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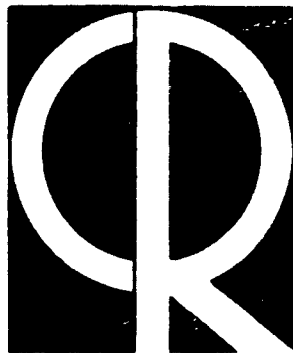
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Research Report

Backfire Antennas for SHF, UHF, and VHF Bands

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Abstract

The application of the backfire principle to endfire antennas increases their gain by 4 to 6 db over that of the original gain-maximized array.

This report describes basic investigations on a 9080-Mcps backfire antenna which was converted from an optimized Yagi antenna. Backfire antenna models have also been successfully tested at frequencies of 3000, 600, and 220 Mcps. The design procedure and physical dimensions are given for all models.

In addition, a method for building backfire antennas with gain figures up to 25 db is discussed.

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Backfire Antennas for SHF, UHF, and VHF Bands

1. INTRODUCTION

The backfire principle, which was introduced by one of the authors in 1960,¹ changes the efficiency of conventional endfire antennas such that gain increases of 4 to 6 db can be obtained without increasing their length. A general report on the application of the backfire principle to a Yagi antenna was published in 1961.² Further information can be found in Ref. 3. Figure 1 shows a sketch of this new antenna type, the backfire antenna. The feed, directors, and the linear reflector, however, and the two linear reflectors mounted approximately 0.25λ on either side of the center reflector are necessary as additions to convert the Yagi to a properly performing backfire antenna. It has been found that with this reflector combination, maximum efficiency and a good control of the back and sidelobe levels can be obtained. Therefore all backfire antenna types described in this report make use of this reflector combination.

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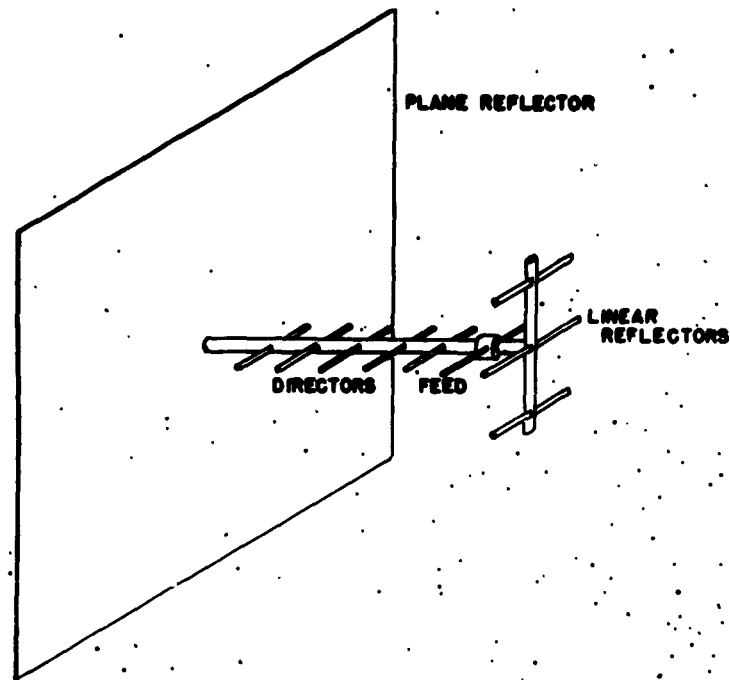


Figure 1. Sketch of the Backfire Antenna

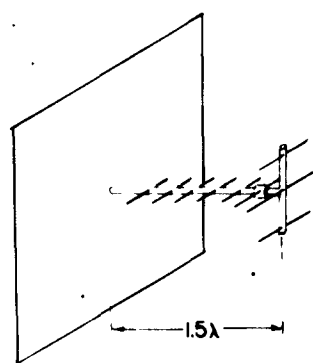
Figure 2 shows a comparison of a Yagi and a backfire antenna with the same gain, 14.5 db above dipole. The Yagi array, fed by a dipole with a linear reflector behind it, has a length of 7.2λ and needs 35 directors if a constant spacing of 0.2λ is chosen. The backfire antenna, however, is but 1.5λ in length and has for the same spacing only 8 elements, 5 directors and 3 linear reflectors. The plane reflector has the dimensions, $2\lambda \times 2\lambda$. The comparable antenna types differ in length by a factor of 4.8.

In this report models of backfire antennas for the following frequency bands are described:

SHF band for 9080 and 3000 Mcps..

UHF band for 600 Mcps.

VHF band for 220 Mcps.



