A NEW BICONICAL ANTENNA FOR USE IN THE FREQUENCY RANGE OF 175 TO 1000 MEGAHERTZ

The traditional biconical antenna, which was used in EMC activities for many years, covers the frequency range from 30 to 200 MHz. While not perfect, this antenna has given satisfactory results in many EMC areas. This article introduces a new type of biconical antenna which offers broadband omnidirectional performance with accurately known VSWR and antenna factors. A set of two such antennas covers the range from 175 to 1000 MHz. It is also capable of handling approximately 100 watts for generating strong RF fields for use in susceptibility studies. These new antennas are lightweight, durable, and extremely convenient to mount and use. This article describes their construction and performance[1].

THE NATURE OF THE BICONICAL ANTENNA

The implementation of the biconical antenna requires a detailed examination of the behavior of a dual cone antenna and the methods for matching it to coaxial line, which covers the following topics:

The feedpoint impedance behavior of the biconical antenna as a function of the cone angle;

The impedance of the antenna as a function of its length;

The gain and directivity of the antenna as a function of length; and

The type of balun to use for matching the naturally balanced biconical antenna to the unbalanced coaxial lines used with EMC measuring equipment.

The biconical shape offers some unique properties for an antenna. It is well known that as one progresses from dipole antennas composed of "thin" elements to antennas made of "fat" elements, the antennas act more broadband — that is, resonance becomes less sharp. In fact, a problem of considerable interest in antenna theory some 40 years ago was the calculation of the exact characteristics of "fat" dipole antennas of varying shapes such as cylinders, spheroids, ellipsoids and cones. Extensive experimental data was generated, and for some of the more mathematically tractable shapes, exact closed form solutions were generated.

Although the biconic was not amenable to an exact closed form solution for large cone angles, (θ in Figures 1 and 2), it was found experimentally that the biconic antenna was unique in the type of resonance behavior it exhibited at wide cone angles. The antenna presents a nearly constant impedance at its input terminals between the cones over an extremely wide frequency range above a well defined lower frequency determined by the cone size (r in Figure 2). The value of this impedance is determined by the cone angle. Below the cutoff frequency the antenna impedance becomes highly reactive and the VSWR climbs dramatically. Below cutoff, the biconic does not function as a biconic — it is just a short, fat antenna. Figures 1 and 2 illustrate this behavior.

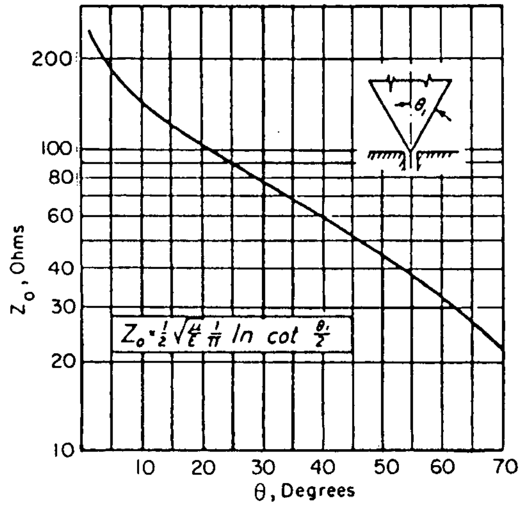


Figure 1. Computed resonance impedance of a conical monopole antenna. Doubling these figures yields the biconic dipole impedance. Impedance ripples about this value.

The directivity pattern of the biconic is also important. It is well known that a long (untuned) dipole antenna exhibits sharp nulls in its pattern which vary with its electrical length (or equivalently, with frequency). Sharp changes in directivity with frequency are extremely undesirable in a measuring antenna. An antenna is desired which will come close to a tuned dipole's pattern. Nulls which line up with either direct or reflected components of the signal to be measured will introduce large measurement error. The biconic is very well behaved in this respect. Although nulls eventually appear in the antenna pattern as the antenna becomes electrically long, the ratio from the cutoff frequency at the low end to the point where this occurs is approximately a factor of 8, bracketing the range over which the antenna is useful. Inside this range, the biconic's gain pattern is very similar to the familiar figure eight pattern of the tuned half wave dipole. There is very little change in gain with direction until one is nearly "end-on". This mild change in directivity with the length of the biconic elements is in sharp contrast to the changes in directivity that thin long wire antennas exhibit. Figure 3 shows the radiation patterns of both biconic and thin wire dipole antennas as a function of the length (expressed in wavelengths) of each element. It should be noted that the chosen antenna cone size does not exhibit unusual lobing behavior within the range from 175 to 1000 MHz.

