MOST Project

LEVEL II

(6) **CHIRP Versus BURST**

# SONAR RESOLUTION TECHNIQUES FOR CLASSIFICATION DURING DETECTION

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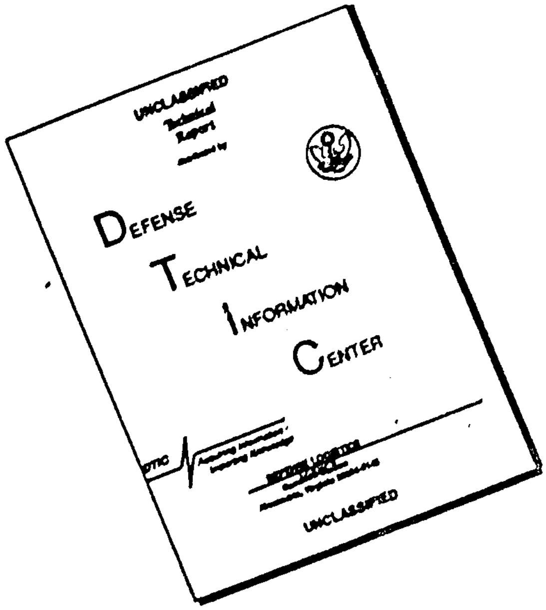


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## ABSTRACT

The Dalmo Victor Company's Report R-2850-2931 has previously proposed the CHIRP pulse compression technique as most adequately resolving detection range, classification and range rate problems for search sonars.

This report qualitatively evaluates the effects of propagation non-linearities and Fresnel zone target scattering interference on CHIRP resolution. Comparisons are made to a BURST short pulse train system. For equal resolution, both techniques require equal bandwidths and similar spectral amplitude distributions. BURST resolves signals from different range cells by phase or time difference alone; CHIRP by both time and frequency. Propagation non-linearities cause similar coherence loss and resolution broadening. Scattering is a linear process. CHIRP resolves overlapping long pulse echoes by superposition of time-frequency separated signals.

It is concluded that CHIRP provides resolution equivalent to BURST for a given sonar bandwidth. CHIRP permits the use of a long, low data rate, detection pulse. In addition, the coherent integration employed in a CHIRP system provides a greater target detection range than can be achieved with the non-coherent integration employed in a BURST system, for the same average power. CHIRP also permits the removal of range rate by triggering the classification display sweep at receipt of the first compressed CHIRP echo.

The Dalmo Victor Company continues to recommend CHIRP for classification during detection.

## 1. INTRODUCTION

The advantages of pulse compression techniques for radar applications have been well verified experimentally. This contractor has proposed that pulse compression techniques be employed to alleviate the problem of classification during detection in sonar equipment.

Some concern has been expressed about the effects of the echoing characteristics of sonar targets and the medium of propagation.

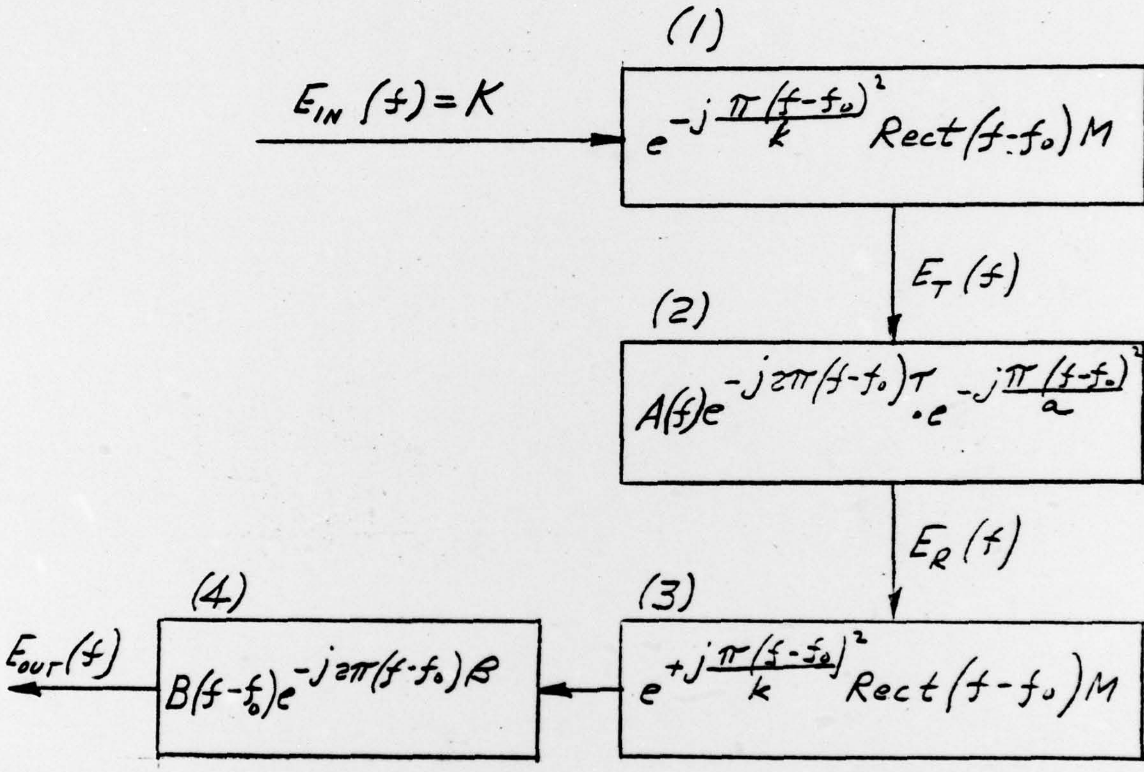
This report is a qualitative evaluation of the performance expected from a CHIRP type sonar system as compared to one employing BURST type short pulse transmission of equal average power.