BACKFIRE ANTENNA

Number of elements 8

Plane reflector $2\lambda \times 2\lambda$

YAGI ANTENNA

Number of elements 36

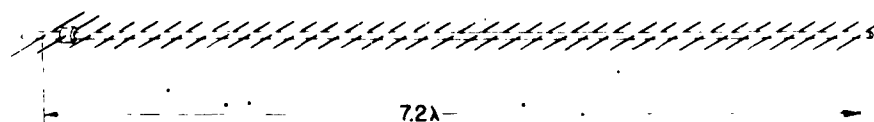


Figure 2. Comparison of a Yagi and a Backfire Antenna for the Same Gain, 14.5 db Above Dipole

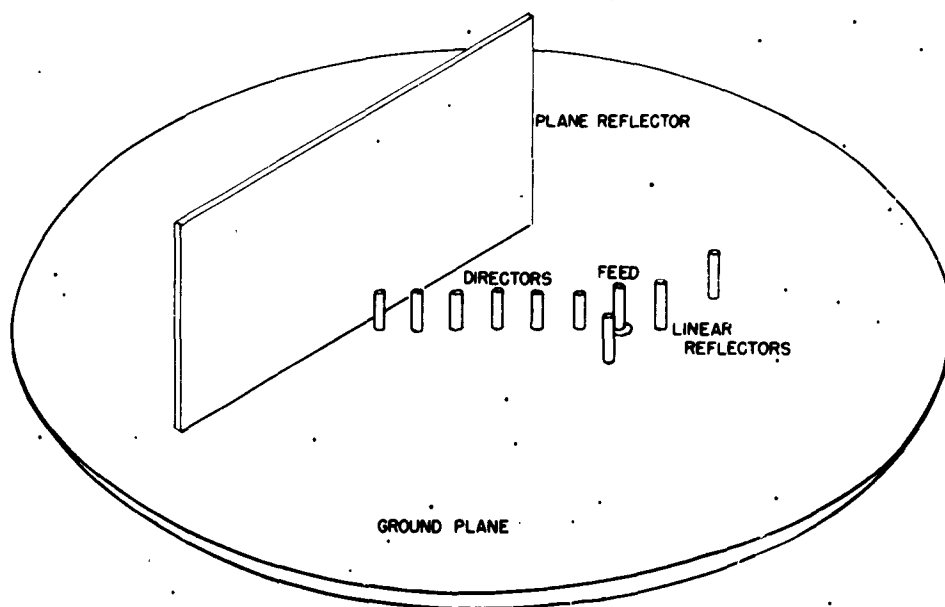


Figure 3. Sketch of Backfire Antenna for X Band

2. BACKFIRE ANTENNAS FOR SHF BAND

2.1 9080-Mcps Measurements (X Band)

All basic measurements and general investigations of the backfire principle were performed at 9080 Mcps ($\lambda = 3.3$ cm). For these experiments a Yagi antenna with monopoles on a ground plane was first measured, and then converted to a backfire antenna. The Yagi endfire array was constructed on a circular plate (Figure 3) fitting flatly into a large ground plane. The director elements were small brass rods fitted to holes drilled in the plate. Their spacing was kept constant at 0.2λ and their height could be easily adjusted with a modified depth gauge. For the conversion of the Yagi to the backfire antenna, two linear reflectors and a plane reflector were added, as shown in Figure 3. The directors had to be adjusted to a new optimum height for maximum gain.⁴ By feeding them from beneath the ground plane, these models were used as transmitting antennas. The receiver was connected to a horn situated at the appropriate end of the ground plane, a distance of 100λ . A calibrated attenuator in the energizing circuit made possible the measurement of gain figures to an accuracy of ± 0.1 db. Farfield antenna patterns could be measured by rotating a mount connected to the circular plate on the ground plane. The results were plotted with a synchronized pattern recorder. A sketch of the experimental setup is shown in Figure 4, while Figure 5 is a photograph of the actual X-band range, with the rotatable circular plate in the foreground and the receiving horn in the background at the opposite end of the ground plane. Figure 5 also shows the technique for measuring phase velocity and element currents. A very small probe is moved along the row of elements as described in Refs. 4 and 5. All gain measurements were referred to the feed radiation alone. Therefore, all gain figures in db represent the gain of the Yagi or backfire antenna on the ground plane above the fed half dipole that is also on the ground plane, or the gain of the free space Yagi or backfire antenna above a dipole.

