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MICROWAVE PHYSICS LABORATORY PROJECT 4600

**AIR FORCE CAMBRIDGE RESEARCH LABORATORIES**

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

# The Short-Backfire Antenna as an Element for High-Gain Arrays

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**AIR FORCE SYSTEMS COMMAND**

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## Abstract

The short backfire (SBF) antenna consisting of a large reflector illuminated by a dipole feed and smaller disk reflector produces a gain of 15 dB above isotropic. As an array element it has been efficiently adapted for various configurations of high-gain antennas producing gains of up to 25dB, with a single SBF element capable of replacing four to six elements of a conventional multidipole array.

Farfield patterns and directivity measurements are presented for a single element and for a twin element mounted on a common reflector. Optimized dimensions for both cases are discussed for possible application to more complex types of antennas.

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Typical short-backfire arrays have already been briefly described by Ehrenspeck (1967). Among these is an 8-element array, which compares favorably with two other arrays of different type—a 36-slot array used by NASA (Lantz, 1964), and a 48-dipole array now being used by the European satellite-tracking network (Oettl and Thomanek, 1968).

## 2. SHORT-BACKFIRE ANTENNA AS ELEMENT FOR HIGH-GAIN ARRAYS

### 2.1 Description of Short-Backfire (SBF) Antenna

The short-backfire antenna is a highly directional radiator. Although a rigorous theoretical solution has not yet been found for this new type of antenna, experimental studies have enabled us to optimize the most important parameters. Engineering data for optimally adjusted high-gain and low-sidelobe versions are already available.

Figure 1 is a sketch of a 3-GHz model of an SBF antenna, showing the front view on the left and a cross section on the right. This model was used for most of the experimental studies. It consists of a circular planar reflector M of diameter $D_M$ with a rim B of width $W_B$ along its edge, a reflector disk R of diameter $D_R$ concentric with M ($D_R$ being much smaller than $D_M$), and a slotted-dipole feed F between the reflectors M and R. In the figure, the spacings between reflector M and feed F, and between reflector M and reflector disk R, are marked $S_F$ and $S_R$, respectively; Q indicates the supporting rod for the reflector disk R.

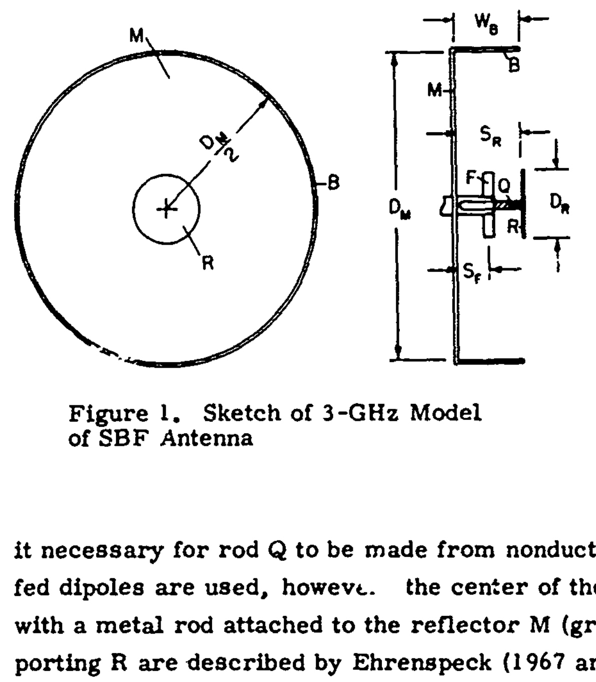


Figure 1. Sketch of 3-GHz Model of SBF Antenna

The special structure of the slotted dipole feed F made it necessary for rod Q to be made from nonducting materials. If symmetrically fed dipoles are used, however, the center of the reflector disk R can be supported with a metal rod attached to the reflector M (ground). Several other ways of supporting R are described by Ehrenspeck (1967 and 1970).

