DIGITAL COMPUTER SIMULATION OF MONOPULSE ANTENNAS BY EXPLOITING A SIGNAL ANTENNA ANALOGY

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ABSTRACT

This paper presents a digital computer simulation methodology approach to mono pulse antennas modeling. Emphasis is given to the techniques for this modeling We consider two central concepts:the 'analytic signal' and the 'signal-antenna analogy'. Frequency domain simulation is facilitated by digital signal processing. The equivalent digital filtering of the model proposed facilitates a shaped pattern design by equivalent spectrum evaluation with F.F.T. techniques.

INTRODUCTION

Digital computer simulation is usually a desirable tool for both analysis and design of radar antennas; as a matter of fact, it can succesfully compensate for the disadvantages of the two other traditional approaches,viz.theoretical analysis and laboratory hardware tests.

The practicality of radar signal and radar antennas modeling using digital computer simulation has been enhanced by developments in both the hardware and software areas during the past years. General-purpose computers are becoming faster and more available, and the availability of mini computers and personal computers offers the potential for an even more economical simulation tool.

Developments in the software area have also had an important impact on the efficiency and realism that can be achieved in the digital simulation of radar signal. A well known example of such a software tool is the Fast Fourier Transform algorithm. Even more important in modeling linear systems is the concept of digital filtering (1). Existing techniques for digital-filter synthesis have resulted from the considerable interest over the past years in the area of real-time digital processing of sampled signals, and this idea is valid for us.

The purpose of this paper is to illustrate a digital computer simulation methodology to exploit a signal-antenna analogy for analysis and/or design of radar monopulse antennas where the far-field pattern of an odd aperture excitation is the Hilbert transform of the far-field pattern of the corresponding even excitation. Analytic signals use the same mathematics of that, and therefore is possible to introduce valid concepts of communication theory in the antennas theory field.

First, we comment the complex envelope representation for signals. This idea is the basis of the modeling and simulation in this paper.

The following paragraph comments a signal-antenna analogy. In the next paragraph we exploit the signal-antenna analogy.

We illustrate the concepts included in the digital simulation and the algorithm chosen, later.

A final paragraph summarizes the advantages of the simulation approach illustrated in this paper.

ANALYTIC SIGNAL CONCEPTS

It is well known (2) that, given a real signal $x(t)$ and its spectrum $X(\omega)$, the knowledge of $X(\omega)$ for nonnegative values of ω is sufficient to set all the informations on the signal $x(t)$, because of the symmetry properties of the spectrum when $x(t)$ is real. The analytic signal $X_a(t)$ associated to the real signal $X(t)$ is the inverse Fourier transform of twice the spectrum $X(\omega)$ taken only for $\omega > a$. Therefore

$$X_a(\omega) = X(\omega) + sgn(\omega) \cdot X(\omega) \qquad [1]$$

The operator $sgn(\omega)$ is plus one for ω grater than zero and minus one for ω less than zero.

In the time domain, $x(t)$ is the Fourier transform of $X(\omega)$, and the Fourier transform of $sgn(\omega)$ is $j \cdot t^{-1}$. Therefore

$$x_a(t) = \mathcal{F}\left\{X_a(\omega)\right\} = x(t) + j \cdot x(t) * \frac{1}{t} = x(t) + j \cdot H\left\{x(t)\right\}$$

where $H\left\{x(t)\right\}$ is the Hilbert transform of $x(t)$.

When is given a signal $X(t)$ with a narrowband spectrum centered around a frequency f_0 (Hz), the associated analytic signal $\mathring{x}(t)$ can be written as (2)

$$\mathring{x}(t) = \tilde{x}(t) \cdot exp(j \omega_0 t)$$

where $\quad X(t) = X_p(t) \cdot \cos \omega_0 t - X_q(t) \cdot \sin(\omega_0 t) \stackrel{\Delta}{=} Real\left\{\mathring{x}(t)\right\} \qquad [2]$

The signals $X_p(t)$ and $X_q(t)$ are the complex envelope representation of the real signal $X(t)$.