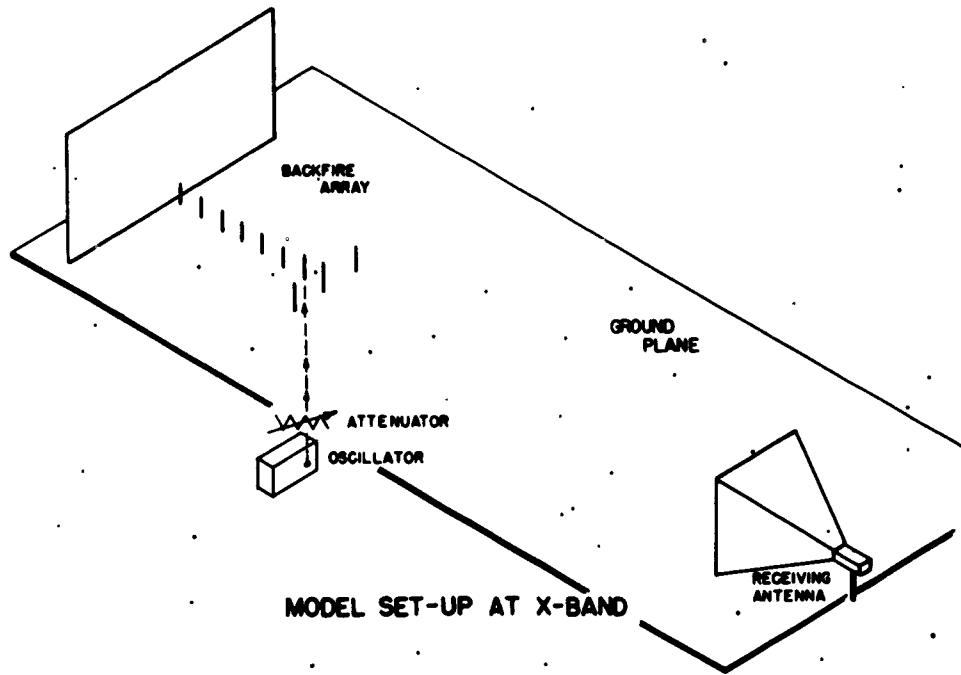


Figure 4. Sketch of Model Setup at X Band



Figure 5. Experimental Setup for Measuring Pattern, Phase Velocity, and Element Current of Yagi and Back-fire Antennas.

With the positioning of a fed half dipole at one edge of the circular plate, the plane reflector had to be placed at the opposite end of the Yagi antenna in order to create the backfire. The main lobe of the pattern is now shifted by 180° from its previous position. The H-plane radiation patterns of a Yagi 2λ in length and the converted backfire with the same length are shown in Figure 6. The plane reflector of the backfire had a size of $1.25\lambda \times 2.50\lambda$; the two outside linear reflectors were spaced 0.20λ from the center reflector. The conversion from Yagi to backfire resulted in a gain increase of 5.2 db and decreased the side and back lobes significantly. The half-power beamwidth was reduced from 41° to 24.5° .

It has been found that for best results, the additional linear reflectors should be located at a distance of 0.20λ to 0.35λ from the center reflector. By changing their length and spacing, the beamwidth and sidelobe and backlobe level can be varied slightly.

Of still greater influence on the gain and radiation pattern of a backfire antenna is the size of its plane reflector. In order to determine the reflector size, a series of gain and sidelobe level measurements were performed on a backfire antenna, 1.5λ in length. The plane reflector was varied from $0.50\lambda \times 1.00\lambda$ to $1.50\lambda \times 3.00\lambda$ in five steps. The results are shown in the curves of Figure 7, gain and halfpower beamwidth as a function of reflector size, and Figure 8, first sidelobe and backlobe levels as a function of reflector size. It can be seen from Figure 7 that maximum gain is obtained for a plane reflector size of $1.25\lambda \times 2.50\lambda$, but the narrowest beamwidth occurs with dimensions of $1.00\lambda \times 2.00\lambda$. According to Figure 8, the first sidelobe is lowest in the region between these two reflector sizes, while the backlobe decreases continuously with an increasing reflector size, as expected. The $1.00\lambda \times 2.00\lambda$ reflector size was chosen for the optimum antenna due to the narrow half-power beamwidth while the gain was very close to maximum.

