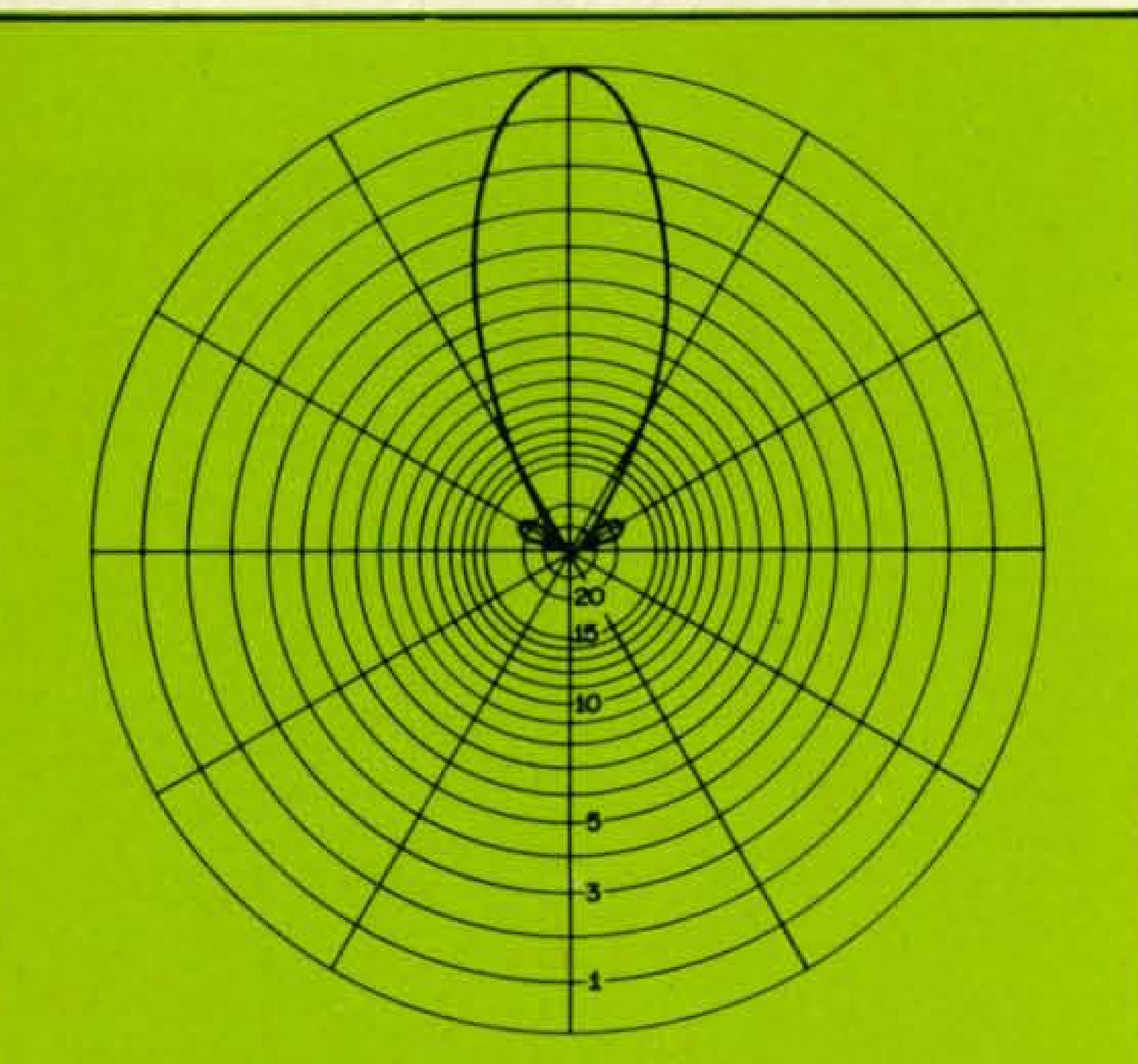


Fig. 7—Polar pattern of the short backfire antenna for the E plane. The H plane pattern is very similar.

the same quality. The short backfire array, however, has less than 1/10 the axial length of the yagi. Chart II shows basic dimensions for the short backfire array of fig. 6 for 144, 220, 432, and 1296 mc.

Tips For Construction

The reader is urged not to plunge into this project head first with a sudden burst of enthusiasm without first considering that he will need to spend much time and patience in construction, tuning, and matching of the backfire antenna. Like most other methods of improving antenna performance, backfire gain is no Santa Claus proposition. Before the project is started one should know how he expects to measure antenna gain and v.s.w.r. Without a properly designed antenna range and pattern recording equipment, it is difficult to obtain gain measurements with any degree of accuracy. This, however, does not mean that it is impossible for the ham to get the backfire antenna to work. It would be well for anyone deciding to build the backfire antenna to read as many reference articles as possible,[5] including the one in *QST,* "Practical Operating Hints for 1215 MC."[6] In this article is described a field strength indicating device consisting of a small dipole, diode and meter. Obviously, this will not read db gain, but is very useful in indicating relative field strength with respect to some reference level. Hence, in tuning the antenna one can tell when the field strength is getting better and when it goes through a maximum value.