The characteristics that are evaluated are the effects of extraneous phase dispersion (non-linear functional relationship between phase and frequency), spectral amplitude weighting, and targets composed of a number of scatterers.

It is assumed that the medium or target will not exhibit significant non-linearities (e.g., attenuation not constant with signal strength, reflection power not proportional to incident power, etc.) that would generate spectral cross products. The principle of linear superposition is assumed valid for the purposes of this report.

## 2. THE CHIRP SYSTEM

Figure #1 is a block diagram of the transfer functions assumed for a CHIRP system. The transfer functions represent: (1) the dispersive filter that generates the transmitted signal; (2) the effect of the medium on spectral amplitude, phase slope and phase dispersion; (3) the receiver's inverse filter; and (4) the receiver's filter for frequency weighting.




ASSUMED CHIRP SYSTEM'S TRANSFER FUNCTION

FIGURE 1

2. THE CHIRP SYSTEM - Continued

a. The Transmitted Signal

The characteristics of the input signal and dispersive filter generate a linearly frequency modulated transmitted signal with approximately rectangular spectral and temporal functions, for large compression ratios. The spectral width of the CHIRP signal is inversely proportional to the temporal resolution, after compression. For example, 2 ms temporal resolution requires 500 cycle bandwidth. The product of the width of the transmitted signal's spectrum and duration in time is approximately equal to the compression ratio. For example, a CHIRPed 500 cycle band, 35 ms long signal, has a compression ratio of approximately 17.

During the time of transmission, the frequency modulated transmitted signal can be represented as,

$$e_T(t) = R\left[e^{j2\pi f_0 t} \cdot e^{j2\pi\left(\frac{kt^2}{2}\right)}\right]$$

The term $e^{j2\pi\left(\frac{kt^2}{2}\right)}$ has an instantaneous frequency of $f = kt$, so that $t = \frac{f}{k}$ and, $e^{j2\pi\left(\frac{kt^2}{2}\right)} = e^{j\frac{\pi f^2}{k}}$

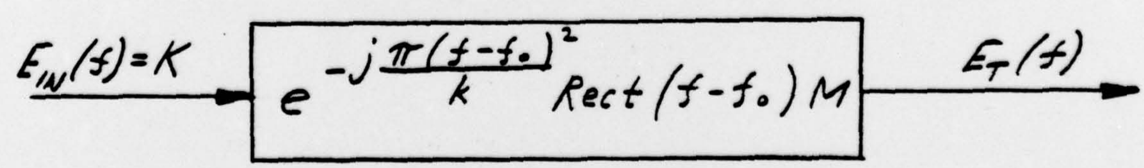
Since the Fourier transform,

$$F\left[u(t)\, e^{j2\pi\phi t}\right] = U(f-\phi),$$

the non-linear functional relationship between the phase of the argument and frequency is

$$\theta(f) = e^{j\frac{\pi(f-f_0)^2}{k}}$$

The desired CHIRPed transmitted waveform can be approximately synthesized passively by a uniform spectrum, generated by a unit impulse, whose phase versus frequency characteristic has been non-linearized by $e^{-j\frac{\pi(f-f_0)^2}{k}}$. These requirements are satisfied by the network in Figure 2.




PASSIVE GENERATION OF TRANSMITTED SIGNAL

FIGURE 2

The width of the rectangular function is determined by the index of frequency modulation generated by a finite bandwidth.

b. <u>The Received Signal</u>

The received signal encounters propagation delay in the medium so that it is of the form of $e_T(t-\tau)$, where $e_T(t)$ represents the transmitted signal.

