FIDELITY OF PULSED MICROWAVE TRANSISTOR AMPLIFIERS

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Abstract

High-power microwave transistor amplifiers characteristically display amplitude and phase droop in the amplification of long RF pulses. The effects of these signal distortions on linear FM modulated waveforms are examined, with specific attention addressed to time sidelobes and main lobe width of a filtered, matched Hamming-weighted pulse.

Introduction

Continuing developments in solid-state and microwave technologies have made feasible the application of moderate power and relatively low cost solid-state transmitters to phased arrays. These transmitter modules are required to amplify both amplitude- and frequency-modulated waveforms and it is the system designer's task to translate the system requirement for pulse replication fidelity to the transmitter designer in terms that he may use directly in establishing laboratory test procedures. This problem is more complex for transmitters than for many passive components because of the intrinsic nonlinear nature of the high-power solid-state devices. This paper will discuss the distortion introduced by typical transmitters and their effects on modulated waveforms representative of those used in a modern solid-state radar system.

Representative Radar System

Figure 1 is a simplified schematic of the transmitter and receiving sections of a simple pulse-compression radar system, and the envelope of the RF waveform at points of interest. The input signal to the transmitter is a linear FM modulated rectangular pulse. After reception the linear FM pulse is filtered by a pulse-compression network, and the resultant output amplitude displayed is the familiar curve as shown. The two items to be treated herein are the effects of amplifier distortion on the main lobe width and the level of the time sidelobes.

Effects of Phase and Amplitude Distortion

The dominant distortion effects introduced by the solid-state amplifier used in the transmitter are conveniently grouped into the following categories:

1. Pulse amplitude droop
2. Pulse phase droop (phase settling)
3. Ripple content in amplitude waveform
4. Ripple content in phase waveform

Figure 2 is a plot showing typical waveforms of the amplitude and phase during a 1.5 msec, 30 MHz, linear FM pulse at the output of a 50-watt L-band five-stage solid-state transmitter. The insertion phase and the amplitude of the pulse change by 28 degrees and 1 dB, respectively. For a linear FM modulated pulse, the total distortion is the combination of these effects in the time domain of the type just shown, in combination with those effects arising from deviations from linearity in the frequency band over which the FM modulation extends.

Representative Receiver Response to Distorted Pulse Spectra

Calculations have been made of the resulting waveform at the output of a Hamming-weighted matched-filter receiver to determine the effects of the distortions introduced in the time and frequency domain on the compressed width of the main lobe and the time sidelobe amplitudes. Figure 3 is a reference plot of the output waveform for the case where there is no phase or amplitude droop. The time sidelobe amplitudes are more than 40 dB below the peak of the main lobe. Figure 4 is the time sidelobe pattern for the amplitude and phase waveforms shown in Figure 2. The main beam amplitude has dropped approximately 0.5 dB and the peak sidelobe (which could be considered as a slight shoulder) has increased to a level of 35 dB below the main lobe. The remaining sidelobes are all below a level of -38 dB relative to the main lobe.

Figures 5 and 6 are plots of amplitude and phase versus time and the corresponding time sidelobe plot for a case in which severe distortion is apparent. For this case, which is by no means typical, the time sidelobe plot shows that the shoulder has increased to a level 30 dB below the main lobe and several other sidelobes approach or exceed the -38 dB level.

Basis of Analysis

It is well known from Klauder, et al[1] that the effects of distortion in a linear FM pulse-compression radar can be analyzed by recognizing that a Fourier pair relationship exists between the spectrum of the FM coded waveform and the range (or time) sidelobes of the processed radar return. Accordingly, a Fast Fourier Transform (FFT) algorithm has been utilized to examine the effects of such distortion. Here we have considered that the radar receiver employs Hamming weighting to reduce the range sidelobe level. The output signal from such a receiver, as a function of time, is given as

$$y(t) = \int_{-\infty}^{\infty} H(f)D(f)H^*(f)W_H(f)e^{2\pi ift}\,df \qquad (1)$$

where

- $H(f)$ = uncontaminated input signal spectrum
- $H^*(f)$ = matched filter receiver frequency response function, the complex conjugate of $H(f)$
- $D(f)$ = complex distortion of the form $A(f)e^{i\phi(f)}$
- $W_H(f)$ = Hamming weighting of the form $\mathrm{Rect}(f/B)\left[1 + 0.852\cos\left(\frac{2\pi f}{B}\right)\right]$
- B = bandwidth which is swept by the linear FM waveform

In the case of a linear FM waveform of large time duration-bandwidth product

$$H(f) \cong \text{Rect}(f/B)$$

where

$$\text{Rect}(x) = 1, \ |x| \leq 0.5$$
$$= 0, \text{ otherwise}$$

and (1) reduces to

$$y(t) \cong \int_{-f/2B}^{f/2B} D(f)W_H(f)e^{2\pi ift}df = F^{-1}\ D(f)W_H(f) \qquad (2)$$

Equation (2) therefore, becomes the basis for analyzing the effects of specific cases of distortion upon a spectrally weighted matched filter receiver. Computationally, the aforementioned FFT is used to evaluate Equation (2), given a specific sequence of amplitude and phase samples as a function of frequency which reflect the product D(f)H(f).

