# Improvement in front-to-back ratio of a bifilar backfire helix by a flared open end

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(出版者 / Publisher)
IEEE
(雑誌名 / Journal or Publication Title)
IEEE Transactions on Antennas and Propagation / IEEE Transactions on Antennas and Propagation
(号 / Number)
11
(開始ページ / Start Page)
1591
(終了ページ / End Page)
1595
(発行年 / Year)
1993-11

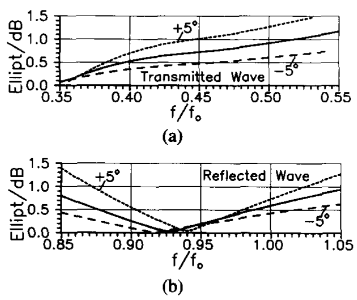


Fig. 4. Phase response of FSS specified in Fig. 3. Solid lines, $\theta_0 = 25°$; dotted lines, variation of incident angle by $+5°$; dashed lines, variation of incident angle by $-5°$. (a) Ellipticity of transmitted wave; (b) ellipticity of reflected wave.

expected from the discussion following (11), a lower incident angle improves the performance slightly [Fig. 3(c)] since it comes closer to the theoretically ideal—but not practical—value of 0°. Therefore, the performance at $-5°$ variation remains entirely within specifications. For a variation of up to $+5°$, however, some slight frequency and amplitude shifts occur, especially for TM excitation (dashed lines), which affect the performance of the FSS at the lower band edges. The isolation drops from 20 to 17.2 and 19.2 dB at the lower band edges of the transmission and reflection band, respectively. All other parameters related to magnitude responses remain within specifications.

The solid lines in Fig. 4 demonstrate that the ellipticity specifications also are met for the transmitted [Fig. 4(a)] and reflected [Fig. 4(b)] signal. Again, we find that a reduction in incident angle leads to an improved performance (dashed lines). An angle of 5° higher than specified results in increased ellipticities of both transmitted and reflected waves (dotted lines). With respect to the specified bandwidth of $0.1f_0$, however, only the transmitted signal exceeds the specified ellipticity (1 dB) by 0.39 dB while the ellipticity of the reflected wave remains below 1 dB.

## IV. Conclusion

A design procedure for multiple dielectric-layered frequency-selective surfaces in circularly polarized millimeter-wave applications is presented. Standard filter theory for high–low impedance structures is used to determine the initial values of a configuration. Optical principles are applied for the analysis, and a final optimization procedure varies the incident angle and layer thicknesses until a specified behavior is obtained. Since the ellipticities of reflected and transmitted waves are considered in the optimization routine, the surface can be optimized especially for incident waves of circular polarization. An example for 40-GHz operation with 4-GHz transmission and reflection bandwidth demonstrates that this design offers an attractive solution for circularly polarized millimeter-wave FSS applications.

## Acknowledgment

The author would like to thank Lizhong Sun of McGill University in Montreal, Canada, for helpful suggestions and discussions.

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# Improvement in Front-to-Back Ratio of a Bifilar Backfire Helix by a Flared Open End

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***Abstract*—The current distribution of a bifilar helical antenna which radiates a circularly polarized wave in the backward endfire direction is decomposed into forward and reflected currents, and the contribution of each current to the radiation is evaluated numerically. Calculations show that the presence of the reflected current deteriorates the front-to-back (F/B) ratio of radiation. To reduce the reflected current and to improve the F/B ratio, flaring of the open end is proposed and investigated. The flared configuration leads to an improved F/B ratio, with an almost constant input impedance.**

## I. Introduction

Patton [1] described the basic concepts of backfire radiation from a bifilar helical antenna as part of an investigation of the

Manuscript received February 5, 1993; revised July 2, 1993.
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IEEE Log Number 9213066.

properties of periodic radiating structures. Patton's backfire helix is characterized by a traveling-wave current distribution. In contrast, Kilgus studied a backfire helical antenna characterized by a standing-wave current distribution [2].

Subsequently, Kilgus developed a quadrifilar helical antenna for satellite and ground-station applications [3]. Application of a backfire helix to the primary feed of a parabolic reflector has also been reported [4], [5].

To improve the properties of a backfire helix, we numerically studied a modified backfire helix [6]. Tapering the feed end of Patton's bifilar helix improves the radiation characteristics, particularly at higher operating frequencies. A subsequent numerical analysis revealed the effectiveness of terminating each arm end with a resistor [7].

