AP-Session 1, 1010, Tuesday, May 16, Room 1105

TRANSIENTS IN RESISTIVELY LOADED ANTENNAS, AND THEIR COMPARISON WITH CONICAL ANTENNAS AND TEM HORNS

Motohisa Kanda
Electromagnetics Division
National Bureau of Standards
Boulder, Colorado 80302

The receiving and transmitting transient responses for a relatively short, linear antenna with continuous resistive loading are investigated theoretically and experimentally. The antenna considered is a nonconducting cylinder with continuously deposited, varying-conductivity, resistive loading. Its receiving and transmitting transient responses are compared with conical antennas and TEM horns.

The radiated electric field $E_\theta^{rad}(f)$ from a linear antenna at distance r in the far-field region is given by [1]

$$E_\theta^{rad}(f) = j \frac{60\, V_o(f)}{Z_o(f) + Z_g} F(f) \frac{e^{-jkr}}{r}, \qquad (1)$$

where F(f) is the field characteristic of an antenna with an antenna impedance $Z_o(f)$, and $V_o(f)$ is the driving voltage of a generator with an impedance Z_g. When the same antenna is used for receiving, the received voltage $V_L(f)$ across a load impedance Z_L is given by

$$V_L(f) = \frac{-h_e(f) E^{inc}(f) Z_L}{Z_o(f) + Z_L}, \qquad (2)$$

where $E^{inc}(f)$ is an incident field to an antenna with an effective length $h_e(f)$. Here a field characteristic F(f) and an effective length $h_e(f)$ are related through the Rayleigh-Carson reciprocity theorem [1],

$$F(f) = k h_e(f). \qquad (3)$$

Therefore, for the analysis of general transient phenomena in the far-field region, it should be noted that, as will be shown in figures 1 and 2 for receiving transient responses and in figures 3 and 4 for transmitting transient responses, a transmitting transient response is simply the time derivative of a receiving transient response. Next, the effective lengths and the driving point impedances of the resistively loaded antenna and a conical antenna are given.

For the resistively loaded antenna with a resistive loading

$$Z^{i}(z) = \frac{60|\psi|}{h - |z|}\,, \tag{4}$$

where

$$\psi \cong 2[\sinh^{-1}\frac{h}{a} - C(2ka,2kh) - jS(2ka,2kh)] + \frac{j}{kh}(1-e^{-jkh}) \tag{5}$$

and C(a,x) and S(a,x) are the generalized cosine and sine integrals. The effective length $h_e(f)$ and the driving-point impedance $Z_o(f)$ are then given by [2]

$$h_e(f) = \frac{2}{k^2h}(1-jkh-e^{-jkh}) \tag{6}$$

and

$$Z_o(f) = 60\psi(1 - \frac{j}{kh}). \tag{7}$$

The more exact analyses for the electric length and the impedance of the resistively loaded antenna were performed by solving the wave equation using the method of moments. The results are given elsewhere by the author [2].

In comparison to the transient responses of the resistively loaded antenna, a conical antenna and a TEM horn are also investigated. The effective length $h_e(f)$ and the driving point impedance $Z_o(f)$ of a conical antenna have been derived by C.W. Harrison Jr., and C.S. Williams, Jr. [3]. The transients in a TEM horn were analyzed as follows. It is assumed that the horn flare angle and the plate widths are chosen so that the TEM horn guides only the TEM mode by maintaining a constant characteristic impedance. Then, by neglecting the edge diffraction effect, the linearly polarized spherical field at the aperture is assumed to be

$$E_y(x',y',0) = \frac{r_o^2}{\sqrt{r_o^2 + x'^2 + y'^2}} \; \frac{e^{-jk\left(\sqrt{r_o^2+x'^2+y'^2} - r_o\right)}}{\sqrt{r_o^2 + y'^2}}\,. \tag{8}$$

The radiated electromagnetic fields, $E^{rad}(x,y,z)$, outside the aperture are then evaluated by use of the plane-wave spectrum analysis technique. That is, since

$$\overline{S}(k_x,k_y) = \frac{1}{2\pi}\iint_{\text{aperture}} \overline{E}(x',y',0)e^{j(k_x x'+k_y y')}\,dx'\,dy', \tag{9}$$

then

$$\bar{E}^{rad}(x,y,z) = \frac{1}{2\pi} \iint_{-\infty}^{\infty} \bar{S}(k_x,k_y) e^{-j(k_x x+k_y y+k_z z)} \, dk_x \, dk_y \qquad (10)$$

with $k_x^2 + k_y^2 + k_z^2 = k^2 = (\frac{2\pi}{\lambda})^2$. These integrations were carried by use of an FFT algorithm.

