A Critique and New Concept on Gain Bandwidth Limitation of Omnidirectional Antennas

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It has been well-known and well-established for over half a century that the gain bandwidth of an omnidirectional antenna is fundamentally limited by its electrical size measured in wavelength (Chu, L. J., "Physical Limitations of Omnidirectional Antennas," *J. Appl. Phys.*, Vol. 19, 1948). The theory has been verified and amplified both theoretically and experimentally by many prominent engineer scholars, and is here collectively referred to as the Chu theory. The present paper is to point out the severe shortcomings of the Chu theory and offers a new concept which enables the design of omnidirectional antennas with gain bandwidth exceeding the limitations imposed by the Chu theory.

The severe shortcomings of the Chu theory are rooted in its basic assumptions which are overly narrow and inconsistent with most real-world problems. First, an omnidirectional antenna is rarely an object isolated in space. Its specific size becomes ambiguous when it is mounted on a platform. Second, the problem was formulated overly restrictively (strictly speaking, inadequately) as an antenna with an external matching network, with single-port connections between them and the transceiver. Third, the Chu theory is applicable only to high-Q narrowband antennas, such as the resonant antennas, since the relationship between Q (quality factor) and bandwidth, a key cornerstone of the Chu theory, is valid only for the case of high Q (say, $Q > 4$). Fourth, the unrealistic assumption of zero dissipative loss often ended up with hardware having unexpectedly low efficiency and gain, especially when it is applied to resonant antennas.

The above observations are straightforward, and readily obvious, upon a close examination of the Chu theory. They have also been verified experimentally recently using refined models of the mode-0 SMM (spiral-mode microstrip) antenna (Wang, U.S. Patent #5,508,710, April 16, 1996; U.S. Patent #5,621,422, April 15, 1997). This antenna is a traveling-wave antenna (Wang, *Electromagnetics*, July-Aug, 2000) with good omnidirectional patterns like that of the monopole. It is in the shape of a disk 1.06-inch or 0.09 λ_L in height, and 5.7-inch or 0.48 λ_L in diameter, where λ_L is 11.8 inch, the wavelength at f_L (1 GHz, the low end of the operating frequencies).

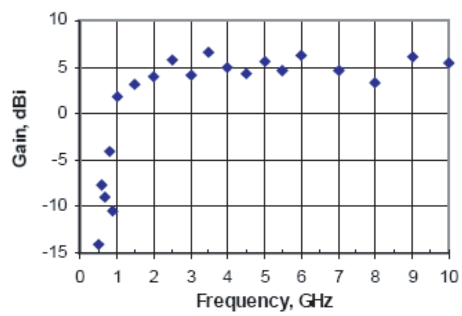

Figure 1: Measured gain of a mode-0 SMM antenna.

Fig.1 shows measured data obtained in WEO's anechoic chamber for this antenna mounted on a ground plane 12-inch in diameter. As can be seen, a 10:1 gain bandwidth (1-10 GHz) with minimum gain of 1 dBi was achieved. The measured gain bandwidth far exceeds the prediction of the Chu theory; this is not surprising since the four assumptions of the Chu theory are invalid for this antenna. Note that a large gain bandwidth exceeding the limitations of the Chu theory can be achieved, as demonstrated here, by circumventing the narrow and often impractical assumptions on which the Chu theory rests.