A Note on the Difference Between Equiangular and Archimedes Spiral Antennas*

There seems to exist in the literature considerable confusion about the various types of spiral antennas, their characteristics, and their bandwidth capabilities. One evidence of this confusion appeared in a paper by Bower and Wolfe,[1] in which they state that the Archimedes spiral antenna can be specified in terms of angles and hence belongs in the class of "frequency-independent antennas." Frequency-independent antennas are relatively new; in fact, until 1955 there was no evidence that a "frequency-independent" antenna did, indeed, exist.[2] Therefore, it would appear appropriate to delineate the characteristics and the terminology of the antennas involved. Perhaps this brief report of some recent work at the University of Illinois Antenna Laboratory will aid in pointing up the differences in operation of the logarithmic (*i.e.*, equiangular) and Archimedean spiral antennas.

It has long been recognized that the log-spiral curve is specified by an angle, α, the angle between the position vector to a point on the curve and a tangent to the curve at that point. This property of the curve leads to the alternate name, equiangular spiral. It was pointed out by Rumsey[3,4] in 1954 that this property of the log-spiral makes it possible to specify an antenna based upon this curve entirely by angles except for a necessary arm length; hence, such an antenna might possibly be a frequency-independent structure. It has been shown[5] that frequency-independent operation of log-spiral antennas is indeed possible over bandwidths limited only by precision of construction. Rumsey also pointed out that magnification of the log-spiral curve is equivalent to a rotation so that a change in the operating wavelength of a log-spiral antenna can be exactly compensated by a rotation of the antenna. For loosely wound spirals in a plane (small α) the radiation patterns are not rotationally symmetric and a rotation of the elliptic cross section of the beam is observed with frequency.[5] For tightly wound spirals this rotation is unobservable because of the symmetry of the beam.

The Archimedean spiral is *not* specified by any one angle. The angle α between the position and tangent vectors on this curve is a function of position on the curve. (It can be easily shown that $\alpha = \arctan \phi$, where ϕ is the azimuthal angle swept out in generating the curve.) For very tightly wound spirals this angle, far from the origin, is a *slowly-varying* function. If, as is widely believed, the radiation from the Archimedean spiral occurs from a localized band on the antennas, then in these few turns of a tight spiral sufficiently far from the origin the angle α will be relatively constant, and the Archimedean spiral is a very close approximation to a tightly wound log-spiral. In fact, the Archimedean spirals which have been utilized over broad bandwidths are so tightly wound that the angle α changes little over the entire radiating structure so that the operation likewise changes little over the operating bandwidths. This difference in the two spiral curves is the principal reason why an Archimedean spiral antenna must have many closely spaced turns to operate successfully while planar log-spiral antennas can be constructed with only $1\frac{1}{2}$ or 2 turns in a relatively loose spiral.

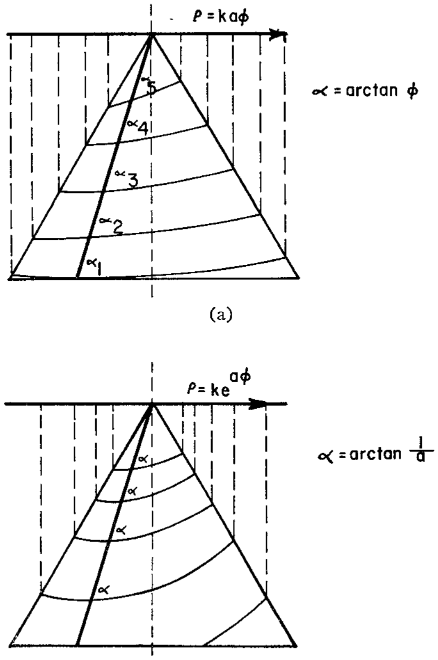

Fig. 1.

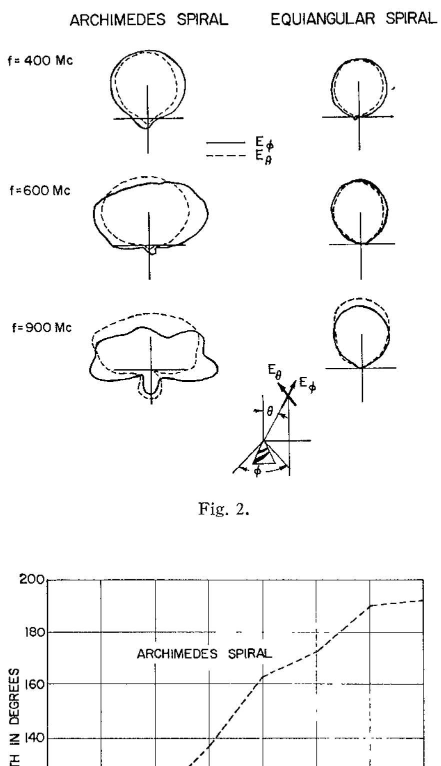

Fig. 2.

