

THE ARCTIC CHANNEL: AN ACOUSTIC WAVEGUIDE

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ABSTRACT

The Arctic Basin provides a unique channel for acoustic propagation. The two features peculiar to the polar environment that most strongly influence the transmission of underwater sound are the permanent ice cover and the uniform sound speed structure. As a result, only a few low order modes will propagate through it to great distances and the non-linear frequency dependent time delay of the channel may be accurately computed. In the Arctic channel, the dispersion is such as to produce a "chirp" frequency modulation on a transmitted pulse. Consequently the channel itself may be used as the matched receiving filter by transmitting a time reversed ("chirp") waveform and letting the dispersion effect compress the waveform. This process will be strictly range dependent but the processing gain (compression ratio) appears to vary slowly over intervals of 50 kyds at ranges in excess of 200 kyds.

In this paper we examine the feasibility of exploiting the unique characteristics of the Arctic Basin to permit optimum signal waveform design and receiver processing. The approach is based upon the following:

(1) our ability to accurately predict the unique propagation behavior in the Arctic Basin, and

(2) the exploitation of pulse compression techniques to realize matched filter processing with simple (broadband filter) hardware.

The Arctic Basin provides a unique channel for the transmission of coherent acoustic signaling. The two features peculiar to the polar environment that most strongly influence transmission are the permanent ice cover and the uniform sound speed structure. The profile, generally described as an increasing function of depth is roughly independent of location and time of year. This allows for the accurate prediction of the details of low frequency waveforms. The ice cover modifies propagation, particularly at the high frequencies, by scattering sound from the rough ice canopy after repeated upward refractions. Thus only low frequency sound is transmitted to great ranges.

A typical experimental waveform with energy predominantly distributed among the first and second normal modes is shown in Fig. 1. Computer programs have been developed to predict the received waveform as a function of range and depth. The predicted dispersion is compared with that obtained from experimental waveforms in Fig. 2. The agreement between the two is excellent at these low frequencies.

The Arctic Basin exhibits propagation characteristics analogous to an inhomogeneous waveguide. Only a few low order modes will propagate through it and the non-linear frequency dependent time delay of the channel may be accurately computed as a function of range. Consequently it is possible to exploit the channel as a "time-compression" filter and thus realize the high "matched-filter" processing gain with very simple receiver instrumentation.

The pulse compression technique was originally developed for radar systems to obtain high range resolution with "long" pulses. In that application the frequency of the pulse is varied with time to produce a wideband waveform. At the receiver a matched filter is implemented by passing the received waveform through a filter with the inverse frequency versus time relationship so that all frequency components of the pulse are properly delayed and appear simultaneously at the filter output. The result is that "the received frequency modulated input pulse is compressed into a pulse of shorter length and high peak amplitude."^[1]

The technique was first used in underwater acoustics by Clay and Parvalessu to examine signal transmission stability in Tongue of the Ocean.^[2] Their experiments were performed at 400 Hz in 1.8 km of water at a range of 36 km. They discovered that the signal enhancement was realizable but sensitive to geometry (source and receiver depth variations). The Arctic offers an extraordinarily better channel (a few modes at 20 Hz versus a few "tens" of modes at 400 Hz) for the application of this scheme.

Specifically in the Arctic channel, the dispersion is such as to produce a "chirp" frequency modulation on the pulse. Since this modulation effect can be predicted quite accurately with the existing computer models the channel itself may be used as the receiving filter by transmitting a time reversed ("chirp") waveform and letting the channel dispersion effect compress the waveform. This process will be strictly range dependent but the processing gain (compression ratio) varies slowly until the matched range and then degenerates rapidly. Figures 3 and 4 show the pulse dispersion and compression effects for a simulated Arctic channel.

In Figure 3 the waveforms resulting from a single cycle of an 8 Hz sine wave are shown at increments of 100 km. The first and second modes are clearly distinguishable and the dispersion evidenced in these simulated waveforms is in close agreement with actual measurement. The "whistle" (chirp) characteristic of the first mode dispersion is consistently observed in Arctic acoustic measurements taken over diverse bathymetry and ice conditions.

Figure 4 shows the effect of the channel on the propagation of a waveform which is the time-reversed version of the response at 400 km (c.f. Figure 3b). Observe that the channel in fact is a filter matched at 400 km to the transmitted waveform. The compression effect is shown, at least qualitatively, to persist over a range window from 310 km to 400 km.