[1]These antennas are part of a three biconic set covering 30 to 1000 MHz. The lower frequency antenna is of traditional construction, as shown in Figure 4.

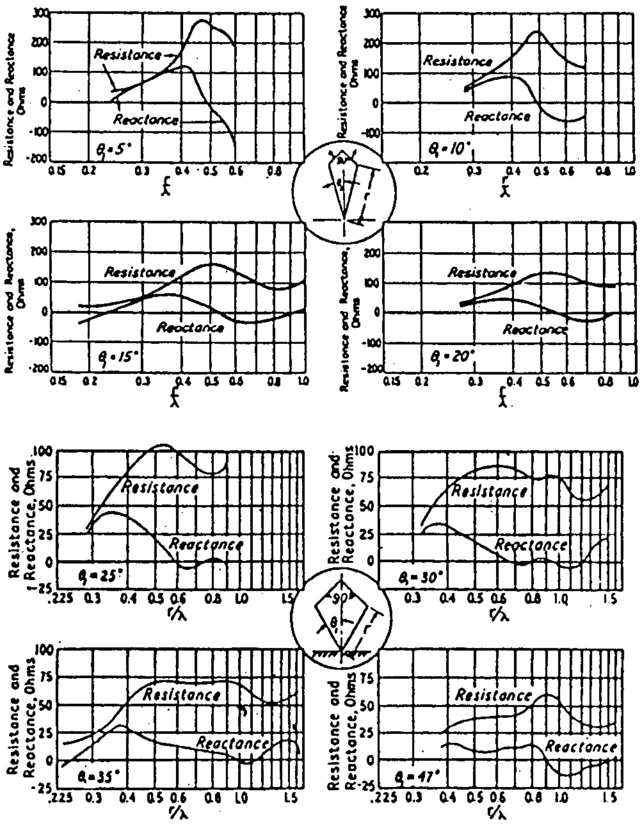


Figure 2. Experimentally measured input resistance and reactance of single cone antennas as a function of cone angle. Biconic values are twice the value. (The "cap" construction is not critical. Experimental measurement of triangularly capped, spherically capped and uncapped biconic antennas has shown that the cap shape changes the effective length of the antenna but does not significantly affect the general shape of the input impedance curve, merely resulting in a slight shift of the curves to the left or right.) The antennas described in this article use uncapped cones with a half-angle of 35 degrees.

VHF BROADBAND TYPES — BICONIC vs LOG PERIODIC vs LOG SPIRAL

Unlike the higher gain, and therefore more directional log periodic antenna usually used from 200 to 1000 MHz, the high frequency biconics described here pick up both direct and ground reflected signals at essentially full strength. Great asymmetry in response to these components, common with log periodics, and due to high directivity (antenna gain) can affect the accuracy of measurements taken especially at the common measurement distance of 3 meters.

Unlike biconics, log periodic antennas have a pattern of directionality much like a dipole antenna in the plane parallel to the plane of the antenna, but have a sharply defined pattern in the plane perpendicular to it. If the direct or reflected wave strikes the antenna at a wide angle in this plane, measurements will be in error. For this reason, the biconic antenna is preferred where the antenna is placed at relatively short distances from the EUT.

Log spiral antennas, by virtue of their circular polarization, are not permitted for use under commercial measurement standards. (See ANSI C63.4, FCC Measurement Procedure MP-4, VDE 0871/0875).