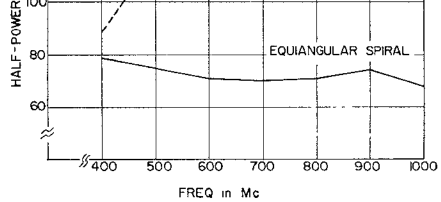

Fig. 3.

In order to point out the difference between Archimedean and log-spirals it is therefore necessary to magnify the changing α of the Archimedean curve. This could be done by constructing a loosely spiraled planar antenna. However, it can also be shown by constructing an Archimedean spiral antenna on a conical surface.

It has been previously shown[6] that the conical log-spiral is a useful antenna because it has a frequency-independent unidirectional radiation pattern. One of the characteristics of the conical log-spiral antenna is that the beamwidth is directly related to the angle α and since this angle is a constant for a given antenna the beamwidth can likewise be held relatively constant as a function of frequency. Similar unidirectional patterns can be obtained from the conical Archimedean spiral. Planar Archimedean spiral curves, which would describe a balanced antenna with well formed bidirectional patterns, may be orthogonally projected onto a conical surface as shown in Fig. 1(a). A similar projection is shown for the log-spiral in Fig. 1(b). In a particular case observed, the angle α for the conical Archimedean spiral antenna varied between approximately 45 degrees and 85 degrees whereas the log-spiral antenna constructed on the same cone has a fixed α of 85 degrees. The effect of the changing α on the radiation pattern of the Archimedean spiral as compared with the frequency-independent pattern of the log-spiral is shown in Fig. 2. The variation of the beamwidth of the conical Archimedean spiral with frequency is contrasted with the constant beamwidth of the conical log-spiral in Fig. 3. A similar contrast between Archimedean- and log-spiral operation has been obtained when using four-arm spirals to produce conical beams.[7]

The above comments are not intended to detract in any way from the merit of the

* Received by the PGMTT, August 8, 1960.

[1] R. Bawer and J. J. Wolfe, "A printed circuit balun for use with spiral antennas," IRE TRANS. ON MICOWAVE THEORY AND TECHNIQUES, vol. MTT-8, pp. 319–325; May, 1960.

[2] J. D. Dyson, "The equiangular spiral antenna," *Proc. 5th Ann. Symp. on the USAF Antenna Res. and Dev. Program*, University of Illinois, Monticello, Ill.; October, 1955 (classified).

[3] V. H. Rumsey first proposed in September, 1954, that the log-spiral geometry be investigated.

[4] V. H. Rumsey, "Frequency independent antennas," 1957 IRE NATIONAL CONVENTION RECORD, Pt. 1, pp. 114–118. Also, Antenna Lab., University of Illinois, Tech. Rept. No. 21, Contract AF33(616)-3220; October, 1957.

[5] J. D. Dyson, "The equiangular spiral antenna," IRE TRANS. ON ANTENNAS AND PROPAGATION, pp. 181–187; April, 1959 Also, Antenna Lab., University of Illinois, Tech. Rept. No. 21, Contract AF33(616)-3220; September, 1957.

[6] J. D. Dyson, "The unidirectional equiangular spiral antenna," IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-7, pp. 329–334; October, 1959. Also, Antenna Lab., University of Illinois, Tech. Rept. No 33, Contract AF33(616)-3220; July, 1958.

[7] J. D Dyson and P. E. Mayes, "New circularly polarized frequency independent antennas with conical beam or omnidirectional patterns," submitted for publication in the IRE TRANS. ON ANTENNAS AND PROPAGATION. Also, Antenna Lab., University of Illinois, Tech. Rept. No. 46, Contract AF33(616)-6079; June, 1960.

Archimedean spiral antenna. The Archimedean spiral was a significant contribution to broad-band antennas and the work of Turner[8] on this antenna preceded that on the log-spirals at Illinois. However, there are basic differences in the Archimedean and log-spiral structures and in their characteristics, such as radiating efficiency and ultimate bandwidth capabilities. To loosely group all spiral antennas together and assume that the characteristics associated with one type are automatically to be found in the other can lead to erroneous conclusions.