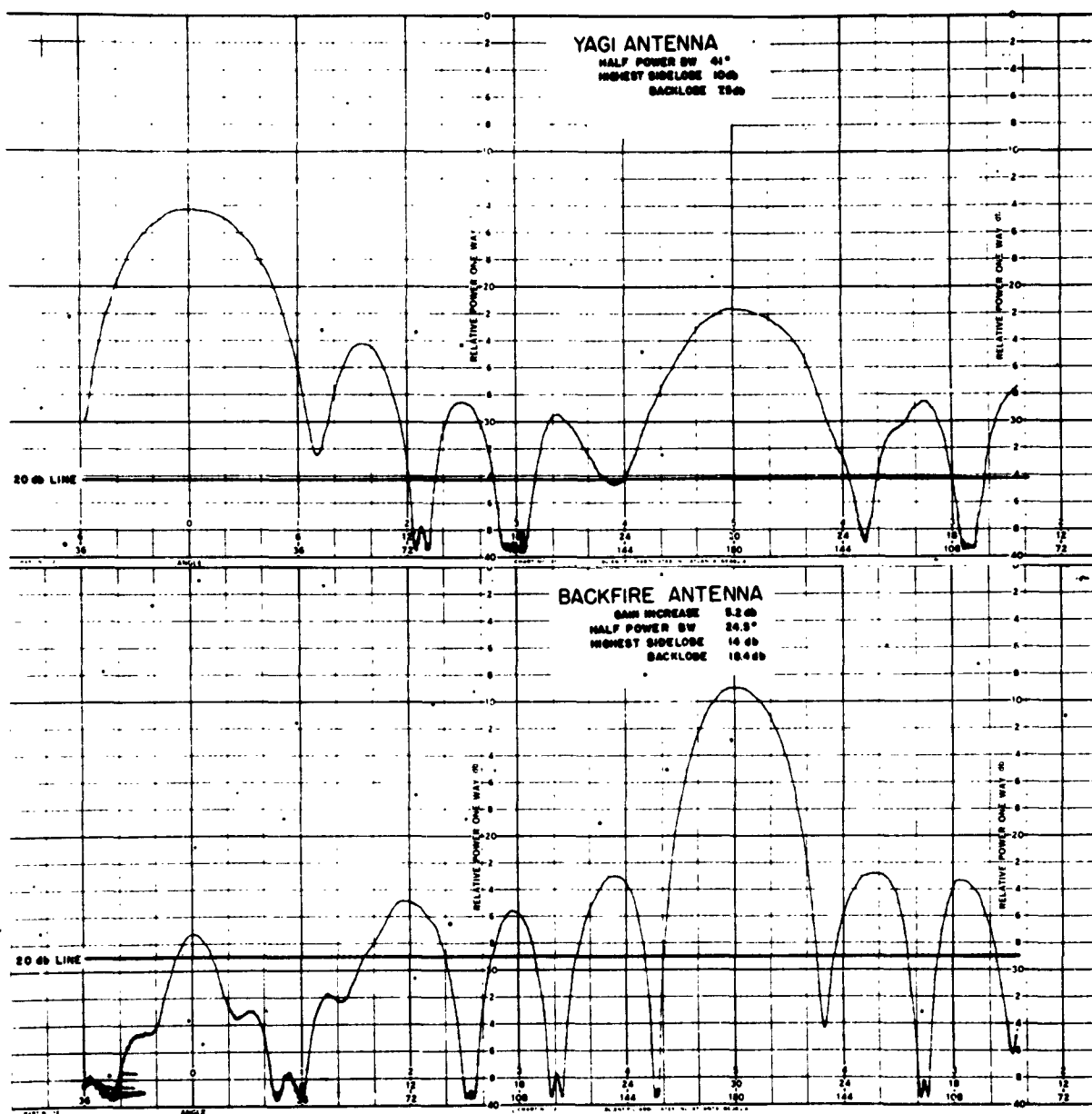


Figure 6. Farfield Patterns of a Yagi and a Backfire in the H Plane, 2λ in Length

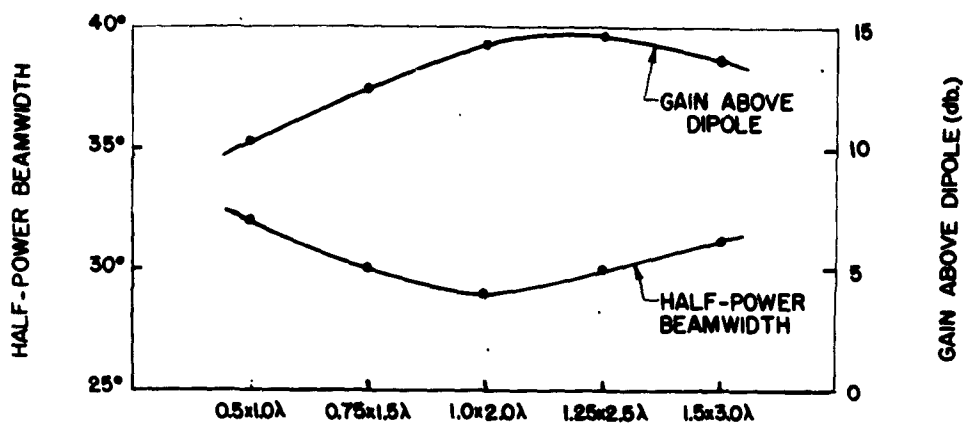


Figure 7. Gain and Half-Power Beamwidth as a Function of Reflector Size

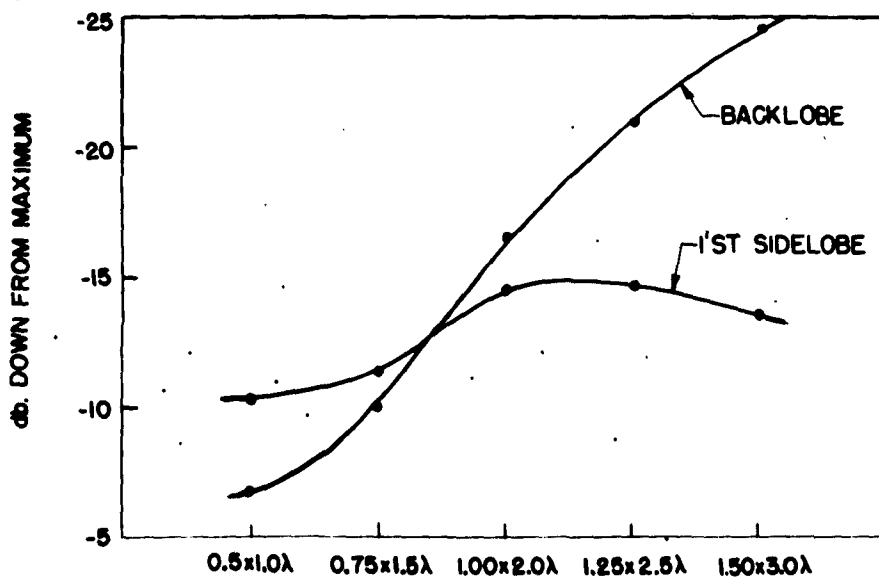


Figure 8. First Sidelobe and Backlobe Levels as a Function of Reflector Size

The physical dimensions for the optimized backfire antenna, similar to that shown in the sketch of Figure 3, were the following:

