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THE USE OF THE FAST FOURIER TRANSFORM IN THE SYNTHESIS AND ANALYSIS OF SMALL SUPERDIRECTIVE ANTENNAS

James R. McDougal, Assistant Professor
School of Electrical Engineering
Oklahoma State University
Stillwater, Oklahoma 74074 U.S.A.

SUMMARY

In many applications, the antenna engineer is compelled to design antennas which are small in terms of wavelength. This is especially true in the case of the use of low frequencies on aircraft. Examples of applications which necessitate the use of small antennas on aircraft include weather research and military reconnaissance. In such cases, the frequency being set by that which is to be observed and the antenna dimensions by those which are aerodynamically feasible, both the frequency range and allowable antenna dimensions are set by conditions entirely outside the engineer's control. It is often the case that a degree of radiation pattern control is required. This leads directly to a consideration of the design of a "superdirective" antenna.

The system is frequently "one of a kind", and the installation of the antenna often requires considerable modification of the aircraft. It is obvious that a good estimate of performance is required in the early stages of design long before actual construction is contemplated. This is notoriously difficult in the case of small superdirective designs. This paper treats the theory and design of superdirective small linear antennas by computer aided methods. First, a particularly efficient means of using the classical Fourier Integral to compute designated far-field radiation patterns has been developed elsewhere.[1] Many authors have suggested that this computation also gives insight into the relative near-field energy storage associated with a particular distribution function and therefore gives a measure of the anticipated bandwidth.[2] Then, the Fast Fourier Transform is adapted to the Fourier Integral method in order to provide a fast and efficient means of computation.[3] This development is summarized as follows:

It is well known that the far-field solution of a linear antenna may be written

$$E_\theta = jZo\ \sin\theta \frac{e^{-j\beta R}}{4\pi R} \int_{\ell}^{\ell} I(z) e^{j\beta Z\cos\theta} dZ. \quad (1)$$

Let $\ell = a\lambda$, $x = z/\ell$ and $u = 2\pi a\cos\theta$. We may now express the current distribution as a function of the new variable x. Write $I(x) = I_o\bar{F}(x)$ where $\bar{F}(x)$ is the complex normalized distribution function. Equation (1) becomes

$$E = ja\frac{ZoIo}{2}\frac{e^{-j\beta R}}{r}\sqrt{1-(u/2a\pi)^2}\int_{-1}^{1}\bar{F}(x)e^{jux}dx, \quad (2)$$

where the integration is now expressed in terms of a Fourier Integral taken over normalized limits. One of the especially beneficial features of this method is that the phase length of the distribution remains arbitrary until after the integration is performed. One may then select in a very visual way the phase length for a given $\bar{F}(x)$ which gives the desired E_θ.

Using strictly analytical techniques one is limited to somewhat fictitious distributions in performing the integration of equation (2). The Fast Fourier Transform provides an efficient method of accomplishing this end. The method is based on the fact that the magnitudes of the coefficients of the complex Fourier Series approach the envelope of the magnitude of the Fourier Integral in the limit of the interval of periodicity becoming infinite. The Fast Fourier Transform is used to approximate this limit. Of course, one may reserve

only a finite interval in the memory of the computer. The limit must be approximated in actual computation by keeping the ratio of the number of points with defined non-zero values to the total number of points reserved in the field sufficiently small. A field of 1,028 points was reserved in memory for the results shown in Figure 1. Only 100 points were entered as data points. As shown, this results in about 120 points of useful output.

Figure 1 shows the results of computations using the methods described above. Diagram (1) shows an ideal distribution which for phase lengths less than or equal to $\lambda/2$ will produce greater than normal directive gain. Here, we define normal gain to be that obtained from a distribution of constant amplitude and phase and of the same phase length. Diagram (2) shows a less ideal version of this superdirective distribution, as one might realize in practice. The appropriate curves in the figure show the results of computing the integral for these distribution functions. Note that a phase length $\lambda/2$ appears slightly before point 10 on the abscissa of the graph. The unlabeled curve shows the computation for a normal distribution. Comparison between the three curves makes it obvious that the area under the complex portion of the curves is very much greater for the superdirective distributions, corresponding to an enormous increase in near-field stored energy and consequent narrow bandwidth. Diagram (3) shows a distribution function which will produce a broader than normal pattern. Diagram (4) shows a less ideal version as one might realize in practice. Again, the computed results indicate large amounts of near-field stored energy for short phase lengths. The effect of making the distribution less ideal is seen to narrow the width of the computed far-field pattern.

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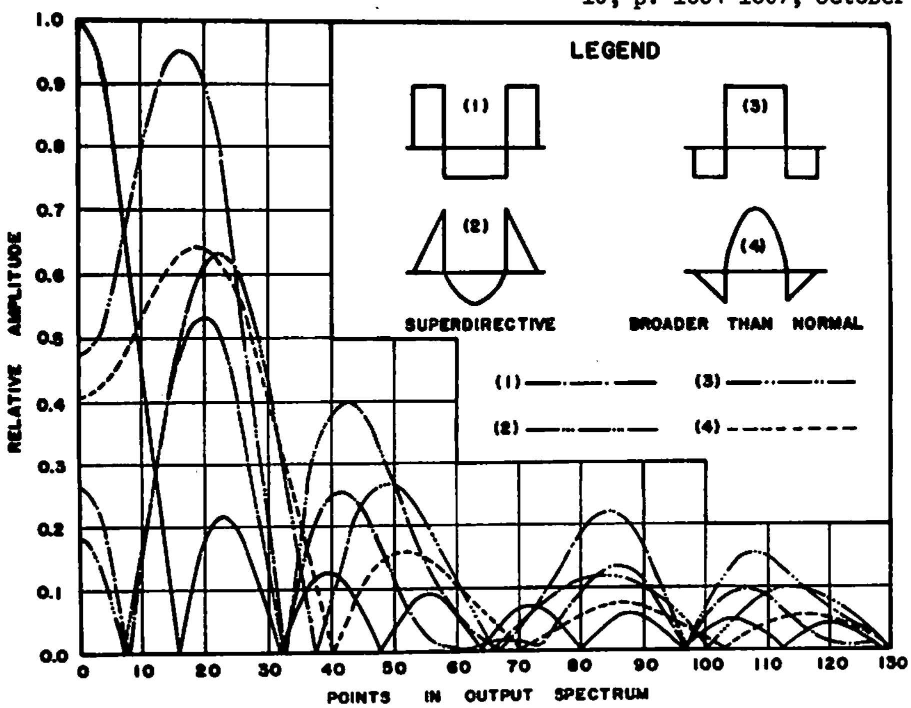

Figure 1: Approximations to the Fourier Integral computed by means of the Fast Fourier Transform for a series of superdirective distributions.