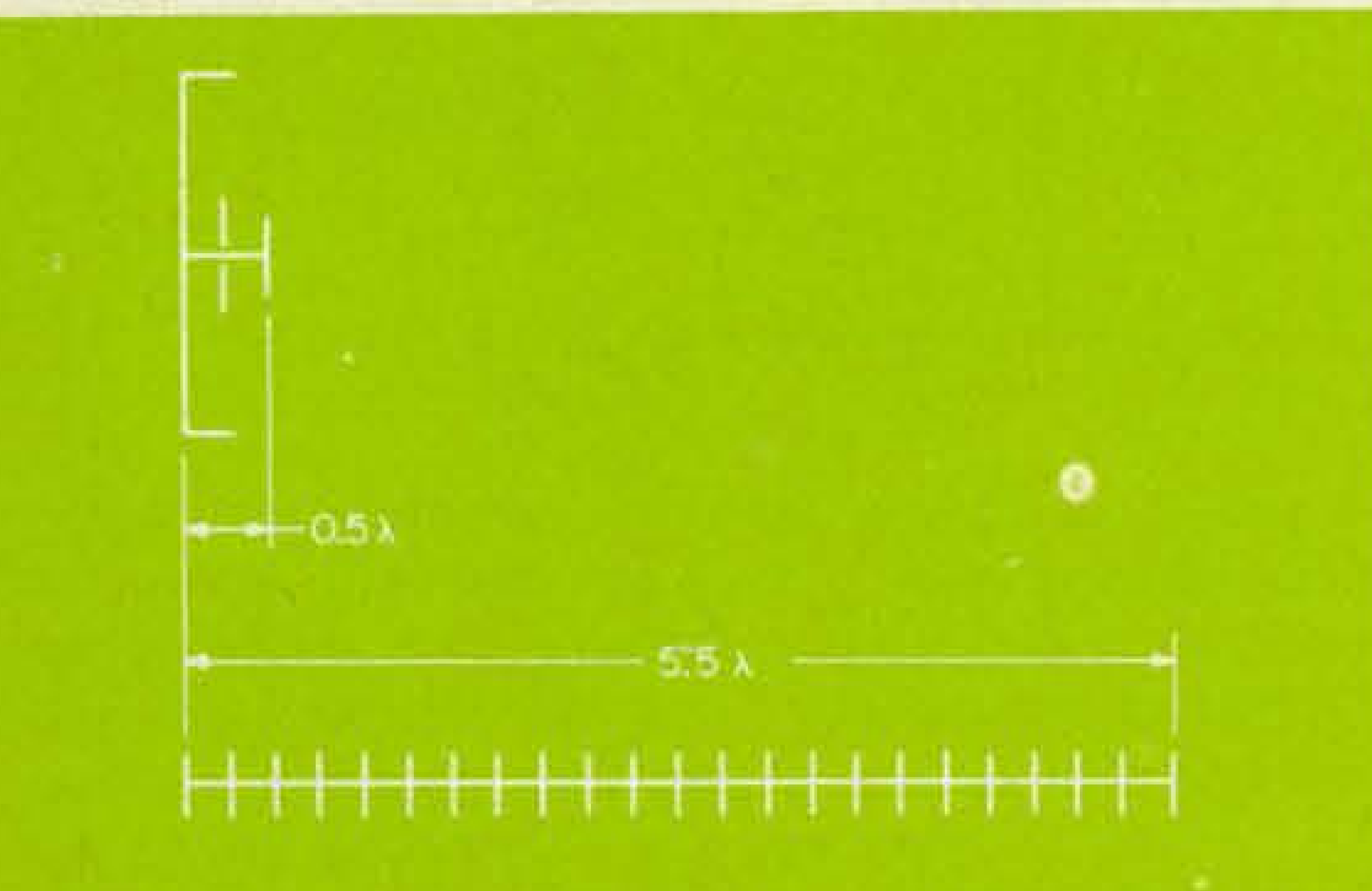


Fig. 8—Comparative size of a medium gain backfire antenna and a Yagi antenna of equal performance.