The purpose of this paper is to investigate the characteristics of the bifilar helical antenna shown in Fig. 1, with emphasis on the behavior of the current distribution. The current distribution analyzed using the integral equation technique [8] is decomposed into forward and reflected components [9]. It is numerically confirmed that the forward and reflected currents radiate in the $+Z$ and $-Z$ directions, respectively, and hence the presence of the reflected current deteriorates the front-to-back ratio.

On the basis of this result, flaring of the open end (as shown in the inset of Fig. 3) is proposed to attenuate the forward current. Flaring of the open end has an advantage over the resistive termination of the arm ends in that the radiation efficiency is not decreased. It is found that rapid attenuation of the forward current is realized in the flared section, so that an improvement in the front-to-back ratio is achieved. Some experimental results are also presented to verify the numerical results.

## II. Generation of Backfire Radiation

First, we consider the properties of the forward and reflected currents of the bifilar backfire helical antenna. The backfire helix to be considered here is the same as that discussed in [6] except for the number of helical turns in the uniform section. The testing frequencies are in the $S$ band (2–3.5 GHz).

Fig. 1 shows the configuration of the backfire helix with tapered feed end (TBH). The TBH consists of a tapered section and a uniform section. Tapering the feed end contributes to the smooth decay of the current distribution, particularly at higher operating frequencies [6]. The tapered section is specified by an equiangular spiral function, $r = r_0 \exp(a\phi_c)$, and the geometric parameters are chosen as follows: generating line of the conical section $r_0 = 3.8$ cm; spiral constant $a = 0.048$ rad$^{-1}$; cone taper angle $\theta_t = 12.5°$. The circumference of the helical cylinder in the uniform section is $C = 10$ cm. In both sections, the pitch angle and the wire radius are $\alpha = 12.5°$ and $\rho = 0.5$ mm, respectively. The helical turns of the tapered section and the uniform section are, respectively, taken to be 2.2 and 5.5. To feed the antenna, a straight wire is inserted between the starting points of the two arms in the tapered section, and a delta-function generator is located at the center of the straight wire. The detailed mathematical expressions which specify the TBH are found in [7].

It is revealed in [7] that the attenuation rate of the traveling current decreases as the frequency is decreased. Calculations show that terminating the arm ends with a matched resistor reduces the reflected current, particularly at frequencies lower than 2.6 GHz, with subsequent improvement of the front-to-back (F/B) ratio. Since this fact implies the presence of a reflected current, we decompose the current distribution into forward and reflected components and calculate the contribution of each component to the radiation.

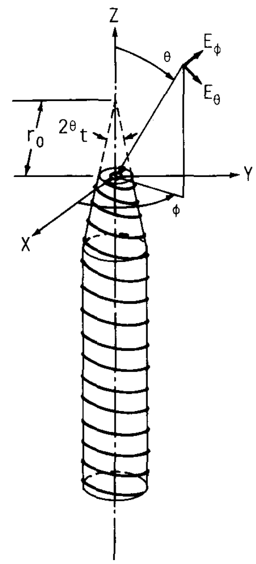


Fig. 1. Configuration and coordinate system of a tapered backfire helical antenna.

Fig. 2(a) shows the current distribution and radiation pattern of the TBH. The current distribution, $I = I_r + jI_i$, is determined by the moment method. Since the current distributions on the two helical arms are symmetrical with respect to the feed point, only the current on one arm is illustrated. The helix is operated at a frequency of 2.1 GHz, which gives a 0.7λ (λ = free-space wavelength) circumference for the uniform helical cylinder. Since the attenuation rate of the traveling current is small at this frequency, the current on the helix exhibits a standing-wave distribution, resulting in deterioration of the radiation characteristics.

Now, we decompose the current distribution into forward and reflected components. The method of decomposition follows that of Lee and Mei [9]. Fig. 2(b) and (c), respectively, show the current distributions of the forward and reflected components and the corresponding radiation patterns. Fig. 2(b) clearly shows that the forward component of the current gradually decays with a small attenuation of about 0.3 Np/λ and is not completely attenuated when it reaches the arm end. Therefore, there is an appreciable reflected component of the current along the helical arm, as shown in Fig. 2(c). This leads to a total current with a standing wave distribution, as shown in Fig. 2(a).

Examination of the radiation patterns reveals that the forward and reflected currents radiate in the backfire mode (the direction of radiation is opposite to the direction of current flow). The deterioration of the F/B ratio in the total radiation field, shown in Fig. 2(a), is due to the existence of the reflected current.

The results mentioned above indicate that it is necessary to reduce the reflected component to realize a high F/B ratio. One of the methods of reducing the reflected component is to terminate the arm ends with a matched resistor [7]. The radiation efficiency is, however, forced to decrease. Therefore, a novel means is proposed here as an alternative to using a terminating resistor.