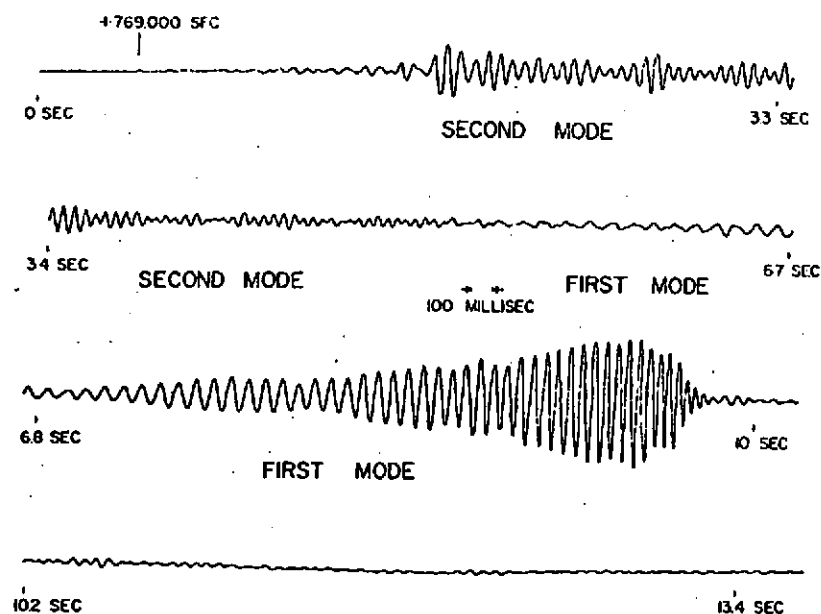


Fig. 1 - Typical Arctic Signal from an Explosive Source (10-21) Hz

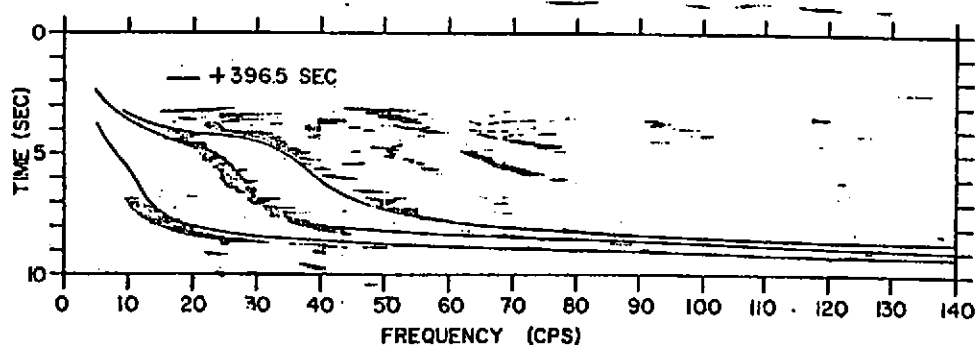


Fig. 2 - Comparison of Observed and Predicted Group Velocity Dispersion for First Three Modes

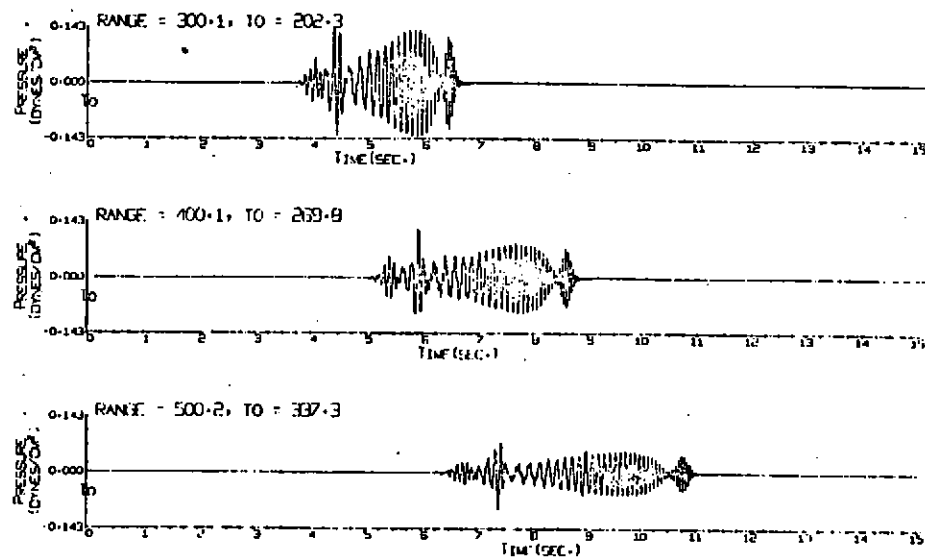


Fig. 3 - Predicted Waveforms as a Function of Range

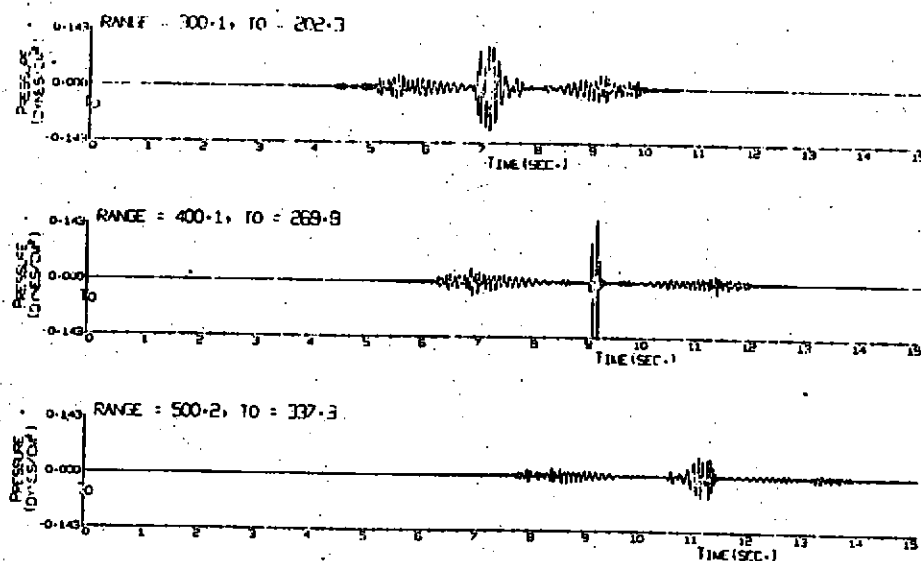


Fig. 4 - Predicted Pulse Compression as a Function of Range (ocean filter matched at 400 km)

REFERENCES

1. WALTHER, "Pulse Compression in an Acoustic Waveguide", JASA, Vol 33 No. 5, May 1961
2. PARVALESCU and CLAY, "Radio Electric Engineering", 29:pg. 223 (1965)