Number of directors	5
Height of directors	0.162λ
Spacing of directors	0.200λ
Number of linear reflectors	3
Height of center reflector	0.230λ
Height of outside reflectors	0.204λ
Spacing of center reflector from feed	0.200λ
Spacing between reflectors	0.333λ
Dimensions of plane reflector	$1.0 \lambda \times 2.0 \lambda$
Spacing between plane reflector and last director	0.300λ
Height of feed	0.212λ
Diameter of all elements	0.048λ

The gain above dipole was 14.4 db and half-power beamwidths were 25.5° in the E and 28° in the H plane.

If higher gain is needed, two or more backfire antennas can be arranged in front of a common plane reflector. Such an antenna is described in Ref. 2. It has a length of 3.6λ and, with a half circular reflector of 2.5λ radius, develops a gain of 21 db above dipole. The same gain can also be achieved with an elliptically formed plane reflector of major axis 5.0λ and minor axis 2.5λ .

2.2 3000-Mcps Measurements (S Band)

The first free-space backfire antenna was built for a frequency of 3000 Mcps ($\lambda = 10$ cm), with a length of 1.5λ . The dimensions were scaled as close as possible to those at X band. The director and reflector elements were fabricated of $\frac{3}{16}$ in. diameter brass tubing ($d = 0.48 \lambda$) and fitted with pins for length adjustment. Director spacing was also kept constant at 0.20λ . The plane reflector had a size of $2.0 \lambda \times 2.0 \lambda$ which corresponds to the $1.0 \lambda \times 2.0 \lambda$ reflector on the ground plane. Only the spacing of the linear reflectors

was modified to 0.20λ for mechanical reasons. All elements were mounted on a boom of $\frac{1}{2}$ in. diameter brass tubing ($d = 0.127 \lambda$). A precast S-band dipole was employed as the energizing element. A sketch of the model is shown in Figure 9.

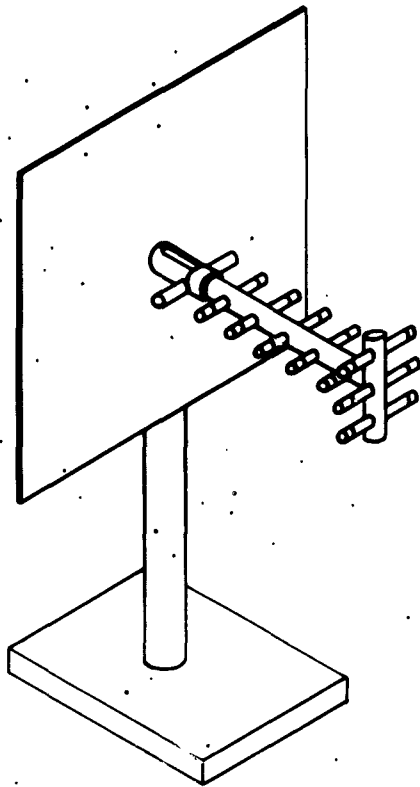


Figure 9. Sketch of the 3000-Mcps Backfire Antenna

Farfield pattern measurements were performed in a microwave reflection-free room. The test model, used as a receiver, was built on a small antenna mount, which was connected to a synchronized pattern recorder. A dipole with a parabolic reflector was used as the transmitter.

Measurements showed that scaling could not be accomplished in perfect agreement with X-band data. This lack of agreement may be attributed to the relatively large size of the boom. The heights of the directors and reflectors required new adjustments for maximum gain. The following dimensions were found experimentally:

Number of directors	5
Length of directors	0.406λ
Spacing of directors	0.200λ
Number of linear reflectors	3
Length of center reflector	0.575λ
Length of outside reflectors	0.500λ
Spacing of center reflector from feed	0.200λ
Spacing between reflectors	0.200λ
Dimensions of plane reflector	$2.0 \lambda \times 2.0 \lambda$
Spacing between plane reflector and last director	0.300λ
Length of feed	0.500λ
Diameter of elements	0.048λ

The pattern of this optimized 1.5λ backfire is shown in Figure 10. The measured gain is 14.5 db and the half-power beamwidth is 25.5° in the H plane. These agree excellently with the corresponding values for the X-band model. The side and backlobe levels are even lower than in the X-band case.

