

TECHNICAL FEATURE

Resonant Quadrifilar Helix Design

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Feeding the elements of the fractional-turn, four element helix in antiphase produces a resonant, circularly polarized antenna with a cardioid shaped radiation pattern. Beamwidths from 90° to 240° , high front-to-back ratios and good circular polarization are simultaneously obtainable by the proper choice of the helical parameters. This paper presents an intuitive analysis linking the helix with the loop dipole antenna. Helix radiation patterns are calculated using this analogy and compared with measured data. Measured beamwidth, back-to-front ratio and axial ratio data are included. Applications of the helix as a satellite antenna and as a ground station antenna, and some practical design details are described.

Circularly polarized antennas with broad beamwidths ($>90^\circ$) have application in space communication links as both non-tracking ground antennas and as stabilized-satellite antennas. Unfortunately, most of the available antennas with broad beamwidth and circular polarization (for example the conical spiral, traveling-wave bifilar helix, or turnstile with reflectors) are cumbersome mechanically at VHF and low UHF.

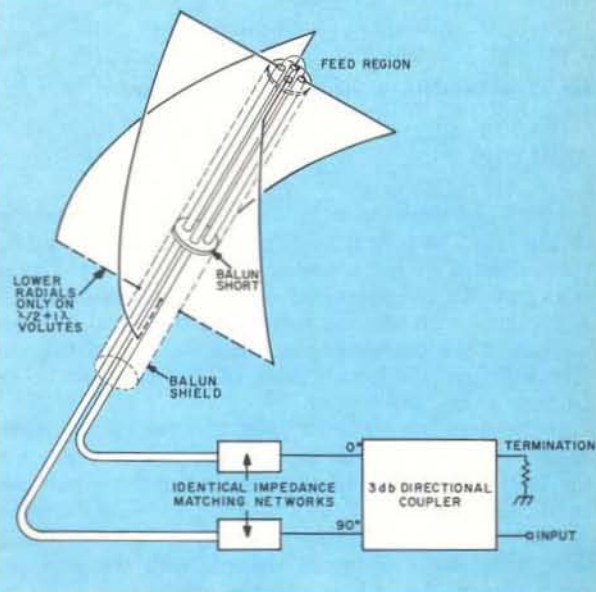
This paper describes a new and more compact antenna, the resonant, fractional-turn, quadrifilar helix with anti-phase feed (called the "volute" in this paper).

Volutes with elements $\lambda/4$, $\lambda/2$, $3\lambda/4$ and 1λ long have been studied. (For convenience, the volute with elements $\lambda/4$ long will be referred to as the " $\lambda/4$ volute".)

These four types of volute are fed in the same fashion (Fig. 1). One end of each element is bent to the center feed point, the opposite end is open circuited ($\lambda/4$ and $3\lambda/4$ volute) or bent to the center and short circuited ($\lambda/2$ and 1λ volute). At the feed point opposite elements are fed in antiphase, producing two independent bifilar helices. Each bifilar helix radiates a circularly polarized, toroid-shaped pattern with the null perpendicular to the helical axis. Feeding these two bifilar helices in phase quadrature produces a cardioid-shaped radiation pattern with circular polarization over the front hemisphere.

In the "analysis" section of the paper a physical argument is presented relating the $\lambda/2$ volute to two orthogonal loop-dipole antennas. The radiation patterns calculated by this equivalence are compared with measured patterns. An earlier paper¹ presented exact integral expressions for the $\lambda/2$ volute radiation pattern shape. Solutions obtained by computer-aided integration were presented and compared with measured data.

The "application" section of this paper includes experimental beamwidth, axial ratio, back-front ratio and radiation pattern data, and details of mechanical construction.



1/4 TURN VOLUTE WITH FOLDED BALUNS
FIGURE 1

Fig. 1 — $1/4$ turn volute with folded baluns.