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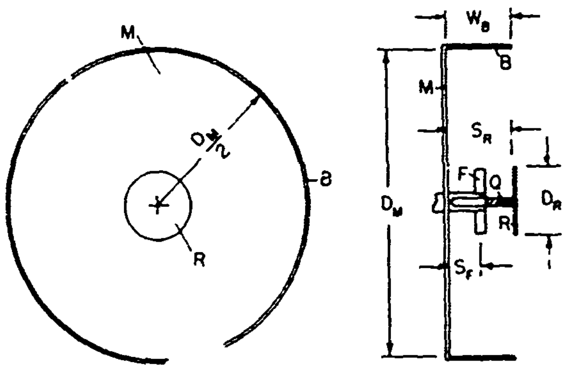


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From extensive studies of the nearfield of the SBF antenna we know that SBF antenna operation is characterized by multiple reflections of a dipole-excited electromagnetic wave between the two planar reflectors M and R, and that the space between M and R acts as an open resonant cavity that radiates most of its energy from a virtual aperture between the edges of R and B, extending somewhat outside B (Reference 3). The best pattern performance and highest efficiency is obtained from a circular reflector because the entire antenna structure is symmetric, but square or other rectangular reflector shapes can also be used with only a small sacrifice in gain and sidelobe level. The directivity of the SBF antenna has been measured as 15.1 dB on the 3-GHz model of Figure 1, with experimental dimensions of:

$D_M = 2.00\lambda$

$D_R = 0.50\lambda$

$S_F = 0.25\lambda$

$S_R = 0.50\lambda$

$W_B = 0.50\lambda$

$M = 3.14\lambda^2$ (area)

Referred to the size of the reflector M, the area efficiency obtained was 83 percent.

Figure 2 shows the E- and H-plane patterns of the antenna diagrammed in Figure 1. In both planes, the first sidelobes are more than 22 dB below the main lobe, and the other sidelobes and backlobes are more than -30dB. Patterns that are cuts of $\pm 45^\circ$ between the two major planes (Figure 3) also have very low sidelobes.

For an HP beamwidth of $34^\circ$ in both the E and the H planes the directivity, calculated from an improved gain-beamwidth product equation (Stegen, 1964), is 14.8 dB. This is in good agreement with the 15.1 dB measurement by a pattern integration technique (Fulmer and Mosely, 1960).

Since feed F in Figure 1 is a linear dipole, the patterns in Figure 2 are those for linear polarization. For transmitting or receiving radiation of arbitrary polarization, crossed dipoles like those shown in the photograph in Figure 4 can be used. With mutual coupling between the dipoles lower than 35 dB, the E- and H-plane patterns for the individual dipoles of this SBF antenna are the same as those in Figure 2.

Because of their extremely short axial length of approximately $\lambda/2$, SBF antennas are especially useful in flushmounted high-gain applications for airplanes and space vehicles. The open end of the cavity can be covered with a dielectric plate (Ehrenspeck, 1967 and 1970) without any noticeable change in antenna performance. Gains of more than 16 dB can be achieved.

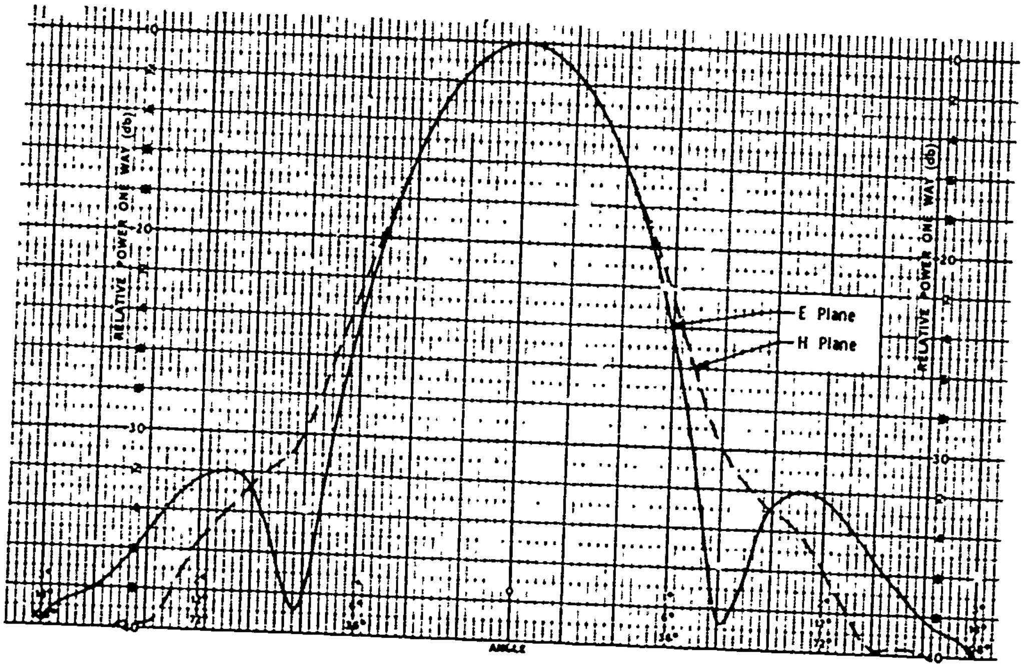


Figure 2. Radiation Patterns (E and H Planes) of 3-GHz Model of SBF Antenna in Figure 1 (Patterns are shown out to approximately ±115°; all lobes outside this range are more than 30 dB below the mainlobe.)