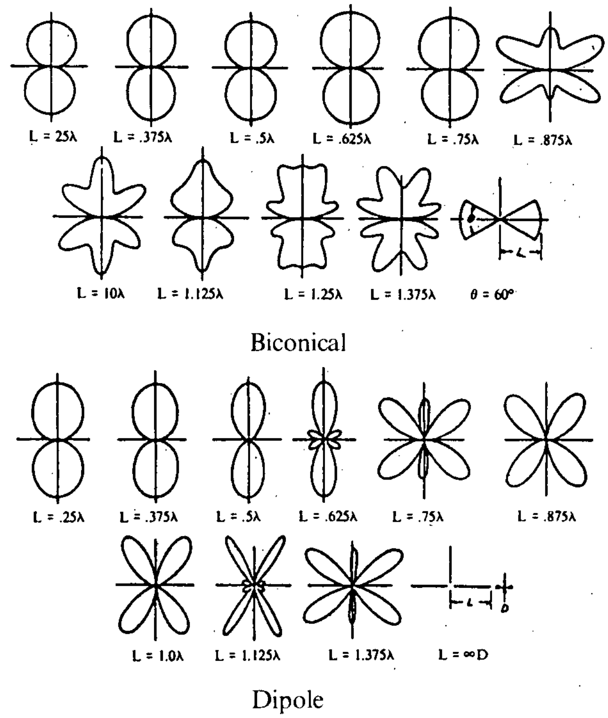


Figure 3. Measured radiation patterns of biconical and long thin wire dipole antennas, shown schematically on a linear scale. For the antenna design discussed in this article, L = 10″, resulting in an electrical size variation of .15 to .76 wavelengths over the 175 to 1000 MHz range of the antenna. Note that the antenna pattern does not exhibit any significant lobing.

THE BALUN

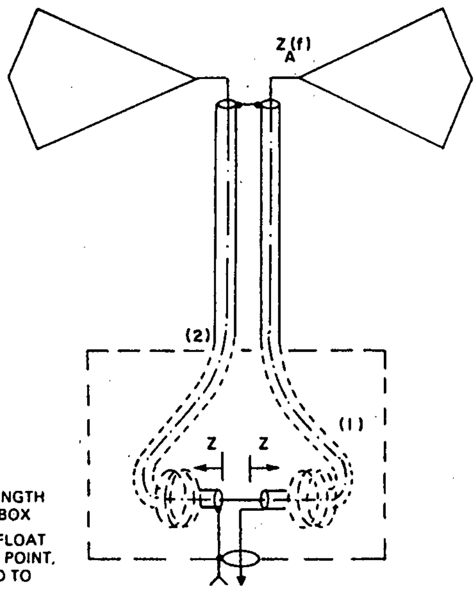
The above information pertains to the behavior of the balanced biconical antenna consisting of two collinear cones. To use this antenna with unbalanced coaxial lines, a balun transformation must be effected from the balanced cones to the unbalanced coaxial line. Several baluns types are possible.

A ferrite transformer type balun. This type of balun is used, for example, in the balanced to unbalanced adapters found on today's television sets. This balun was rejected because:

in the 200 to 1000 MHz range, losses due to material heating are difficult to avoid;

winding spacing and connecting lead length would have to be critically controlled to prevent mechanical construction variability from producing large impedance variations; and

power handling capability would be limited, preventing the dual use of this antenna for reception and high field generation in susceptibility studies.



NOTES:

(1) EXTRA BALUN LENGTH COILED IN BASE BOX

(2) SOME DESIGNS FLOAT SHIELDS AT THIS POINT, OTHERS GROUND TO BASE BOX

(3) IMPEDANCE Z IS

$$Z = \frac{Z_A(f)\cosh\theta + Z_o \sinh\theta}{\cosh\theta + \sinh\theta}$$, where θ IS ELECTRICAL LINE LENGTH, $Z_A(f)$ IS SINGLE CONE IMPEDANCE, SHUNT REACTANCES ARE NEGLECTED

Figure 4. Secrets of the "old biconic antenna". The biconical antenna widely used in EMI measurements below 200 MHz is composed of a wide range voltage divider balun and two conical cage elements.