Since,

$$F[u(t-\tau)] = e^{-j2\pi y\tau} \cdot U(y)$$

where y = f-$f_o$

$$F[e_T(t-\tau)] = e^{-j2\pi(f-f_o)\tau} \cdot E_T(f-f_o)$$

This signal is passed through a filter whose phase characteristic is the inverse of that employed for generating the transmitted signal. The filter removes the phase dispersion generated in the transmitter so that the spectrum at its output is,

$$E_o(f) = e^{-j2\pi(f-f_o)\tau} \cdot Rect(f-f_o)M$$

The output signal as a function of time, is the Fourier transform of this equation. The transformation can be accomplished by successive substitutions of transform relationships.

Since,

$$F[U(f-f_o)] = e^{j2\pi f_o t} \cdot u(t)$$

$$e_o(t) = F[e^{-j2\pi(f-f_o)\tau} Rect(f-f_o)M]$$

$$= e^{j2\pi f_o t} \cdot F[e^{j2\pi f\tau} Rect\, fM] = e^{j2\pi f_o t} \cdot \frac{1}{M} Sinc\left(\frac{t-\tau}{M}\right)$$

This output signal is an amplitude modulated carrier whose peak value occurs at a time equal to the propagation delay encountered in the medium. The duration of the filtered pulse is inversely proportional to the transmitted bandwidth.

The sinc function has the narrowest pulse width that can be achieved with a given bandwidth, but has relatively high side lobe level. It is common to employ additional spectral shaping to reduce the side lobe level with a resultant widening of the pulse.

3. THE BURST SYSTEM

A BURST short pulse train sonar system, with the same range resolution and average power propagates a spectrum of approximately the same width but with a linear functional relationship between phase and frequency. If the medium and the target do not generate a non-linear phase characteristic, or change the relative amplitudes of its spectral components, the received signal will be of the same form as the transmitted signal, for a point scatterer, and its peak value will occur at a time determined by the delay it has encountered during propagation.

4. CHIRP VERSUS BURST

a. Propagation

Any phase dispersion encountered in the medium should have the same effect on the similar spectrum content of a CHIRP or short pulse BURST sonar. This medium dispersion should be of the same magnitude at the outputs of both systems and generate the same broadening of the output pulse due to loss of coherence.

The non-linear phase component of the transmitted CHIRP signal is removed by the receiver matched filter. Its output spectrum contains the same phase components that appear at the output of the BURST short pulse system. In both cases, the linear phase component determines when the peak of the output signal occurs in time. The non-linear phase distortion encountered in the medium will occur at both outputs and generate the same aperture widening.

The spectral weighting that is performed at the output of a CHIRP system results in approximately the same effective overall spectrum shape as for a conventional short pulse system. For a linear process, the spectral distortion encountered in the medium should have approximately the same effect in both cases.

The effect of the addition of the spectral components of the received signals in both cases is to generate spatial apertures whose widths and shapes are functions of the widths and shapes of the effective system's spectra!

The overall system transfer characteristics should be approximately the same in both cases. It follows that their receiver output spatial apertures should be similar.

b. Submarine Highlight Scattering

Interfering signals are received from targets that are composed of a number of discrete scatterers spaced by many wave lengths in the sonar's range dimension. The same phenomenon is exhibited by targets with continuous surfaces and physical dimensions of many wave lengths. The magnitude and phase of the received signals are a function of the frequency of the illuminating signal.

The longer transmitted CHIRP pulse will illuminate a larger range increment than a BURST short pulse. The fact that the longer transmitted pulse will encompass more scatterers, whose signals will interfere, should not effect its overall performance. A BURST short pulse system separates the echoes from scatterers spaced by distances greater than a range resolution cell in the time domain. The same separation is achieved in a CHIRP system in both the time and frequency domain.

The spectrum of signals received from different range cells in a BURST system differ only in phase. Their separation can only be accomplished in the time domain. The signals received from a particular range cell in a CHIRP system have a functional relationship between their time of occurrance and frequency. For ideal conditions, the proper frequency versus time relationship required for the signals at the output of the receiver's filter to add in phase, at any particular time, can only be generated for signals coming from the corresponding range cell. The linear data processing technique employed in a CHIRP system provides for the separability of the components to prevent the interference of signals from different range cells.

The CHIRP transmitter filter's phase characteristics, frequency modulates an amplitude modulated signal to generate a longer pulse, for the same spectral bandwidth as the BURST. The CHIRP receiver filter removes the frequency modulation to perform the inverse operation. The echo from an individual scatterer has a duration determined by the system's overall resolution. The process is assumed linear. The echo for a complex target is the superposition of the responses for the separate scatterers, or Fresnel zones on the surfaces. The processed CHIRP signal resolution should be the same as for a BURST short pulse system with the same resolution.