The analytic signal concept can be applied also to the representation of the impulse response of a narrowband linear system centered around the frequency f_0 Hz.

If $X(t)$ and $z(t)$ are the input and output signals from the linear system, then

$$\tilde{z}(t) = \frac{1}{2} \int \tilde{h}(\tau) \cdot x(t-\tau) \cdot d\tau \qquad [3]$$

where

$$\tilde{h}(\tau) = \mathring{h}(t) \cdot exp(-j \omega_0 t) \qquad [4]$$

The convolution integral holds also between the complex envelopes of narrowband signals and filter impulse response.

Equations [2] and [3] and [4] are the key point for the simulation approach, because each signal, at each sampling instant, can be represented by three numbers: the sample of the in-phse component, the sample of the quadrature component, and the value of the center frequency.

The analytic signal concept makes it easy also the translation in the frequency domain.

SIGNAL-ANTENNA ANALOGY

It is known that, the sum and difference excitations of a phase-monopulse antenna can be related to the aperture ordinate. In fact, the far-field sum and difference patterns are a Hilbert transform pair (3). Therefore, if y a variable denoting the aperture ordinate, is substituted for ω in [1], $X(y)$ and $sgn(y) \cdot X(y)$ are the sum and difference excitations of a phase-monopulse antenna.

A very important feature of this approach must be emphasized at this point, to show the importance of the signal-antenna analogy, and to introduce shaped beam design by computer digital simulation. In fact, it is known (4) that an antenna pattern, for both linear and circular apertures, can be described by a Lambda function $\Lambda_\nu(u)$, defined as

$$\Lambda_\nu(u) \triangleq J_\nu(u) / u^\nu$$

where $J_\nu(u)$ is the Bessel function of the first kind.

The pattern produced by the corresponding odd excitation can be evaluated by the Hilbert transform, and it is given by the Lambda-Struve function defined as

$$\mathcal{H}_{\nu}(u)/u^{\nu}$$

where $\mathcal{H}_{\nu}(u)$ is the Struve function of the first kind, which is tabulated in mathematical tables. Therefore, it is possible to use signal design concepts in the shaped beam antennas design.

MONOPULSE ANTENNAS MODEL CONSTRUCTION

Functionally, a monopulse antenna can be represented by a pattern shaping device, a spatial filter for dividing illumination in two halves, and a hybrid junction. Figure 1.

Modeling and simulation consider, the pattern shaping device replaced by a weighting filter, the spatial filter replaced by a contiguous-channel diplexer (5), and the hybrid junction. Figure 2.

The pattern shaping device provides the configuration of the pattern, and the beamwidth and sidelobes levels are determined by design of that. Therefore, the device operates as an invariant linear system.

The spatial filter provides the even and odd excitations. Then, we can consider this function as made by a contiguous-channel diplexer which divides the signal spectrum into two halves (5). We assume, as first approach, no mutual coupling in the antenna. Therefore, there isn't aliasing error.

The output of the sum port of the hybrid is the original envelope down by 3 dB. The output of the difference port is a "difference" envelope having a null at the point in time corresponding to the centroid of the original envelope signal. Addition of the sum envelope and difference envelope would produce an analytic signal.

FREQUENCY DOMAIN SIMULATION

In the paragraph above, we propose a monopulse antenna model constituted by a cascade invariant linear systems, and we can use digital signal processing techniques for spectral relocation and illumination function. Frequency domain simulation approach is here considered for simulating invariant linear filters.

For the simulation purposes it is well known that the signals are represented by a stream of samples taken at a sampling rate according to the theorem constraints. It is assumed that our signals and functional blocks are all contained into a narrow band centered around a center frequency. The bandwidth of the cascade system implies the choice of the sampling rate independently from the center frequency. This choice is based upon the concept of analytic signal $\mathring{x}(t)$ associated to signal $x(t)$.