A coaxial voltage divider balun of the type used on the familiar low frequency biconic antenna. This type of balun can be used over an extremely wide frequency range, usually in excess of 8:1, but provides a match — or mismatch — whose value varies cyclically with frequency. See Figure 4, "Secrets of The Old Biconical". The biconical antenna widely used in EMI measurements below 200 MHz is composed of a wide range voltage divider balun and two conical cage elements. The cage has a half angle of 30 degrees and is generally about 25″ long, and is therefore too short to act as a true biconical antenna below 60 to 65 MHz. At lower frequencies, this is a short, fat antenna, with an impedance consisting of a small resistive component and a large capacitive reactance. It is operating below the cutoff frequency. This accounts for its VSWR greater than 15:1 and antenna factors approaching 15dB. The balun used with this antenna is essentially a voltage divider. The impedance placed across the coaxial line is twice that seen looking into each coaxial section. To see why the transformation offered by this balun must vary cyclically with frequency, it must be noted that the impedance seen looking into each coaxial section will vary cyclically with frequency unless the impedance each coaxial line "sees" matches the coaxial line characteristic impedance. For an ideal biconic antenna of 30 degrees half angle, each cone would present an 80 ohm impedance, so a cyclically varying mismatch results at higher frequencies. This behavior is shown in Figure 8.

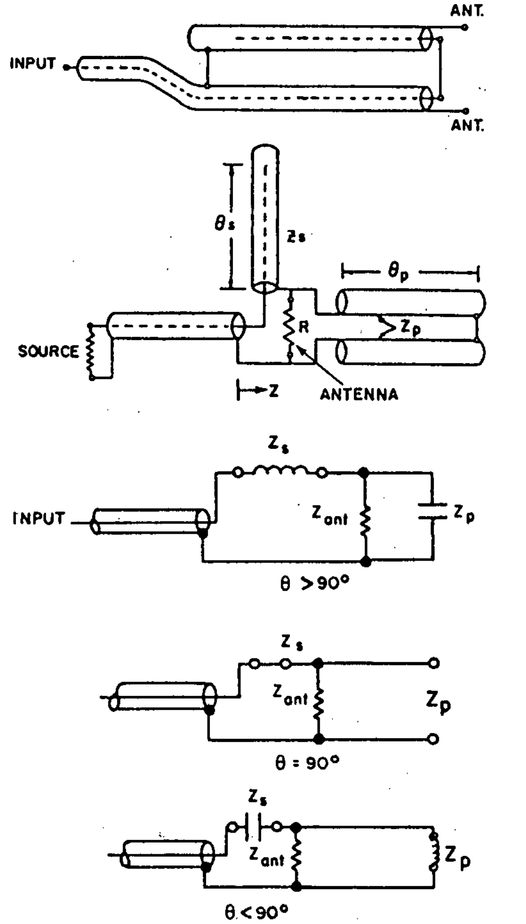


Figure 5. The Roberts balun is a series-parallel stub tuned balanced-to-unbalanced impedance transformer.

A Roberts type balun,* which is a series-parallel balun composed of coaxial sections. This balun is used by the FCC to provide an accurate match to tuned dipole antennas. (See ITEM 1984, "Inside the FCC; A Look At How The FCC Tests For Computing Equipment Compliance," by G. Dash, pg. 109). See Figure 5. The physical balun construction is shown, along with an equivalent circuit.

*Roberts Balun is a trademark of Compliance Design, Inc.

The shorted balanced line and the open coaxial sections appear in parallel and series with the load, respectively. The parallel section forces the load to be fed in a balanced manner. Although the use of a parallel shorted stub alone will effect a balanced to unbalanced transformation, it will only do so over the narrow range where the stub presents a high impedance. The combined action of the series open and parallel shorted stubs extends the range of approximate match. The two matching stubs are tuned to 1/4 wavelength at the middle of the frequency band to be matched. The open series coaxial stub looks like a short circuit at resonance, while the parallel shorted balanced line looks like an open circuit. Equations for the stub impedances are shown below:

Series Stub $Zs = -j\ ZoCot\ \theta s$ where θ = electrical length,
Parallel Stub $Zp = j\ Zp\ Tan\ \theta p$ Zo, Zp = coax and balanced line characteristic impedance

To see how compensation occurs, assume that θ is slightly above 90 degrees, corresponding to a frequency slightly above stub resonance. Then Zs will be a positive, or a small inductive reactance, while Zp will be a small (high impedance) capacitive reactance. The lag introduced by Zs is nearly cancelled by the lead produced by Zp. At frequencies below resonance, the roles of the stubs are reversed. This compensation works well over a frequency range of nearly 3 to 1. Dipoles using this balun exhibit a 1.5:1 or better VSWR.