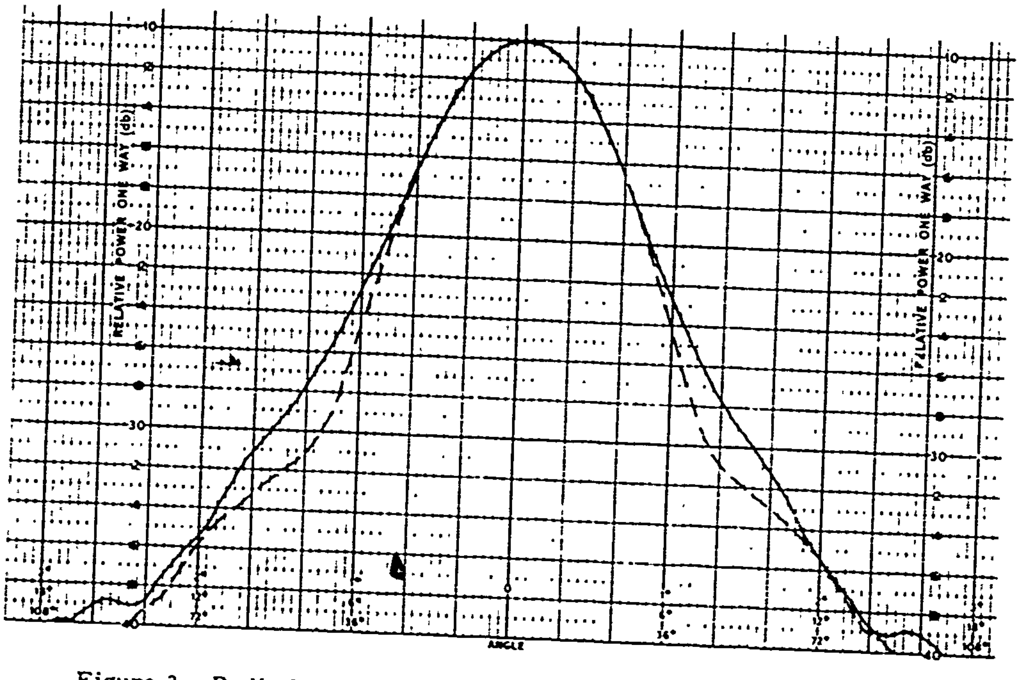


Figure 3. Radiation Patterns for ±45° Cuts Between E and H Planes of SBF Antenna in Figure 1 (Patterns are shown out to approximately ±115°; all lobes outside this range are more than 30 dB below the mainlobe.)

2.2 Description of Short-Backfire (SBF) Element

Earlier investigations with two antennas like the one in Figure 1 arrayed side by side with their reflectors M in the same plane proved that this type antenna is suitable for use as an array element for high-gain antennas. Because it has a relatively wide radiating aperture, the number of SBF antennas needed for illuminating a reflector area is much smaller than the number of dipoles or slots required for illuminating the same area. Such a two-SBF antenna array developed the expected gain increase of approximately 3 dB. Its E-plane pattern, however, showed relatively high sidelobes for horizontal polarization of both feeds F. This being due to the unfavorable array factor of the combination, the sidelobes can be decreased only by narrowing the spacing between the two feeds to approximately 1λ, which automatically prohibits the use of one-half of rim B of each SBF antenna and leads to the oval shape of the planar reflector M shown in Figure 5.

Figure 4. Photograph of SBF Antenna With Crossed Dipoles

In Figure 5, a sketch of the resulting array, the letter designations have the same meaning as those in the SBF antenna of Figure 1. The array consists of two feeds F, each with a reflector disk R supported by a rod Q of approximately $S_R/2$ length, and the oval-shaped planar reflector M with rim B surrounds its entire circumference. The spacing between the two feeds is $S_E$, and the largest dimension of the array $D_M$.