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Rebuttal

Naturally, we were quite interested in Mayes and Dyson's letter on the difference between the equiangular and Archimedean spiral antennas, and we appreciate their calling our attention to a controversial statement in our paper.[1] We implied that, except for diameter, the Archimedean spiral is *completely described* by angles, and hence belongs to the class of so-called frequency-independent antennas. We are afraid, however, that some of the remarks in the correspondences cannot pass unanswered, and we should like to comment on three points:

1) the statement in our paper,
2) the meaning of frequency independent antennas, and
3) the comparative data given in the correspondence.

As the note so aptly points out, the Archimedean spiral is *not specified* by any one angle. In fact, had this spiral been capable of such a description, namely, that the angle between position vector and the tangent to any point on the curve is constant, Archimedes himself would probably have called it the equiangular spiral. We do admit, and apologize, for a poor choice of words, but hasten to add that there is a distinct difference between the statement as we made it, and the statement attributed to us in the correspondence; the words "specify" and "describe" are not synonymous, in either the vernacular or the mathematical sense.

With respect to our having included the planar Archimedean spiral in the class of frequency-independent antennas, Mayes and Dyson's comments are far more apropos. There is, indeed, widespread confusion about the term "frequency-independent antennas." For our part, there is no confusion; a frequency-independent antenna is just that—none of its characteristics exhibit *any* change with frequency. It is indeed unfortunate that the term was applied to a physical structure in the first place. The confusion stems entirely from the fact that many authors have associated the term "frequency-independent antenna" with the fact that the *characteristics* of the antenna are frequency-independent, and with a *geometry* which *theoretically* gives rise to an antenna which has frequency-independent characteristics. The two descriptions are not the same.

Mayes and Dyson properly point out that, in contrast to the equiangular spiral, the angle α between the position and tangent vectors for Archimedean spiral is a function of position on the curve. However, they go on to say that "this difference in the two spiral curves is the principal reason why an Archimedean spiral antenna must have many closely spaced turns to operate successfully, while planar log-spiral antennas can be constructed with only $1\frac{1}{2}$ to 2 turns in a relatively loose spiral." With respect to the effect of α on the characteristics of log-spirals, we quote from Dyson's paper,[5] in which he states that ". . . the more tightly spiraled antennas, and the antennas with wider arms, tend to have smoother and more uniform patterns." He later states, with reference to a particular antenna: "the variation in beamwidth is held within 4 degrees by antenna reorientation when the frequency is varied from 2 to 5.18 kMc . . . compared with the variation of approximately 50 degrees over the same band of frequencies without reorientation." In other words, for pattern or rotational symmetry corresponding to small beamwidth variations *without reorientation*, the log-spiral *must* be tightly wound—a conclusion quite analogous to that made for the Archimedean spiral.

Mayes and Dyson go on to say that in order to point out the difference between the two spirals, it is necessary to magnify the changing α of the Archimedean curve, and proceed to illustrate their point by constructing spirals on a conical surface. Now in our opinion, conclusions drawn from the conical surface are *not* directly applicable to the planar case in question. The data shown in Fig. 3 of the correspondence are of little value in the absence of further qualifications; and even if suitably qualified, they might have little bearing on the more appropriate comparison based on planar spirals.

To illustrate what can be done with planar Archimedean spirals, we call your attention to Figs. 4 and 5 which show actual

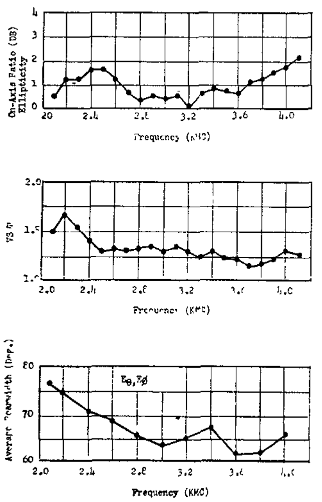

Fig. 4—Typical spiral antenna characteristics.

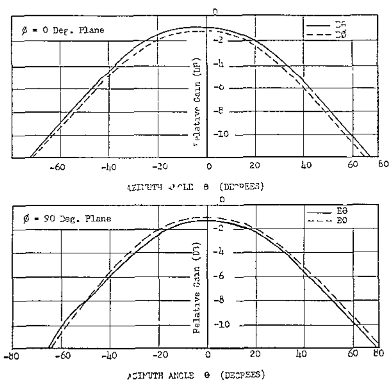

Fig. 5—Spiral antenna radiation patterns at 2800 Mc.