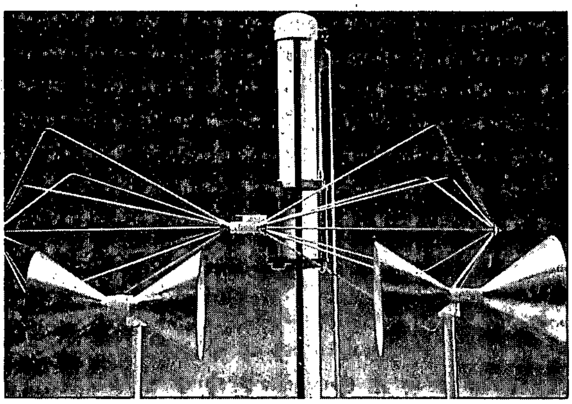


Figure 6. Portrait of a biconic family. The two high frequency antennas have the solid cones. The baluns are built into their support tubes. The low frequency antenna is of the traditional design shown in Figure 4.

The Roberts balun is often used because of its performance when connected to the constant impedance of a tuned dipole. Relatively constant impedance without element tuning is the property which makes the biconic structure unique. Although this limits the range of each antenna to slightly under 3:1, it avoids the problems of the other two baluns. Figure 6 shows the construction of two antennas designed to cover the ranges of 175 to 425 MHz and 375 to 1000 MHz. The cones are made of spun metal with welded studs. Each cone is approximately 10 inches along the side, with a cone angle of 70 degrees. The Roberts balun is housed inside the reinforced antenna rod. The performance of the antennas is shown in Figure 7. In reviewing these figures, several things should be noted.

The antenna factors were derived by substitution against a set of Roberts dipole antennas using the method outlined in U.S. Government Memorandum, "ANSI/FCC Site Attenuation," dated August 18, 1983. A dipole-dipole transmitting-receiving antenna setup was established over a ground plane at an open field test site, and the biconic substituted for the receiving antenna. The difference between the signal received with the biconic and the dipole was added to the dipole antenna factor to establish the antenna factor for the biconic. Note that these antennas track the gain pattern of the dipole very well. The deviations that occur in antenna factor between the two antenna types are due to differences in matching and to the slight differences in the directivity patterns of

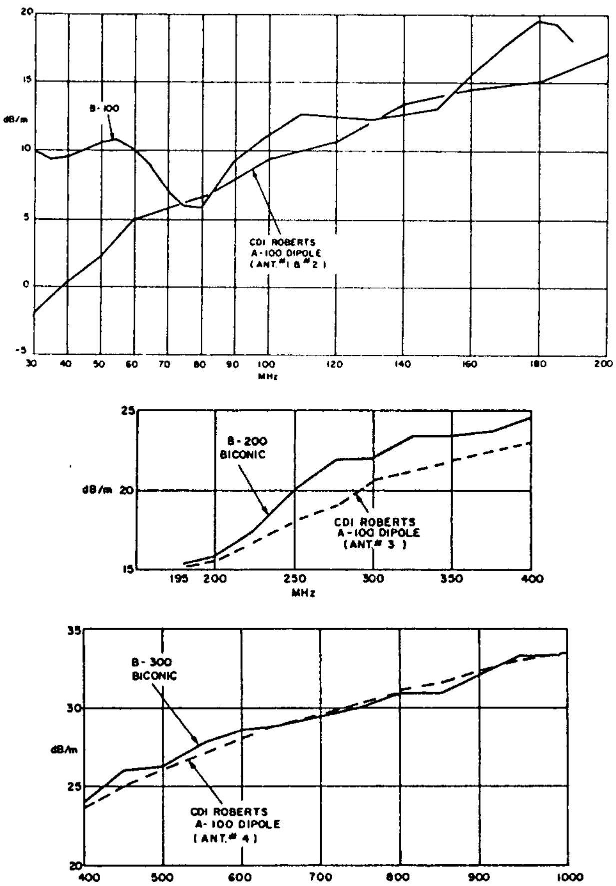


Figure 7. Performance of a biconic antenna family. The two lower curves are for the biconics described in this article. The upper curve is for a MIL type low frequency biconic. All antenna factors are plotted against those for a Roberts Dipole set.

the cones versus the dipole elements. Also shown is the antenna factor of a low frequency biconic of traditional design.