In terms of multielement arrays, the combination of F and R as a unit, the basic element for fabricating short-backfire arrays of any predetermined size, will be called 'SBF element' in the following. Multielement arrays that use a number of SBF elements instead of conventional radiators like dipoles or slots in front of a common planar reflector will be called 'SBF arrays.' For optimum performance (highest possible gain with sidelobes of about 20 dB below the mainlobe) the SBF elements have to be inserted into their common reflector M such that the reflector disk R is parallel to, and spaced a distance $S_R$ from, M. The spacings are $S_R \approx \lambda/2$; $S_E \approx 1\lambda$ to $2\lambda$. Variations of these dimensions result in changes in the directivity, sidelobe level, and bandwidth, and can be used for adjusting SBF arrays according to the specific requirements of any application.

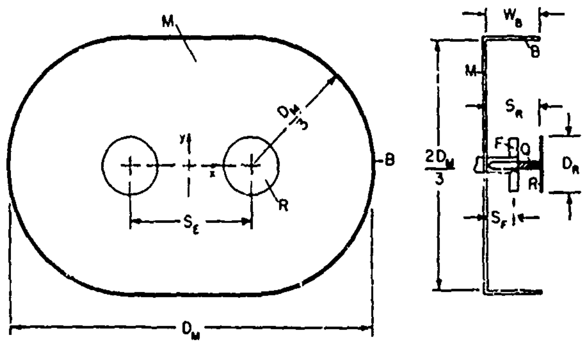


Figure 5. Sketch of Two-Element SBF Antenna Array

The antenna as described is a two-element SBF array. Its 3-GHz E- and H-plane patterns, shown in Figure 6 for the longer axis of the oval-shaped reflector and both dipoles oriented in a horizontal direction, were obtained with an array of the following dimensions:

$D_M = 3.00\lambda$

$D_R = 0.50\lambda$

$S_E = 1.00\lambda$

$S_F = 0.25\lambda$

$S_R = 0.50\lambda$

$W_B = 0.50\lambda$

$M = 5.14\lambda^2$ (area)

Although the E-plane pattern is narrowed, the H-plane pattern shows very little change compared with that of the SBF antenna in Figure 1. The sidelobes are respectively 20 dB and 22.5 dB below the mainlobe in the E- and H-plane patterns. The directivity was measured at 17.5 dB, corresponding to an area efficiency of 87 percent (referred to the area of reflector M). Calculating according to Stegen (1964), we get a directivity of 17.5 dB for the beamwidth values of $22^{\circ}$ and $31^{\circ}$ in the E and H planes respectively.

The similarity of the pattern shapes of Figures 2 and 6 indicates that approximately the same illumination function can be assumed for the reflector M of the SBF antenna in Figure 1 (area $3.14\,\lambda^2$) and that of the two-element SBF array in Figure 4 (area $5.14\,\lambda^2$). Based on the reflector areas of both antennas we could anticipate a 2.2 dB increase in the directivity of the two-element SBF array. The