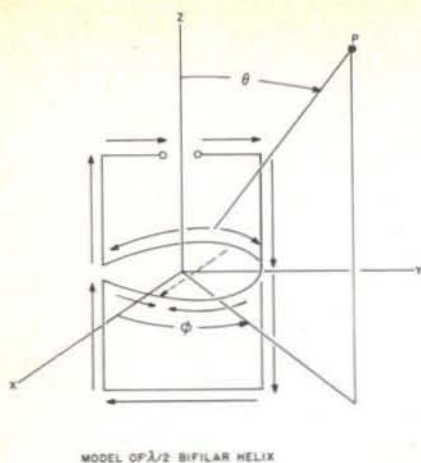


Fig. 2a — Model of $\lambda/2$ bifilar helix.

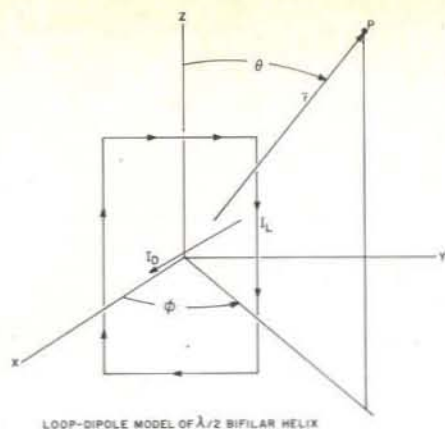


Fig. 2b — Loop-dipole model of $\lambda/2$ bifilar helix.

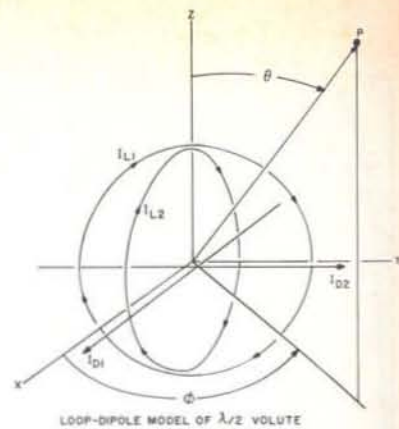


Fig. 2c — Loop-dipole model of $\lambda/2$ volute.

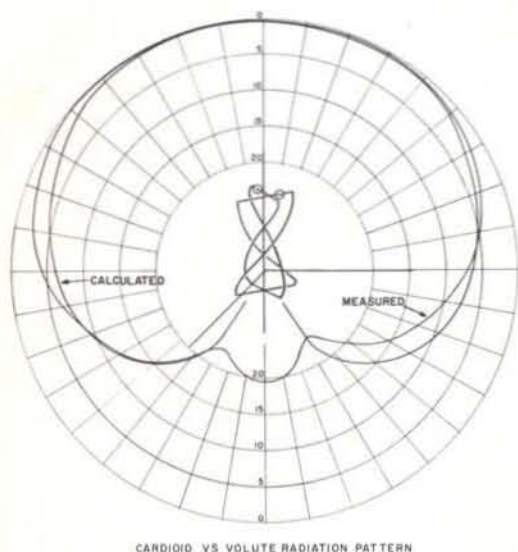


Fig. 3 — Cardioid vs. volute radiation pattern.

ANALYSIS

A simplified model of a $\lambda/2$ turn bifilar helix is sketched in Fig. 2a. The helical parts of the elements have been approximated by linear and semi-circular pieces. The arrows indicate the measured current distribution of the $\lambda/2$ volute; with maxima at the feed and distal ends and minima at the centers of the elements. The dotted current indicates the vector sum of the currents in the circle.

If the wires are removed (Fig. 2b) the current distribution is similar to that of a loop-dipole antenna with the loop in the plane of the radials and the dipole perpendicular to the plane.

The circularly polarized radiation pattern of the $\lambda/2$ turn bifilar helix is toroid shaped, with the null perpendicular to the radials and the helical axis. This experimentally measured similarity with the radiation pattern of the loop-dipole antenna supports the validity of the current model.

Extending this argument, two orthogonal loop dipole antennas (Fig. 2c) fed in phase quadrature provide a model of the $\lambda/2$ volute.