The VSWR was also measured to yield the results shown in Figure 8. The 175 to 425 MHz antenna exhibits a moderate but fairly constant VSWR, which can be padded to a very low level with a 3 or 6dB pad. The 375 to 1000 MHz antenna exhibits low VSWR over its entire range without the need for any padding at all. The VSWR and antenna factor are much better behaved than for a low frequency biconic of traditional MIL-STD-461 construction, which is also shown.

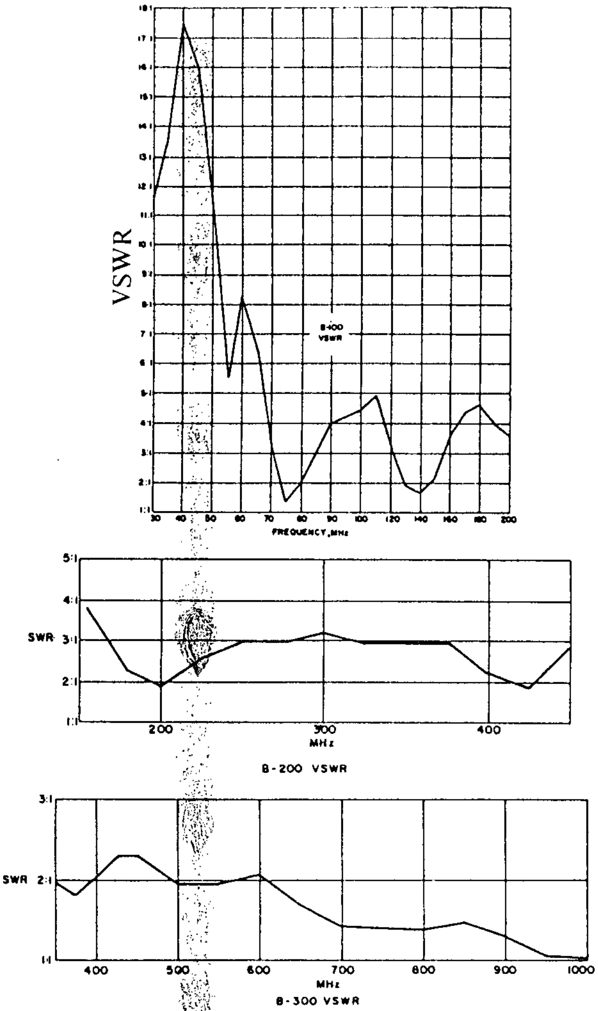


Figure 8. Measured VSWR of biconic antennas. Note the fluctuations of the low frequency biconic (upper graph) below cutoff, and the ripples due to its voltage divider balun. The lower two curves are for the antennas described in this article.

On the 175 to 425 MHz antenna, the cone size is a little short with respect to the wavelengths of operation. This puts the inherent antenna performance slightly above the low frequency cutoff discussed in Figure 2, and accounts for the higher VSWR. This compromise was accepted for practical reasons. Preliminary experiments showed that in this frequency range, the solid cone shape performed better than the wire cage commonly used at lower frequency. However, a solid cone soon becomes heavy in use and non-portable if it is made much larger than its present size. Portability considerations also limit the practical cone angle size.

On the higher frequency antenna (400 to 1000 MHz), on the other hand, the cones are long enough for near ideal biconic behavior. Special attention was given to the terminating bushing shape to maintain the cone apex near the feed point. Both antennas perform much better than the more familiar 30 to 200 MHz biconic.

SUMMARY

This article has presented the construction of a novel and useful new biconical antenna design. The antenna combines the performance of a Roberts balun match with the convenience of a broadband antenna. It is light in weight and offers an omnidirectional radiation pattern. This combination of features suits it to use under both manual and automated test conditions.

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