3. UHF MEASUREMENTS

Due to equipment and test range capabilities at AFCRL, a frequency of 600 Mcps ($\lambda = 50$ cm or 19.7 in.) was selected for a backfire antenna in the UHF range. Scaling from X- or S-band models could not be accomplished without having elements with extremely large diameters. Therefore, the elements were constructed from $\frac{1}{4}$ in. diameter aluminum rod ($d = 0.0127 \lambda$) and fitted with thin aluminum sleeves for ease in length adjustment. Aluminum tubing of $\frac{5}{8}$ in.

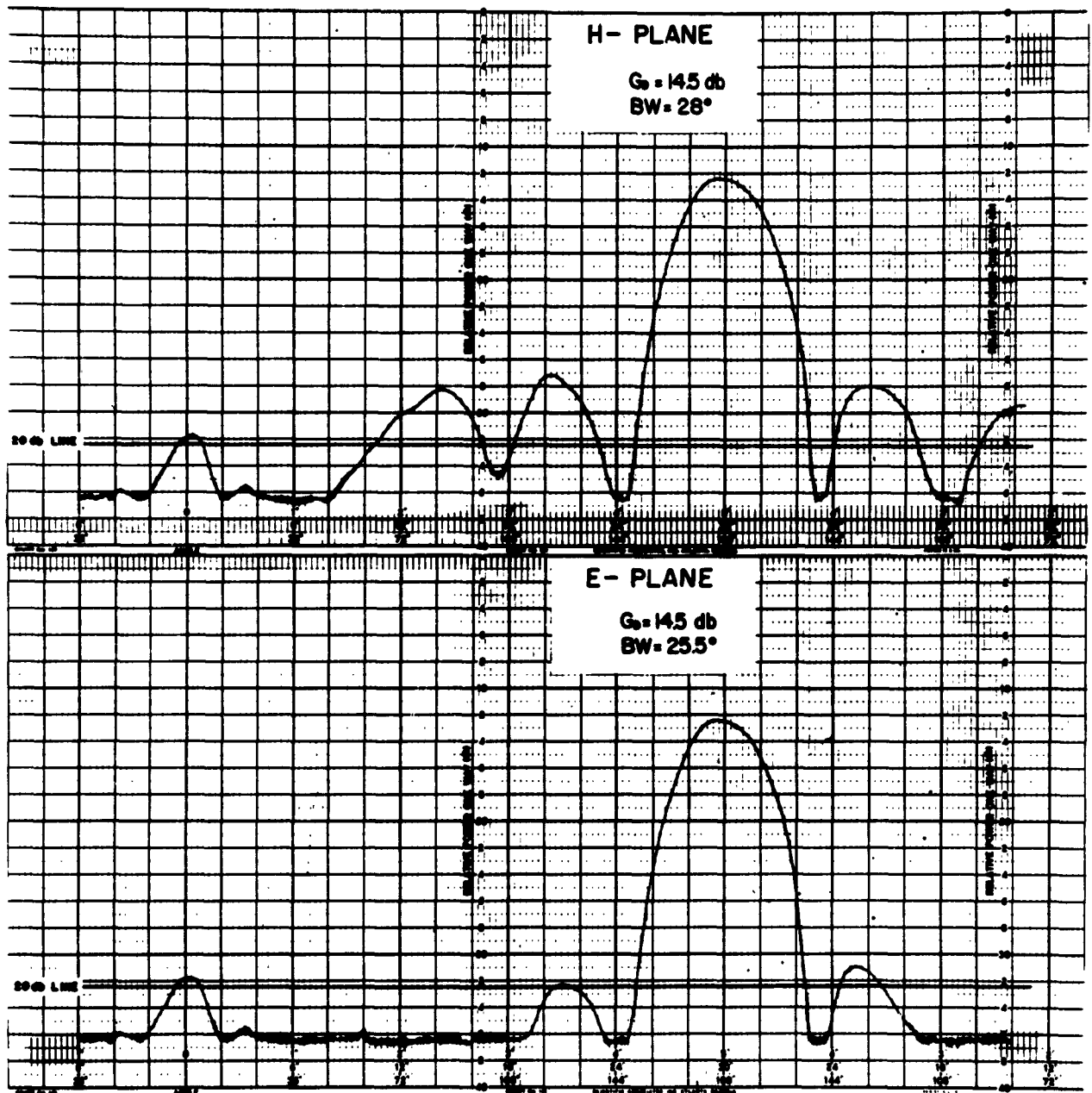


Figure 10. Farfield Patterns of a 1.5λ , 3000-Mcps Backfire Antenna in the E and H Planes

diameter ($d = 0.032 \lambda$) was used for the boom, while the plane reflector was constructed of a $2 \lambda \times 2 \lambda$ sheet of expanded aluminum and mounted on a wooden frame as shown in Figure 11. The backfire model again had a length of 1.5λ and the director spacing was 0.20λ . For the best pattern, the spacing between the linear reflectors was selected as 0.30λ .

