1-I B1 PROCESSES OF TRANSIENT RADIATION AND RECEPTION

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The transmission of transient signals from one antenna to another as indicated in Fig. 1 can be described by combining the process of transient radiation from one antenna with the process of transient reception by the other antenna.

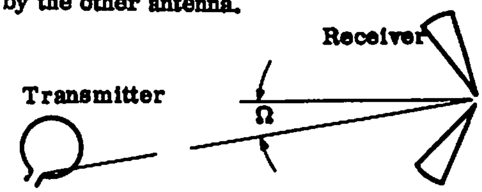

Fig. 1: A system involving a transmitting antenna and receiving antenna.

Both radiation and reception can be formulated compatibly by using the vector effective height function for antennas:

$$\bar{h}(\omega, \Omega) = \frac{1}{I(\omega)} \iiint \hat{R} \times \bar{J}(\omega, \bar{R}') \times \hat{R}\, e^{j \frac{\omega}{c}(\bar{R}' \cdot \hat{R})}\, dv' .$$

I and $\bar{J}$ are respectively the current and current distribution of an antenna expressed in terms of the Fourier transform angular frequency ω. Here, $\bar{R}$ is used to denote the 3-dimensional position vector, Ω represents the two angular dimensions of $\bar{R}$ in a spherical coordinate system, and $\hat{R}$ is the radial unit vector.

This approach calls upon the reciprocity theorem as applied to the two sets of fields corresponding to the two coupled antennas. In general, the formulation requires the solution of an integral equation in both the spatial domain and the frequency domain. This is accomplished in a systematic manner by using the Fourier transform method within the framework of a boundary value problem. The fast Fourier transform algorithm is useful for economical computation.

A transient source current exciting a transmitting antenna produces the following transient waveform across the load impedance Z_L of a distant receiving antenna;

$$v(t, \Omega) = \frac{-j\eta}{8\pi^2 cR} \int_{-\infty}^{\infty} \frac{\omega Z_L(\omega) I_t(\omega) \bar{h}_t(\omega, \Omega) \cdot \bar{h}_r(\omega, \Omega)\, e^{j\omega(t - \frac{R}{c})}}{Z_L(\omega) + Z_r(\omega)}\, d\omega,$$

where t is time, c is the propagation velocity, η is intrinsic impedance of the simple medium, Z is impedance and the subscripts t and r refer to the transmitting and receiving antennas respectively. This formulation displays explicitly the antenna properties that are needed for the output waveform to duplicate the input waveform. To preserve the waveform, the scalar product of the transmitting and receiving antenna vector effective height functions must be a frequency-dependent phasor quantity with a magnitude proportional to $(\omega Z_L)^{-1}[Z_L(\omega) + Z_r(\omega)]$ and a phase proportional to ω. The design goal for a dispersionless antenna communication link, therefore, should be guided by such a criterion. The formulation also makes evident the fact that the received waveform is proportional to the time derivative of the source waveform if all impedances and antenna radiation patterns are frequency-independent. In practice, the extremely broad bandwidths are more difficult to attain in the radiation patterns than in the impedance characteristics. The mutual impedance between the transmitting and receiving antennas can also be identified.

To illustrate the consequences of the general formulation in a simple specific case, two center-fed linear antennas parallel to each other are examined. In this example, the current distribution on each antenna (when excited as a transmitting antenna) is taken to be a transient waveform traveling from the center outward to the ends.

$$\bar{I}(\omega, z) = \hat{z}\, I(\omega)\, e^{-j \frac{\omega}{c} |z|}$$

Multiple reflections of the waveform from the ends and generator could be included but are omitted for brevity. The vector effective height function for each antenna is then given by

$$\bar{h}(\omega,\theta) = -\hat{\theta}\frac{jc}{\omega}\sin\theta\left[(1+\cos\theta)^{-1}e^{-j\frac{\omega}{c}\ell(1+\cos\theta)} + (1-\cos\theta)^{-1}e^{-j\frac{\omega}{c}\ell(1-\cos\theta)} - 2(\sin\theta)^{-2}\right],$$

where $\hat{\theta}$ is the unit vector in the θ direction and ℓ is the half-length of each antenna. To simplify this example Z_L is taken to be resistive and $[Z_L+Z_r(\omega)]^{-1}$ is expanded in a power series involving phase retardation terms and a constant characteristic impedance by analogy with the transient analysis of a transmission line.

$$\frac{1}{Z_L+Z_r(\omega)} = \frac{1}{Z_L+Z_c}\left(1+a_1 e^{-j\frac{2\omega\ell}{c}} + a_2 e^{-j\frac{4\omega\ell}{c}} + \cdots\right).$$

With these simplifications, the transient voltage at the load of the receiving antenna when $\theta=\pi/2$ can be found by the convolution theorem to be

$$v(t)_{\theta=\frac{\pi}{2}} = \frac{-\eta c Z_L}{2R(Z_L+Z_c)}\int_t^{\infty} U(t-\tau)\left[i_t(\tau-\frac{R}{c}) - i_t(\tau-\frac{R}{c}-\frac{\ell_t}{c}) - i_t(\tau-\frac{R}{c}-\frac{\ell_r}{c}) + i_t(\tau-\frac{R}{c}-\frac{\ell_t+\ell_r}{c}) + \cdots\right]d\tau,$$

where $U(t-\tau)$ is the unit step function and $i_t(t)$ is the transmitting antenna's current waveform expressed as a function of time. As indicated in Fig. 2, the terms in the above expression can be identified with waves experiencing time delays in propagating along the arms of the two linear antennas. If $i_t(t)$ is a continuous function possessing continuous derivatives, the received voltage is approximately given by

$$v(t)_{\theta=\frac{\pi}{2}} = \frac{-\eta\ell_t\ell_r Z_L}{2cR(Z_L+Z_c)}\int_t^{\infty} U(t-\tau)\,\frac{d^2 i_t(\tau-\frac{R}{c})}{d\tau^2}\,d\tau.$$

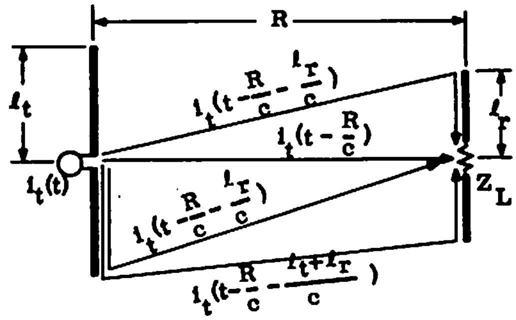

Fig. 2: Wave paths in transmission between two parallel linear antennas.

The differentiating action of antennas is thus illustrated. If it is desired to preserve the input waveform, terms other than $i_t(\tau-R/c)$ should be eliminated. In practice, this may be done by using long antennas such that ℓ/c is large compared to the duration of the transient waveform. The successive terms which are represented by

$$i_t(\tau-\frac{R}{c}-\frac{\ell}{c}),\quad i_t(\tau-\frac{R}{c}-\frac{2\ell}{c}),$$

etc, may be gated out at the receiving terminal by a switching system.

The concept of directivity of antennas radiating or receiving transient signals is re-examined. A definition of directivity, which reduces to the conventional form for monochromatic fields, is postulated based on the energy content of general time-varying fields. The difficulties in constructing a highly directive antenna for video pulsed signals are pointed out.

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