Therefore, each signal in the system, at each sampling instant, can be represented by three numbers: the sample of the in-phse component, the sample of the quadrature component, and the value of the center frequency.

Equation [3] is the key relation for the low-frequency simulation of narrow band filters. In fact, it can be expanded into the equations which give the components of the output signal complex envelope. Digital filters are obtained from the corresponding analog transfer functions by using bilinear Z-transform techniques. More details on their implementation are given in (6)

The purpose of a simulation run is the evaluation of some system performance parameter (spectral density). This goal is usually achieved through a suitable process of the signal samples in some points of the system. To this purpose it is not strictly necessary to perform the processing algorithm while the system is being simulated. It is possible an average power spectrum (shaped pattern) evaluation routine based on a mixed-radix Fast Fourier Transform algorithm, and we use one described in the reference (7)

CONCLUSION

A frequency domain simulation approach has been proposed to design and/or analyze monopulse antennas. One of the major advantages of this simulation is the easy and natural way of shifting signals in the frequency domain.

Central idea for the above is the analogy between spectrum mathematics and illumination function. We can simulate linear filters by digital signal processing techniques, and this work is valid for making different illumination patterns in monopulse antennas. Therefore, we can obtain data about reflectors or lens and spatial filters.

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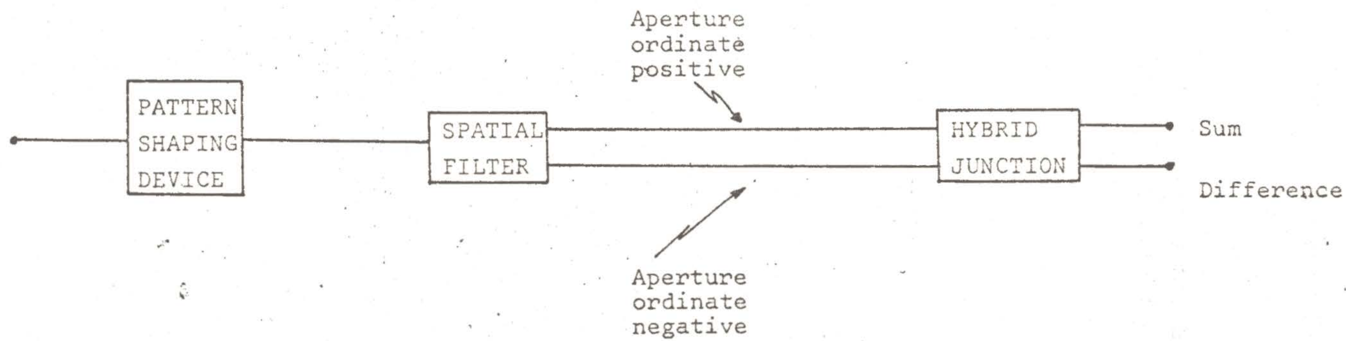

Figure 1.

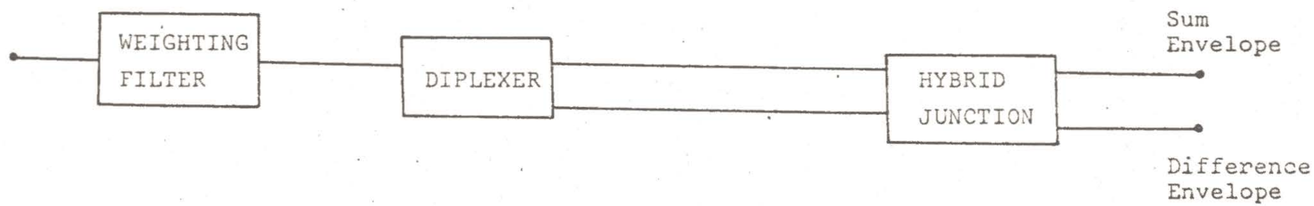

Figure 2.