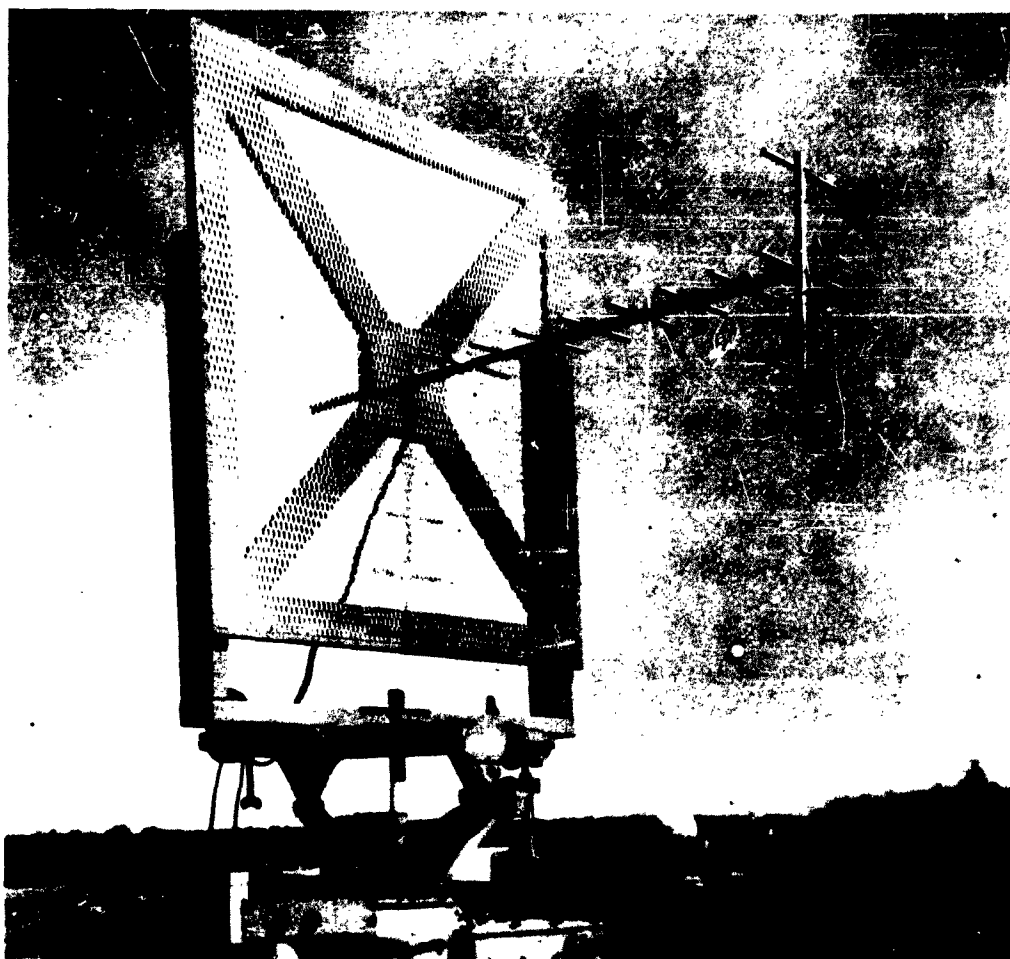


Figure 11. Photograph of the 600-Mcps Backfire Antenna

For the best performance, the backfire had the following dimensions:

Number of directors	5
Length of directors	0.381λ
Spacing of directors	0.200λ
Number of linear reflectors	8
Length of center reflector	0.514λ
Length of outside reflectors	0.412λ
Spacing of center reflector from feed	0.200λ
Spacing between reflectors	0.300λ
Dimensions of plane reflector	$2.0 \lambda \times 2.0 \lambda$
Spacing of plane reflector from last director	0.300λ
Length of feed	0.450λ
Diameter of elements	0.0127λ

The farfield pattern for horizontal polarization of this antenna is shown in Figure 12. The gain measured approximately 14 db above a dipole with the first sidelobe and backlobe, 16 db and 20 db below maximum.

4. VHF MEASUREMENTS

Measurements in the VHF range were made on 220-Mcps backfire antennas at the AFCRL Ipswich Field Station and are described in Ref. 6. A photograph of a 2λ long backfire model is shown in Figure 13. The construction is very similar to that of the UHF model as it also employs elements of aluminum rod and a plane reflector of expanded aluminum. The element spacing is again 0.20λ . A far-field pattern of a 1λ 200-Mcps backfire antenna is shown in Figure 14. For comparison the pattern of the Yagi, before it was converted, is shown. The gain of the backfire was increased by 4.6 db over that of the Yagi, and the half-power beamwidth decreased from 48° to 34° . At the same time, the backlobe was decreased significantly.