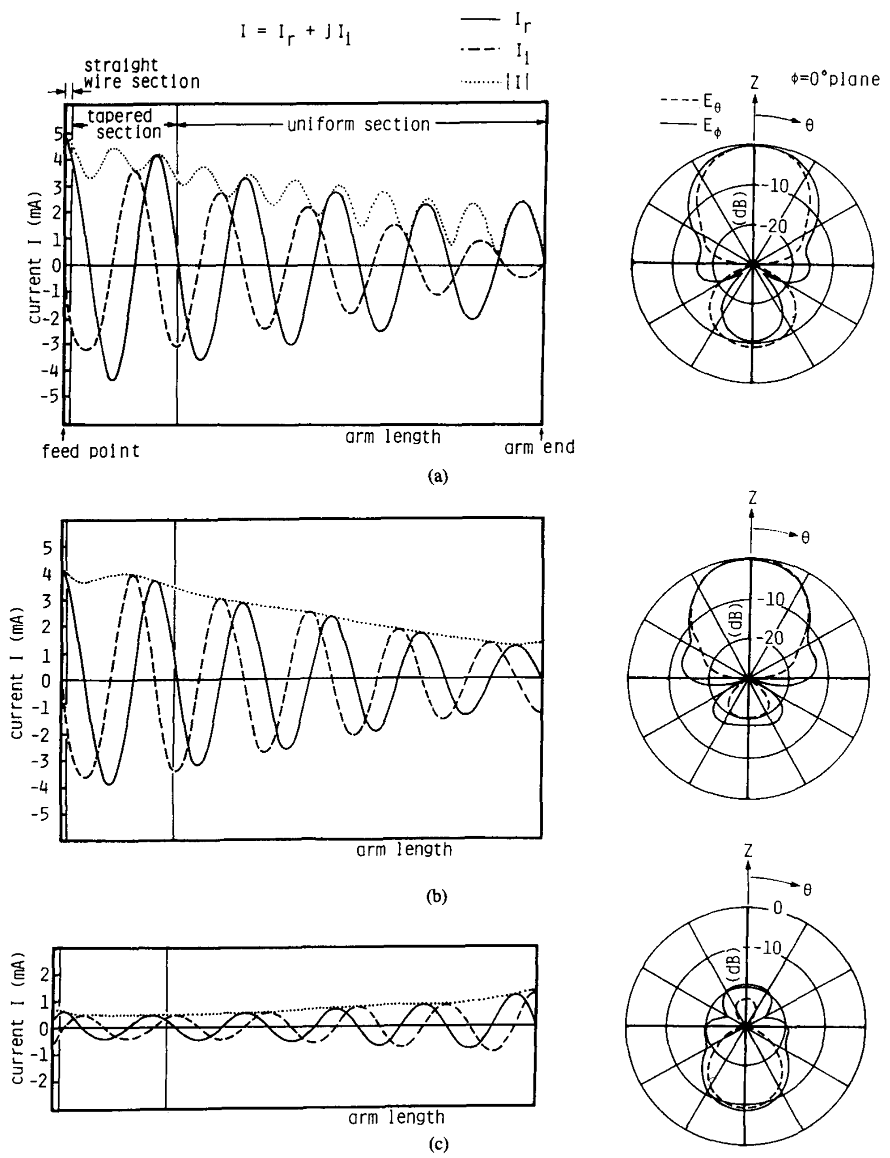


Fig. 2. Decomposition of the current distribution and radiation pattern of a tapered backfire helix at 2.1 GHz. (a) Total current and corresponding radiation pattern; (b) forward current and corresponding radiation pattern; (c) reflected current and corresponding radiation pattern.

## III. Modification of the Open End

The attenuation rate of the forward current changes as a function of frequency. In other words, the attenuation rate changes in terms of the helical circumference (in wavelengths). Since the slow decay of the forward current at lower frequencies is caused by the decrease in the helical circumference (in wavelengths), it is beneficial to flare (not taper) the open end for rapid decay of the forward current.

The inset of Fig. 3 shows the proposed configuration, in which the open end section of the TBH is flared using an equiangular spiral function. The pitch angle of the flared section is chosen to be the same as that in the uniform section. For brevity, the proposed helix is termed an FTBH (tapered backfire helix with flared open end). Fig. 3 shows the behavior of the F/B ratio as function of the flare angle $\theta_f$. In this calculation, the arm length of the flared section is fixed to be 25.1 cm, corresponding to approximately 1.9 turns for $\theta_f = 12°$. The total arm length is the same as that of the unflared TBH. An excellent F/B ratio of more than 18 dB is obtained when $\theta_f$ is between 12 and 28°.