From this model expressions for the volute radiation pattern can be written:²

$$E_{\theta \text{ Loop Dipole } 1} = K e^{-j(kr - \pi/2)} (\sin \phi + j \cos \phi \cos \theta)$$

$$E_{\phi \text{ Loop Dipole } 1} = K e^{-j(kr - \pi/2)} (\cos \theta \cos \phi - j \sin \phi)$$

$$E_{\theta \text{ Loop Dipole } 2} = K e^{-jkr} (-\cos \phi + j \sin \phi \cos \theta)$$

$$E_{\phi \text{ Loop Dipole } 2} = K e^{-jkr} (\sin \phi \cos \theta + j \cos \phi)$$

where: The loops and dipoles are assumed to be electrically small.

$e^{j\pi/2}$ expresses the phase quadrature between the loop-dipole antennas.

K is a function of range, current and length. This constant is the same for the θ and ϕ components of a single loop dipole because of the requirement for circular polarization, and equal for the two loop-dipoles because of physical similarity and equal feed currents.

The normalized total field is:

$$E_{\theta T} = E_{\theta 1} + E_{\theta 2} = (\cos \theta + 1) \angle -\phi$$

and

$$E_{\phi T} = E_{\phi 1} + E_{\phi 2} = (\cos \theta + 1) \angle 90^\circ - \phi$$

The relative phase is 90° and $E_{\theta} = E_{\phi}$ for all θ and ϕ , indicating circular polarization over the sphere. The pattern is cardioid shaped with the maximum along the helical axis. Figure 3 compares the radiation pattern of a $\lambda/2$ turn $\lambda/2$ volute (with $L_{ax} = .27\lambda$) with a cardioid.

APPLICATION

Physical Form

The radius and axial length of the volute are related by:

$$L_{ax} = N \sqrt{\frac{1}{N^2} (L_{hel} - A r_0)^2 - 4\pi^2 r_0^2}$$

where:

L_{ax} = axial length of the volute (in.)

L_{hel} = length along a helical element (in.)

r_0 = radius of the volute (in.)

N = number of turns for one element

$A = \begin{cases} 2 & \text{for the } \lambda/2 \text{ and } 1\lambda \text{ volutes} \\ 1 & \text{for the } \lambda/4 \text{ and } 3\lambda/4 \text{ volute} \end{cases}$

A slightly convex shape improves the symmetry of the radiation pattern.

Experimental Data

Measured beamwidth, axial ratio and back-front ratio data for the $\lambda/4$, $\lambda/2$, $3\lambda/4$ and 1λ volutes with the number of turns as a parameter is presented as Fig. 4. The dashed lines on Figs. 4g and 4j indicate the region

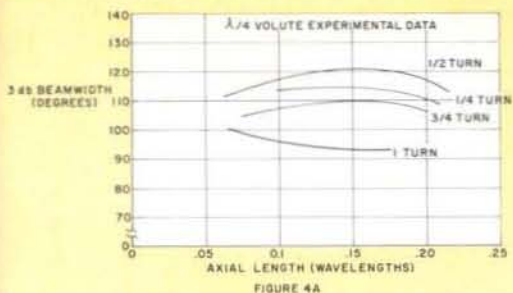


Fig. 4a — $\lambda/4$ volute experimental data.

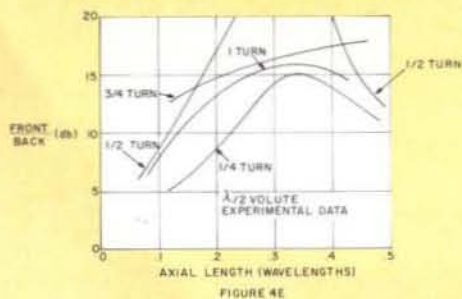


Fig. 4e — $\lambda/2$ volute experimental data.

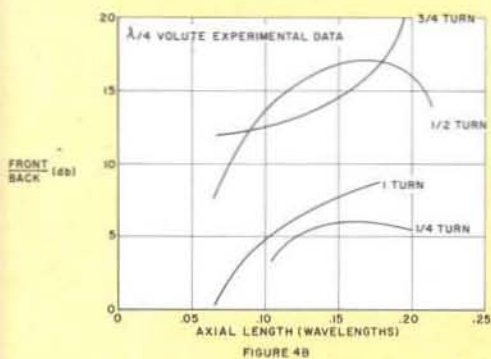


Fig. 4b — $\lambda/4$ volute experimental data.