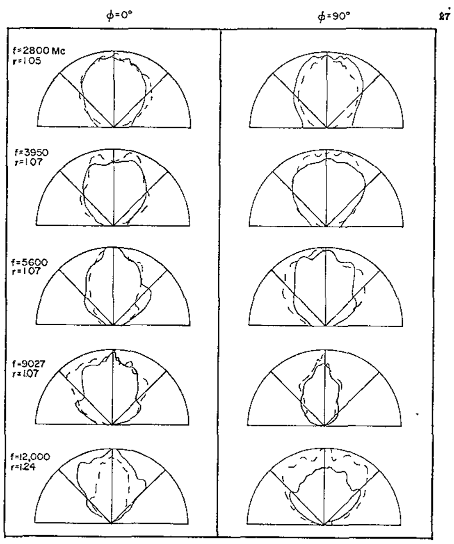

Fig. 6—Radiation patterns of antenna 2M15-C. $a=0.30$; $K=0.62$, solid line indicates E_θ; dashed line indicates E_ϕ.

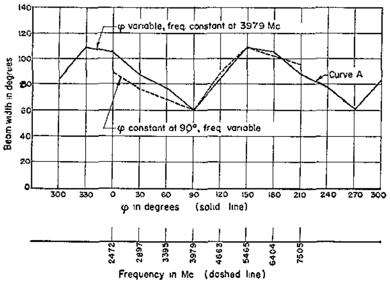

Fig. 7—Rotation of radiated field with a change in frequency (antenna M-10-3 slot length, 33 cm).

[8] E. M. Turner, "Sprial slot antenna," Wright Air Dev. Ctr., Wright-Patterson AFB, Ohio, Tech. Note WCLR-55-8; June, 1955.

data[9] taken on a cavity-backed Archimedean spiral; these data are typical of what has been observed on similar units over the frequency range from 200 through 5000 Mc. The antenna shown is *not* frequency-independent, although its characteristics might easily be termed "broad-band."

In contrast, data obtained by Dyson[5] for a bidirectional, planar, equiangular spiral antenna (no cavity) are reproduced in Figs. 6 and 7. These are the antennas which Dyson and others have called "frequency-independent." The fact is, any antenna whose pattern is asymmetrical and rotates with frequency or which yields data as shown above, is simply not frequency-independent (with *or* without quotes).

To continue to describe the equiangular spiral antenna as frequency-independent may not lead to erroneous conclusions, but will consistently and continually lead to confusion.

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[9] R. Bawer and J. J. Wolfe, "The spiral antenna," 1960 IRE International Convention Record, pt. 1, pp. 84–95;

A Further Note on the Equiangular and Archimedes Spiral Antennas

The intent of the original note was to point out basic differences between the two types of spiral antennas and that, although they have many similar characteristics, conclusions reached about one of the types do not necessarily apply to the other.

In regard to the "rebuttal" by Bawer and Wolfe to the note, we would like to make only four short comments:

1) The pattern rotation of the equiangular spiral antenna has been adequately covered in paragraph two and in our references.[2,4–6] In fact, the graph which Bawer and Wolfe reproduce as Fig. 7 was originally chosen and published[5] to point out this fact.
2) On the plane or on the cone the angle α, the angle between the position vector and a tangent to the curve, is a constant parameter for the equiangular spiral and a changing parameter for the Archimedes spiral.
3) The objection to the use of the term "frequency independent" as applying to *any* physical structure has some merit. However the logarithmic (*i.e.*, equiangular) spiral antennas are certainly in a class apart from the structures normally associated with the term broad band as it has been used over the years. Further, the conical logarithmic spiral has many characteristics which *are* essentially frequency independent over bandwidths which are limited only by practicality of construction and not by any basic parameter of the spiral.

   A new term is required which conveys the idea that the bandwidth, over which pattern and impedance characteristics of an antenna are essentially constant, is theoretically unlimited. We, and others, have been using the term "frequency-independent" in this sense for several years. Perhaps this question of terminology should be decided by an IRE Standards Committee.
4) Bawer and Wolfe need not have felt that they must defend the Archimedes spiral antenna. As we indicated in the final paragraph of our original note, it is an excellent antenna for many applications.

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