Adjustments

As mentioned earlier, the gain of a yagi, or in our case, a backfire, can be maximized by proper adjustment of the velocity of the wave traveling along the yagi. An almost infinite number of combinations of director spacing, diameter and height will give the same phase velocity. The method of obtaining this optimum phase velocity is not important. There is a very practical approach to this problem. (Ehrenspeck & Poehler mentioned earlier.) Here it is suggested that all but one of these variable parameters be fixed. The one remaining variable can then be adjusted for optimum gain (field strength). Perhaps the simplest adjustment is that of element lengths by means of telescoping tubing. Fortunately, v.h.f. antennas are very small. Most hobby stores stock telescoping brass tubing in various sizes, which works very well for tuning a v.h.f. yagi. Once the proper element lengths have been experimentally derived, the telescoping sections of brass tubing may be soldered together to prevent accidental detuning. Copper pipe may be used for the boom, making it very convenient to solder or silver solder the brass dipole elements directly to the boom. Brass pipe fittings with thread are available at the plumber, which enables fastening the mast to reflector surface T_1.

T_1 and T_2 may be constructed on metal sheet or fine mesh. L brackets are convenient to join T_1 and T_2 to their respective rims. To make the structure more rigid, it is well to guy the yagi boom to the plane re-

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[5] Ehrenspeck, H. W., "The Backfire Antenna: New Results," *Proceedings of the IEEE,* June, 1965, p. 639-641.

[6] Tilton, E. P., "Practical Operating Hints for 1215 Mc.," QST, February 1961, page 27.

flector with nylon cord. (*Don't use wire.*)

Balun

The feed system is a most important part of the antenna. Fifty ohm coax is the best transmission line for this application. Therefore some balancing device must be used to couple the balanced dipole driven element to the unbalanced coax. The consequences of not doing this is that r.f. currents will travel on the outside of the coax and thus destroy the antenna's directional properties. A convenient and symmetrical balun assembly as shown in fig. 6 may be used. Although there are many types of baluns, the one shown provides a smooth continuous and symmetrical boom from reflector to the last director.

This arrangement uses 50 ohm air coax within the boom. The characteristic impedance of the air insulated coax is given by $Z_0 = 138 \log b/a$

where Z_0 = characteristic impedance.
b = inside diameter of outer conductor.
a = outside diameter of inner conductor in the same units as b.

The inner conductor may be held in position by the use of small washers made from Teflon, plastic, etc.

Tuning the antenna is best accomplished on the test site. Pick a location free from surrounding obstructions. The elements may be made from small telescoping brass tubing approximately 3/16″ o.d. This elment diameter is not too particular since the length may be varied. In general, however, a larger element diameter will increase the antenna bandwidth. To start, each element is set near ½ wavelength, tip to tip. If operating on 1296 mc, a wavelength is only a few inches. This permits tuning up the antenna at almost table top height.

With the yagi fastened to the planar reflection, and feeder connected, a reference field strength reading is taken at a distant point (20 wavelengths or more). Next, shorten all directors together in very small increments (1/16″ or less) until the field strength is maximized. After the directors have been adjusted for maximum gain, the driven element needs to be matched for impedance. Since very few of us have impedance measuring facilities, the next best is to adjust the dipole length for minimum v.s.w.r. Impedance does not need to be known exactly if the operator has an s.w.r. bridge.[7]

PART	144mc	220mc	432mc	1296mc
$M_{(DIAM.)}$	164"	107.3"	54.7"	18.2"
$R_{(DIAM.)}$	32.8"	21.5"	10.9"	3.6"
L	41"	26.8"	13.7"	4.6"
r	20.5"	13.4"	6.8"	2.3"

Chart II—Dimensions for the medium gain backfire array shown in fig. 6.

Both the adjustments for gain and matching are a long and tedious process, requiring much patience, but this is perhaps the simplest way without the use of costly pattern recording and impedance measuring equipment. Careful adjustments and measurements at this point will pay big dividends in the form of antenna gain and efficiency.

The yagi must be tuned when coupled to the backfire reflector. The antenna will not perform if the yagi is tuned independent of the reflector and then coupled to the reflector.

Since at the higher frequencies the cable loss is considerable, it is well to keep the length of the transmission line to a minimum.

Conclusion

Endfire arrays with patterns of the quality described in this article are impractical because of length and stacking problems. Construction of a wiring harness for an array of yagis to yield a gain of say 23 db would obviously be a formidable task. Mechanical problems would also be very involved. In this respect the backfire array excells because there is only one simple driven element to feed and match for impedance. Not only is this feed system simpler to construct, but it is also lower in cost, lighter in weight, and less subject to failure because of its inherent mechanical and electrical simplicity. Parabolic reflectors which also yield high gain are not competitive from a cost standpoint as the construction of a large parabolic reflector is far more complex than that of a planar reflector. Therefore, from a gain versus cost and ease of construction standpoint, the backfire array is an extremely competitive antenna.

The author wishes to express his gratitude to Charles Liu (Member Technical Staff Texas Instruments Inc., Dallas, Texas) for his encouragement and advice. ■

[7] Burhans, R., "UHF Coaxial SWR Bridge," *QST*, June 1960, p. 30.