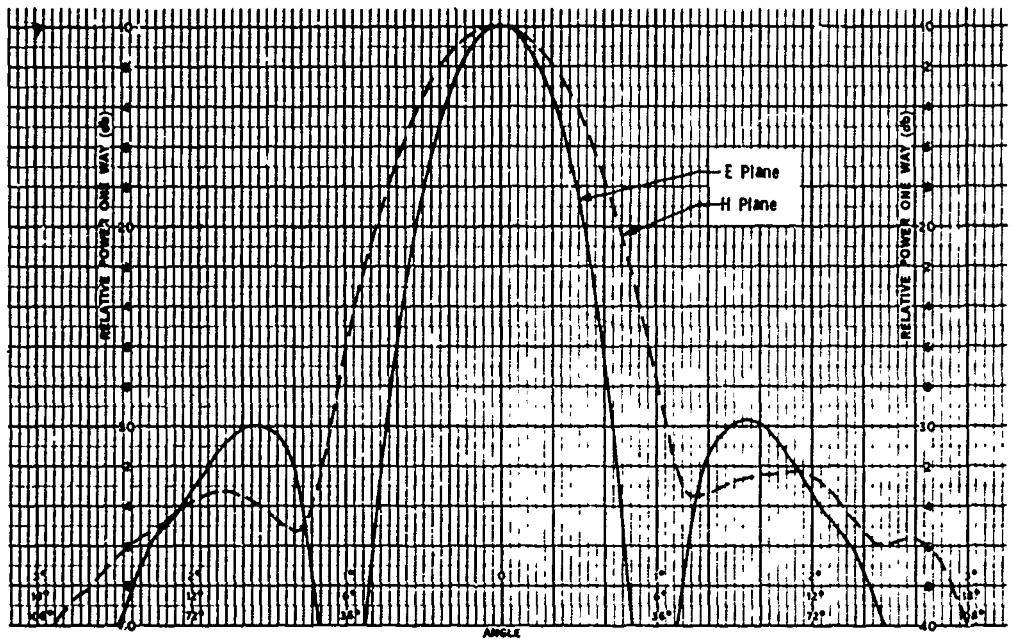


Figure 6. Radiation Patterns of Two-Element SBF Antenna Array in Figure 5 (Patterns are shown out to approximately ±115°; all lobes outside this range are more than 30 dB below the mainlobe.)

measured directivity increase (by pattern integration) of 2.4 dB is thus again in good agreement with the calculations.

## 3. CONCLUSIONS

It was the goal of this report to show how the short-backfire antenna can be easily converted into a very efficient array element. Only a two-element SBF array — in fact, the smallest version of this type of array — was discussed but the described development opens the possibility of combining larger numbers of SBF elements for multielement high-gain broadside arrays. The most significant improvement offered by the short-backfire arraying technique is that every four to six fed elements of conventional multielement arrays can be replaced by a single SBF element, without any decrease in gain. In addition, the greatly reduced number of feeds reduces the complexity and increases the gain and reliability of the array.

A program of experimental studies on SBF arrays with 4, 8, and 16 SBF elements, with gains varying between 17 and 25 dB is currently being carried on at the AFCRL Microwave Physics Laboratory. The results will be published shortly in a series of research reports.

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## References


1. Chen, K. M., Nyquist, D. P., and Lin, J. L. (1968) Radiation fields of the short-backfire antenna, IEEE Tr. Antennas and Propagation, AP-16 (No. 5): 596-597.
2. Dod, L. R. (1966) Experimental Measurements of the Short-Backfire Antenna, Tech. Rpt No. X-525-66-480, Goddard Space Flight Center, Greenbelt, Md.
3. Ehrenspeck, H. W. (1965) The 'Backfire'-A high-gain cavity antenna, in Electromagnetic Wave Theory (Part 2) J. Brown, Ed., pp. 739-749.
4. Ehrenspeck, H. W. (1965) The short-backfire antenna, Proc. IEEE 53:1138-1140.
5. Ehrenspeck, H. W. (1966) The short-backfire, a new type of broadband receiving antenna for UHF (in German), Funk-Technik 1966, Nr. 1, Jan. 1966.
6. Ehrenspeck, H. W. (1967) A family of novel antennas: the 'backfire' antenna, Proc. OAR Research Applications Conference, March 1967, pp. 80-104.
7. Ehrenspeck, H. W. (1969) 'Backfire' Antennen (in German), NTZ-Nachr tech. Z. 22 (Nr. 5):286-292.
8. Ehrenspeck, H. W. (1969) Short-Backfire Antenna, U. S. Patent No. 3438043, April 1969.
9. Ehrenspeck, H. W. (1970) Short-Backfire Antenna, U. S. Patent No. 3508278, April 1970.
10. Fulmer, M. R., and Mosely, R. E. (1960) Determination of antenna directivity by pattern integration method, The Essay (No. 2), Scientific Atlanta, Inc.
11. Lantz, P. A. (1964) Handbook of NASA/GSFC Tracking: Data-Acquisition and Communication Antennas, Tech. Rpt X-525-64-222, Goddard Space Flight Center, Greenbelt, Md.
12. Nielsen, E. Dragø (1969) Influence of Variation of Backfire Antenna Parameters, Sci. Rpt No. 2, Contract No. F61 052-67-C-0056, Laboratory of Electromagnetic Theory, Technical University of Denmark, Aug. 1969.

13. Nielsen, E. Dragø, and Pontoppidan, Knud (1970) Backfire antennas with dipole elements, IEEE Tr. Antennas and Propagation AP-18 (No. 3): 367-374.

14. Oettl, H., and Thomanek, L. (1968) Monopuls-Antenne der Bodenstation für Satelliten funk der Deutschen Versuchsanstalt für Luft und Raumfahrt e V, NTZ-Nachrtech. Z. 21 (Nr. 10):631-634.

15. Stegen, R.J. (1964) The gain-beamwidth product of an antenna, IEEE Tr. Antennas and Propagation AP-12 (No. 4):505-506.

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