A—11—1 ELECTRICALLY SMALL ANTENNA STUDIES AT OSU

by

C. H. Walter

The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

INTRODUCTION

This paper describes work at The Ohio State University on studies related to electrically small antennas. The scope of the work includes efficiency measurements, effects of nearby bodies and electrically small arrays.

EFFICIENCY MEASURING TECHNIQUES

The pattern integration and gain comparison methods usually provide reliable methods for measuring antenna efficiency but the time required may be prohibitive when a parameter study is to be made in order to optimize the antenna in some way. Thus other experimental techniques have been explored and two of these, the Wheeler Cap Method and the Q Method, have been found to be quite useful for rapid parametric studies.

A. Wheeler Cap Method

If we define R_R to be the antenna radiation resistance and R_L the antenna loss resistance, the quantity R_R+R_L may be determined by measuring the antenna input impedance. Wheeler[1] suggests that enclosing the antenna with a conducting sphere a radian length (about one-sixth wavelength) in radius will eliminate R_R from the input impedance without significantly changing R_L. This assumes that the conducting sphere causes no change in the current distribution on the antenna. If this assumption is corect, the real part of the input impedance with the sphere in place will be R_L. Thus by making two impedance measurements, one without the sphere and one with the sphere in place, the antenna efficiency can be determined using the relation

$$(1) \qquad E_W = \frac{R_R}{R_R+R_L}$$

B. The Q Factor Method

A second method for measuring antenna efficiency is based on a comparison of measured to ideal Q. The Q of a realizable antenna is defined as

$$(2) \qquad Q_{RL} = \frac{\omega \text{ x peak energy stored}}{\text{average power radiated + average power dissipated}}$$

and the Q of the ideal, lossless antenna is

---

*The work reported in this paper was supported in part by Contract N00014-78-C-0049 between the Associate Joint Services Electronics Program and The Ohio State University Research Foundation.

(3) $$Q_R = \frac{\omega \times \text{peak energy stored}}{\text{average power radiated}}$$

If the current distributions on the realizable and on the ideal antenna are considered to be the same, then the stored energies will also be the same, and the efficiency of the realizable antenna is simply the ratio

(4) $$E_Q = \frac{Q_{RL}}{Q_R} = \frac{\text{power radiated}}{\text{power radiated} + \text{power dissipated}}$$

Q_{RL} can be determined by measuring the impedance bandwidth of the actual antenna. Q_R for the ideal lossless antenna can be found from the results of Chu[2] and Harrington[3] where the antenna is considered to radiate a number of spherical waveguide modes emanating from a spherical surface surrounding the antenna. The solid curve of Figure 1 shows the ideal Q_R of an antenna which can be enclosed by a sphere of minimum radius a, and which radiated the TM_{01} mode only. The dashed curve in Figure 1 is the ideal Q_R of an antenna which radiated equal amounts of the TE_{01} and TM_{01} modes.

A comparison of efficiencies by the Wheeler and Q methods is shown in Table I. In this set of measurements five multiturn loop (MTL) antennas, each with a different number of turns, were made from No. 18 tin-coated copper wire. For each MTL, Table I lists the number of turns in the loop (N), 2π times the radius a in wavelengths of the smallest sphere which could completely enclose the MTL and its feed and matching capacitors, the Wheeler efficiency, and the Q efficiency. Table I shows that for ka $\leq$ 0.156 the Wheeler method and the Q method yield approximately the same efficiency. For larger ka the antenna can radiate significant amounts of higher order modes, and the methods for choosing the radius a and the modal distribution fail, and thus the Q method fails as used here since only the dominant mode is assumed to exist. In Table I this is illustrated by a Q efficiency of 122 percent for ka = 0.286.

TABLE I
A COMPARISON OF WHEELER AND Q EFFICIENCY
FOR VARIOUS SIZE MTL

N	ka	E_W (percent)	E_Q (percent)
6	0.056	6	4
4	0.076	10	12
3	0.118	26	34
2	0.156	46	47
1	0.286	84	122

ELECTRICALLY SMALL RADIATING ELEMENTS

An electrically small antenna is an antenna whose maximum dimension is much less than the wavelength Electrically small antennas are generally categorized as either capacitive or inductive although many practical small antennas are some combination of the two types. The categorization is done on the basis that the antenna is principally an electric or magnetic element. Of these two basic types the electric element can be considered to be the most fundamental since the loop, or in general any wire antenna, can be constructed from a superposition of electric elements.

Some examples of small electric dipole or capacitive antennas are given in Figure 2 and some examples of small loop or inductive antennas are given in Figure 3.

The representation of a small antenna by means of a capacitor or inductor is a convenient application of lumped circuit concepts to antennas and is a justifiable approximation for many small antennas. Many successful antennas, particularly for VLF-HF applications, have been developed on this basis and a good summary of capacitive and inductive antennas has been given by Wheeler[4]. However, modern high-speed digital computers now enable the antenna engineer to analyze, with almost any degree of accuracy, small antennas of arbitrary shape such as those shown in Figures 2 and 3.