Fig. 4 shows the current distributions and corresponding radiation patterns for $\theta_f = 12°$. The frequency is chosen to be 2.1 GHz. It is revealed that the forward current nearly dies out along the flared section, so that the reflected current reduces to a negligible amount. It follows that the total radiation pattern is characterized by the forward current alone, indicating a backfire mode.

The forward current obtained by the decomposition technique is a smooth function, from which the complex propagation

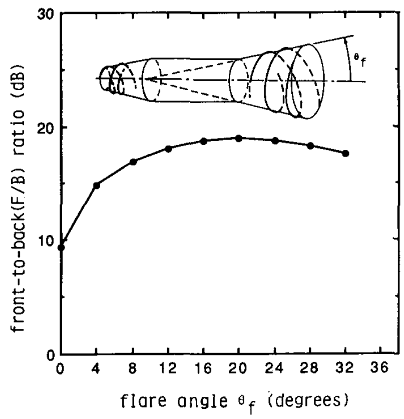


Fig. 3. Front-to-back ratio at 2.1 GHz as a function of flare angle $\theta_f$.

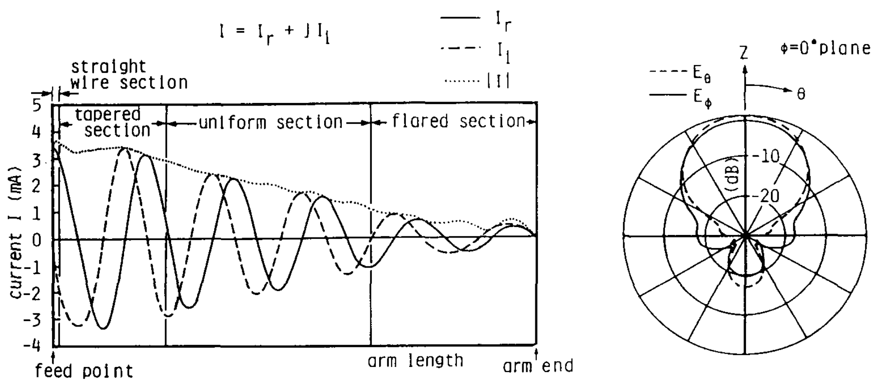


Fig. 4. Current distribution and radiation pattern of a tapered backfire helix with a flared open end at 2.1 GHz.

constant, $\gamma = \alpha + j\beta$, can be determined. Fig. 5 shows the propagation constant as a function of position along the arm. It can be said that the flared section acts as an effective radiator, causing a maximum attenuation of about 0.9 Np/λ. It is also seen that the phase constant is nearly equal to that in free space, i.e., $\beta\lambda \simeq 2\pi$ rad.

## IV. Frequency Characteristics and Experimental Verification

The frequency characteristics of the radiation patterns are presented in Fig. 6. The results are for the FTBH at 2.1 and 2.6 GHz, respectively. Since the patterns are nearly uniform in any azimuth plane $\phi$, they are illustrated only for the $\phi = 0°$ plane. It is seen that the FTBH satisfactorily operates in the backfire mode with an excellent axial ratio. For example, at 2.1 GHz the FTBH shows an F/B ratio of 18 dB and an axial ratio of 1.0 dB. As the frequency is decreased, the main beam becomes sharper, with a subsequently higher gain. A gain of 8.7 dB at 2.6 GHz increases to 10.3 dB at 2.1 GHz.

Experimental data are also plotted in Fig. 6. The experimental results are obtained by feeding the antenna from a semirigid coaxial line, which has a split-tube balun located on the $-Z$ axis. Good agreement between calculated and experimental results is found for the main beam. Some discrepancy in the back lobe is caused by the presence of the semirigid coaxial line. The experiment also confirms the calculated results concerning the axial ratio and gain. The maximum errors of the axial ratio and gain are 0.2 and 0.3 dB, respectively.

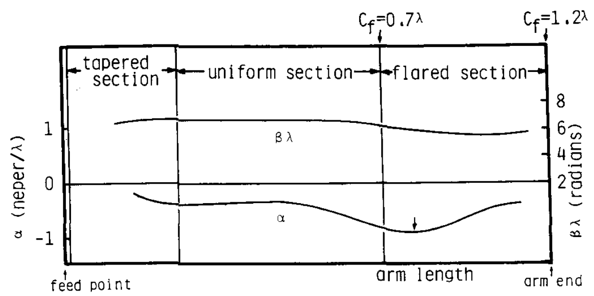


Fig. 5. Complex propagation constant ($\gamma = \alpha + j\beta$) versus position along the antenna arm at 2.1 GHz.