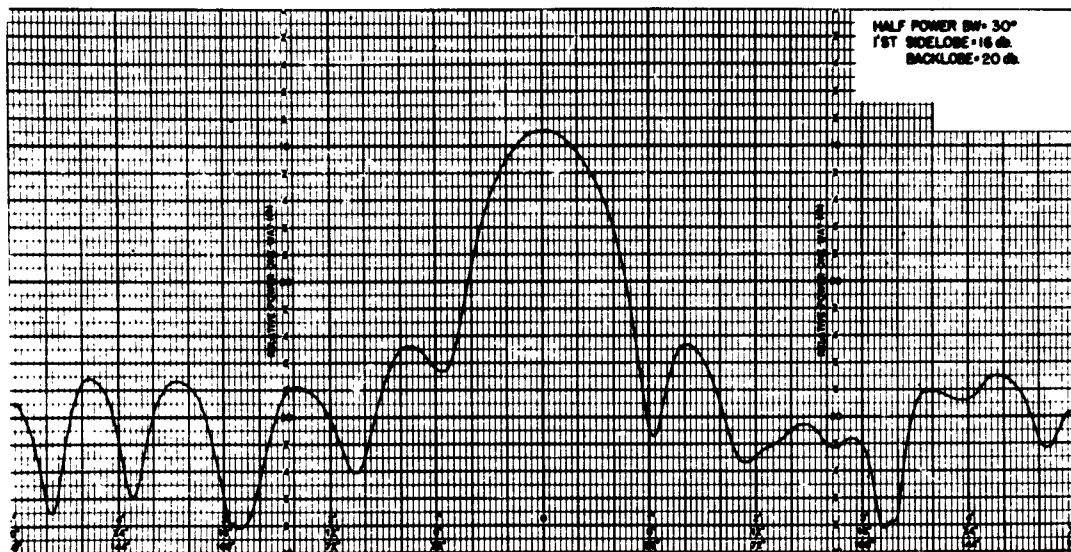


Figure 12. E-Plane Farfield Pattern for a 1.5λ Backfire Antenna

In order to obtain these results the antenna dimensions had to be adjusted to the following dimensions:

Number of directors	3
Length of directors	0.350λ
Spacing of directors	0.200λ
Number of linear reflectors	3
Length of center reflector	0.503λ
Length of outside reflectors	0.410λ
Spacing of center reflector from feed	0.200λ
Spacing between reflectors	0.200λ



Figure 13. A Backfire Antenna for 220 Mcps

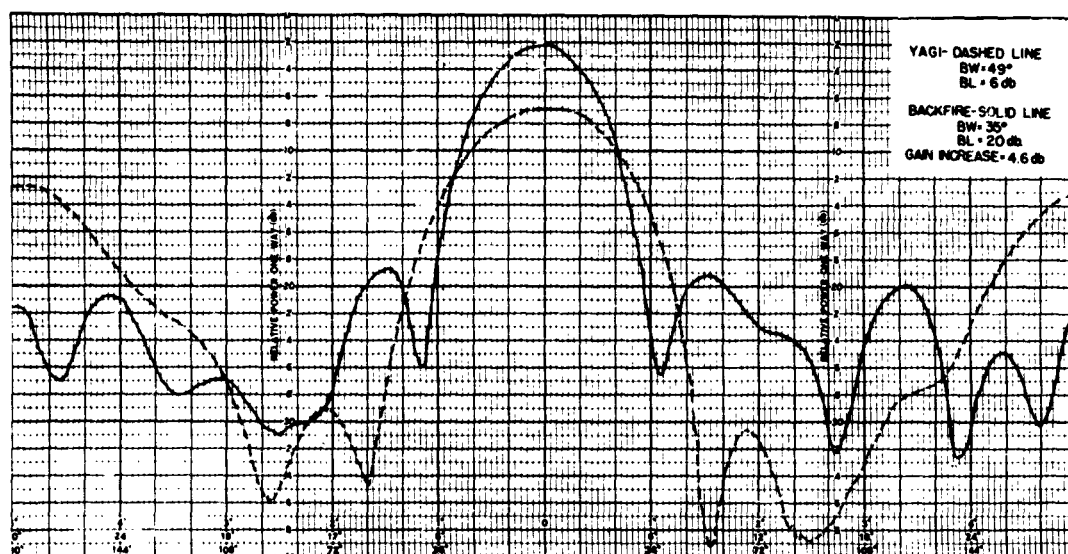


Figure 14. E-Plane Farfield Patterns of a Yagi and Backfire Antenna 1λ in Length for 220 Mcps

Dimensions of plane reflector	$2.0\lambda \times 2.0\lambda$
Spacing of plane reflector from last director	0.200λ
Length of feed	0.518λ
Diameter of elements	0.0117λ

5. CONCLUSIONS

The experimental work performed on the backfire antennas, which were converted Yagis, shows that the backfire principle is applicable to endfire antennas for a wide range of frequencies. The gain of the backfire antenna is between 4 and 6 db higher than that of an optimized endfire antenna of the same length; conversely, to achieve the same gain, the backfire antenna needs to be only $\frac{1}{4}$ to $\frac{1}{3}$ as long as the ordinary endfire antenna. By stacking a number of backfire antennas in front of a common plane reflector, gain figures of 25 db can be obtained. The size of the plane reflector is the only limiting factor for applications of the backfire principle, especially at the lower frequencies.

The backfire antenna may have a wide application to the field of medium gain antennas (10 db to 25 db), when conventional endfire antennas are becoming too long and parabolic dishes are still too expensive.

Acknowledgments

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