EFFECTS OF NEARBY BODIES

An interesting example of a small antenna coupling to a nearby structure is shown in Figure 4. This is the case of a small, single turn loop $\lambda/100$ on a side which in free space has an efficiency of about 7%. When near a $\lambda/2$ length of conductor, the efficiency is dramatically increased by virtue of coupling to and radiation from the nearby structure. The point here is that even though the efficiency of a small antenna may be low, when it is mounted on or near a practical structure such as a plane it can couple to modes on the structure which greatly increases the radiation efficiency.

A present study is devoted to determining the characteristic modes of an arbitrary body such that these modes may be selectively excited by a small antenna to make the antenna and body radiate more efficiently or with more desirable radiation patterns than the small antenna by itself. Arrays of small antennas on the body may be used to obtain even more desirable radiation characteristics than from a single small antenna. The body may be metal, dielectric, ferrite or some combination.

ELECTRICALLY SMALL ARRAYS

In the HF region and below, where the background noise is the dominant noise source and it is more or less uniformly distributed in space, the SNR is proportional to the directive gain in the direction of the incident signal. Thus, the SNR is optimized by optimizing the directive gain and achieving superdirectivity. A study has been made to show that superdirective arrays with practical tolerances and sidelobes can be obtained. This is done by including a tolerance and a sidelobe constraint in the directive gain optimization procedure.

REFERENCES

1. H. A. Wheeler, "The radiansphere around a small antenna," Proc. IRE, pp. 1325-1331, August 1959.

2. L. J. Chu, "Physical limitations of omni-directional antennas," J.A.P., vol. 19, pp. 1163-1175, December 1948.

3. R. G. Harrington, Time Harmonic Electromagnetic Fields, New York; McGraw-Hill, pp. 264-316, 1961.

4. H. A. Wheeler, "Fundamental limitations of small antennas," Proc. IRE, pp. 1479-1488, December 1947.

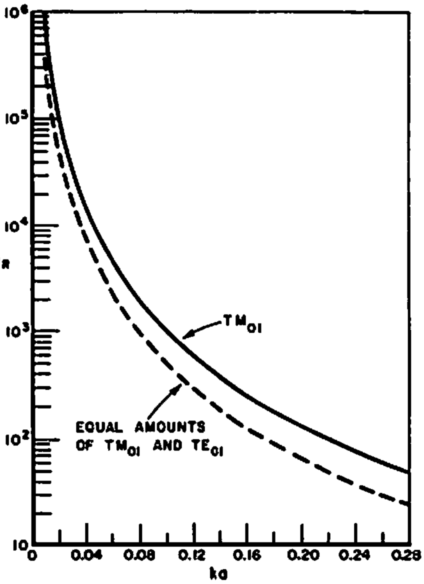

Figure 1. Theoretical ideal Q as function of $2\pi a/\lambda$.

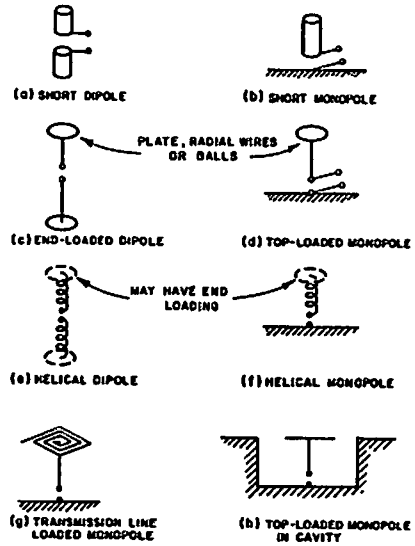

Figure 2. Examples of small electric dipole or capacitive antennas.

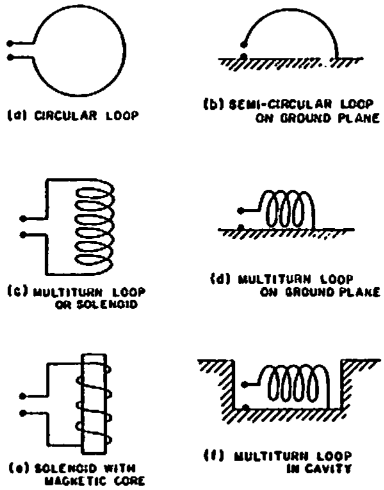

Figure 3. Examples of small magnetic dipole (loop) or inductive antennas.

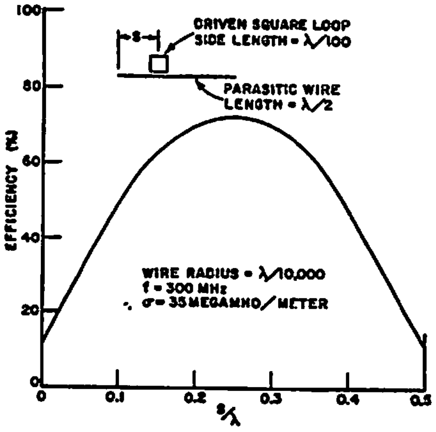

Figure 4. Increased efficiency of a small loop by coupling to a nearby structure.