Once frequency domain solutions are determined, a final use of the FFT then allows the determination of transient fields for a known input waveform. The experiments were performed by use of a time domain antenna range with a time domain automatic network analyzer. The impulse generator generates extremely narrow (70 ps) duration impulses with flat spectrum amplitudes greater than 60 dBμV/MHz up to 5 GHz. This impulse was used both as a driving voltage for the investigation of transmitting transient responses and as an incident impulse field for the investigation of receiving transient responses.

The theoretical and experimental receiving transient responses of the resistively loaded antenna and the TEM horn are, respectively, shown in figures 1 and 2. The theoretical and experimental transmitting transient responses of the resistively loaded linear antenna, the TEM horn, and the conical antenna are, respectively, shown in figures 3, 4, and 5. The agreements between theory and experiments of the receiving and transmitting transient responses for the resistively loaded antenna, the conical antenna, and the TEM horn are satisfactory.

The receiving transient response of the resistively loaded antenna indicates that the impulse shape of 70 ps duration is well preserved. This provides the unique capability of this antenna to measure fast, time-varying, transient fields with minimal pulse-shape distortion due to nonlinear amplitude or phase characteristics.

The author wishes to thank A.R. Ondrejka for his careful measurement assistance.

References

[1] R.W.P. King, The Theory of Linear Antenna (Harvard University Press, Massachusetts, 1956).

[2] M. Kanda, "A Broadband Linear Antenna with Tapered Resistive Loading for Picosecond Pulse Measurements," to be published in IEEE Trans. Antennas Propagat.

[3] C.W. Harrison, Jr., and C.S. Williams, Jr., "Transients in Wide-Angle Conical Antennas," IEEE Trans. Antennas Propagat., Vol. AP-13, pp. 236-246, March 1965.

1

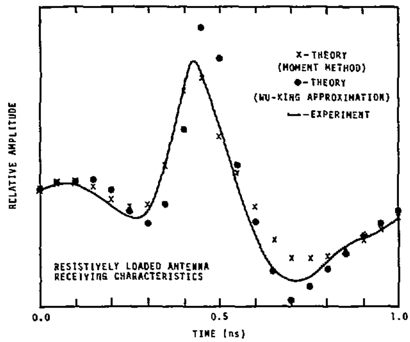

Fig. 1

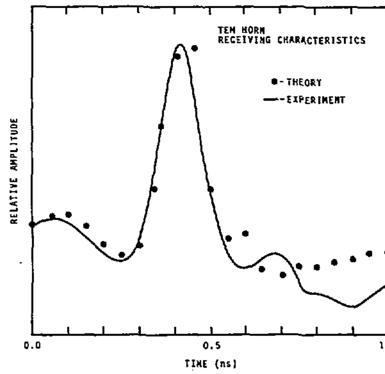

Fig. 2

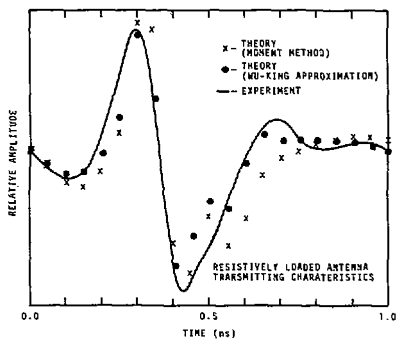

Fig. 3

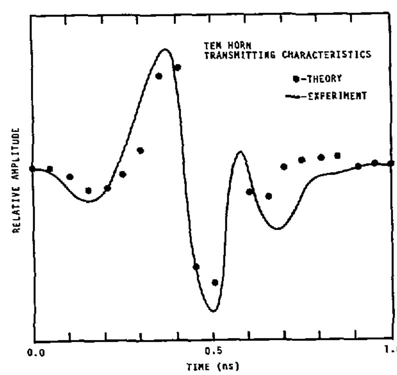

Fig. 4

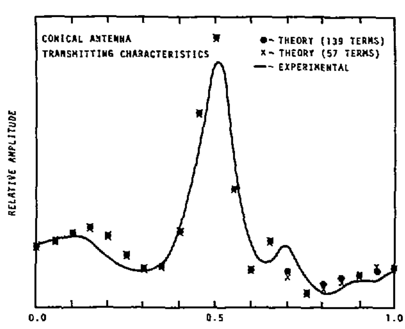

Fig. 5