For $\theta_f = 12°$, the outer circumference of the flared section, $C_f$, ranges from 10 to 17 cm, corresponding to 0.7λ to 1.2λ at 2.1 GHz. Since the location of the largest attenuation (0.9 Np/λ) corresponds to a circumference of 0.86λ (indicated by an arrow in Fig. 5), the flared section is expected to operate as an effective radiator even at frequencies lower than 2.1 GHz. Further calculations at 2.0 GHz show that a traveling-wave current distribution is still maintained, and the 3-dB F/B ratio for the TBH is improved to 14 dB for the FTBH.

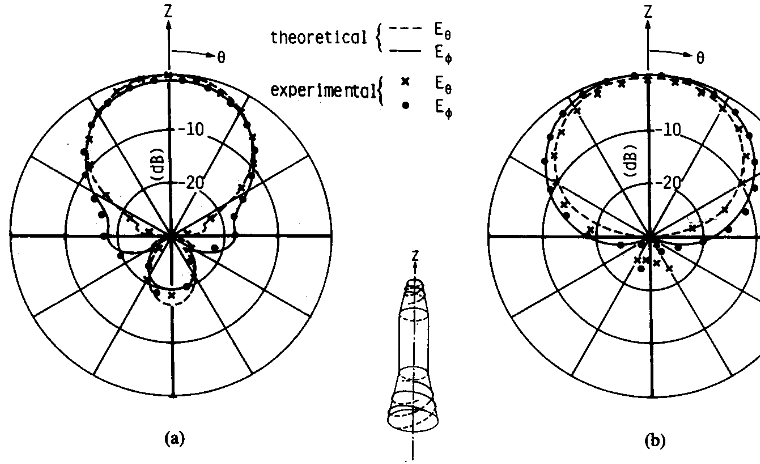


Fig. 6. Radiation patterns of a tapered backfire helix with flared open end in the $\phi = 0°$ plane. (a) 2.1 GHz; (b) 2.6 GHz.

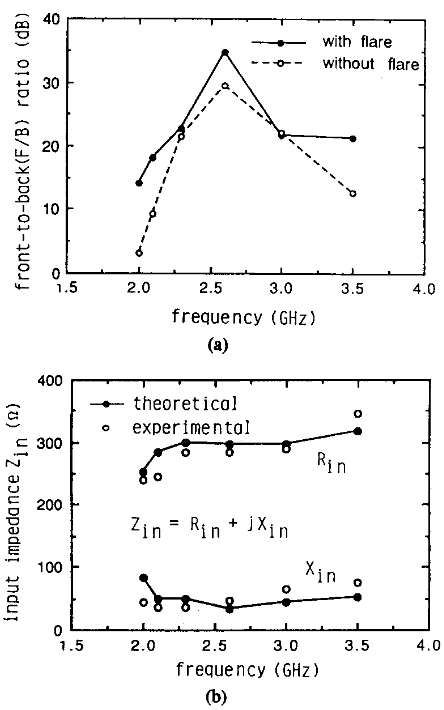


Fig. 7. Frequency characteristics of the front-to-back ratio and the input impedance.

At higher operating frequencies, the current attenuates rapidly from the feed point, resulting in a negligible current in the flared section. It follows that the radiation characteristics of the FTBH are similar to those of the TBH.

The fact that the reflected current of the FTBH is reduced over a wide range of frequencies leads to wideband characteristics of not only the backfire radiation pattern but also the input impedance. Fig. 7(a) and (b) show the frequency responses of the F/B ratio and the input impedance ($Z_{in} = R_{in} + jX_{in}$). It is observed that the FTBH operates in the backfire mode over a frequency range of 2.0 to 3.5 GHz (1:1.75), with an almost constant input impedance. A typical value of the input impedance is about 300 Ω resistive and about 40 Ω reactive. Experimental values verify these calculated results.

## V. Conclusions

The current distribution of a backfire helical antenna has been decomposed into forward and reflected components. The contribution of each component to the radiation pattern has been evaluated. It is numerically revealed that the deterioration of the front-to-back ratio at lower frequencies is caused by the reflected current from each helical arm end. In order to reduce the reflected current, a flared configuration at the open end is proposed. A helix with a flared open end (FTBH) has a wideband characteristic for the backfire radiation, while maintaining a constant input impedance.

## Acknowledgment

The authors would like to thank Dr. W. T. Patton for his invaluable discussion of the backfire mode at the 1982 AP-S Symposium in Albuquerque. To H. Mimaki and V. Shkawrytko, the authors are particularly grateful for their kind assistance in the preparation of the manuscript.

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