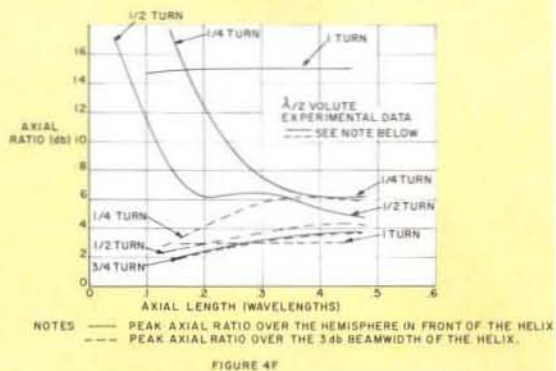


Fig. 4f — $\lambda/2$ volute experimental data.

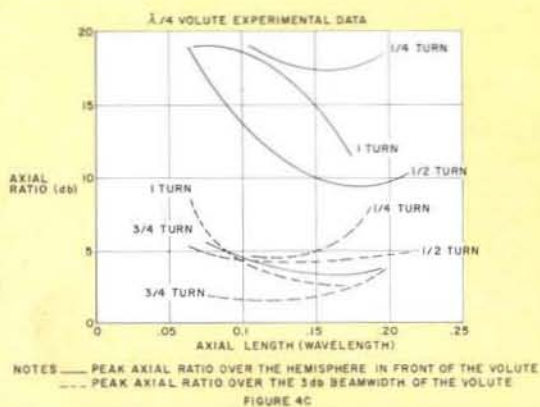


Fig. 4c — $\lambda/4$ volute experimental data.

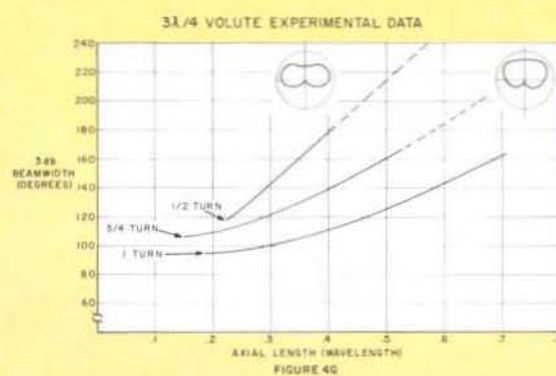


Fig. 4g — $3 \lambda/4$ volute experimental data.

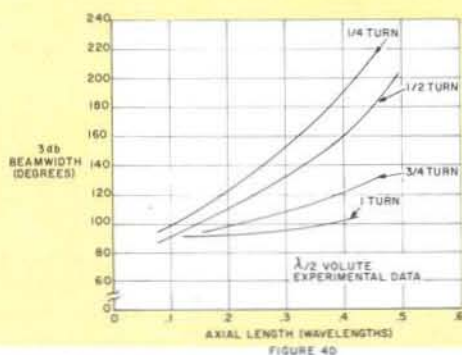


Fig. 4d — $\lambda/2$ volute experimental data.

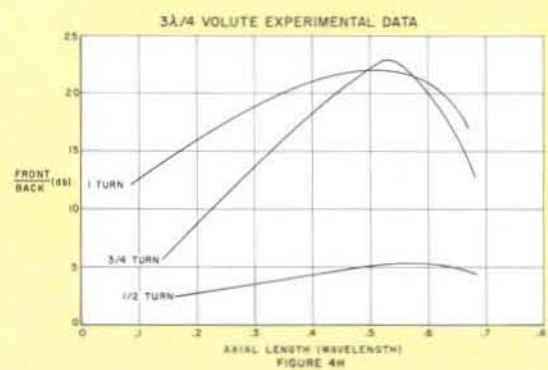


Fig. 4h — $3 \lambda/4$ volute experimental data.