Acknowledgement

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Reference

1. Klauder, J. R., et al, "The Theory and Design of Chirp Radars," Bell System Tech. Journal, Vol. 34 (July 1960), pp. 724-808.

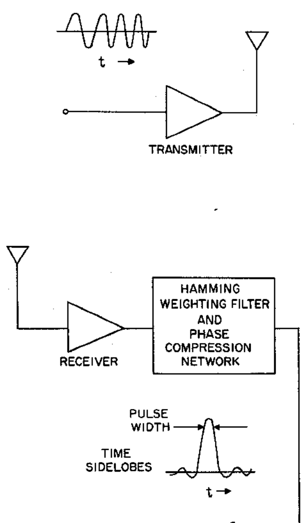

Fig. 1 Simplified Schematic Diagram of Typical Pulse Compression Radar Transmitter and Receiver

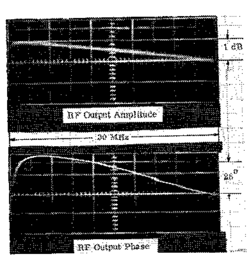

Fig. 2 Amplitude and Phase vs Time for 1.5 msec. 30 MHz Linear FM Pulse (f_o = 1275 MHz)

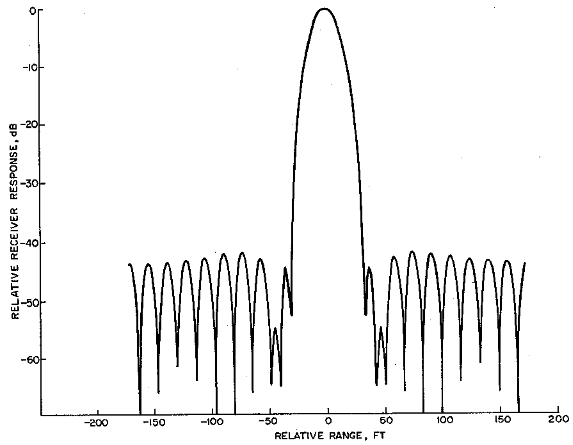

Fig. 3 Time Sidelobe Plot Ideal 30 MHz Distortion Free Waveform (Hamming Weighting Applied)

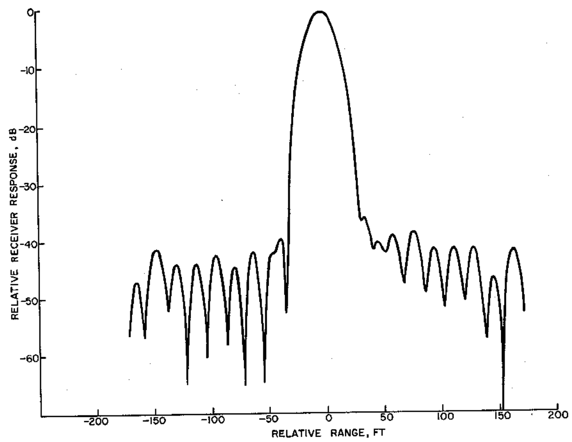

Fig. 4 Time Sidelobe Plot for 30 MHz Waveform f_o = 1275 MHz Typical Power Amplifier Fidelity (Hamming Weighting Applied)

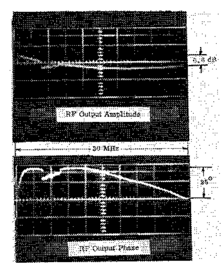

Fig. 5 Amplitude and Phase vs Time for 1.5 msec. 30 MHz Linear FM Pulse (f_o = 1165 MHz)

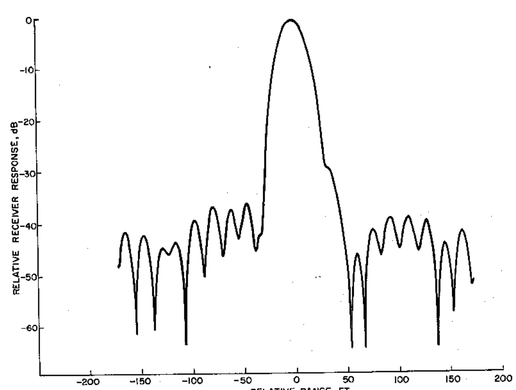

Fig. 6 Time Sidelobe Plot for 30 MHz Waveform f_o = 1165 MHz Severe Distortion Present (Hamming Weighting Applied)