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VISUAL TECHNIQUES LABORATORY  
OPERATIONS NOTE

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To: Durnand File  
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### Introduction

Prior to this test, we had only experimented with chirped signals on the computer. Our simulations had shown that chirped broadband waveforms offered improved range resolution over single frequency pulses, and at the same time offered good immunity to random noise and multipath receptions. This test, carried out by Roger Lord, provided the first real data which confirmed the feasibility of using chirps in the Durnand array acoustic survey system.

### Procedure

Roger positioned two stereo speakers, one to act as a transmitter and the other to act as a receiver, as shown in Fig. 1. The receiving speaker was mounted on the machine shop crane to provide a convenient way to change the separation. An analog chirper circuit, designed by Fritz Toeys, synthesized a fixed band (10-20 KHz) linear FM waveform which was fed into the Ron Steiner amplifier. This signal was used to drive the transmitting speaker. The receiving speaker was connected to the Gespac computer, with the Toshiba laptop acting only as a terminal.

On a trigger signal from the chirper circuit, the Gespac logged 32768 samples of 12 bit data at a 200KHz sample rate. Four sets of data were taken at each of 5 speaker separations. Datafiles are listed in the laboratory notebook. Roger has separately documented the procedure used to take data (see "Instructions for Durnand Data Logger/Chirper", dated 6-21-91, in the orange Chirps and Pings notebook).

The data was analyzed using Matlab on the 286 clone in Rm 44. The received signals were correlated with a stored replica of the transmitted pulse. A functional block diagram of the relevant signal processing appears in Fig. 2. For computational efficiency, the calculation is done in the frequency domain. A separate procedure has been written on how to generate correlograms using Matlab (see "Procedure for Analyzing Chirps Using Matlab", dated 6-12-91, also in the orange notebook).

A signal measured across the transmitting speaker terminals was chosen as a suitable replica upon which to correlate. Other possible choices were the signal directly out of the chirper circuit, or a received pulse at short range. The former was rejected because it didn't display the rolloff due to the amplifier and the latter was not highly repeatable. Fig. 3 shows the replica and its power spectrum.

### Results

The location of the peak in the correlation function was tabulated for each data run. Table 1 is a copy of Ken Young's analysis using Quattro Pro. One figure of merit is the "residue", the difference between the measured location and that predicted from a least squares fit of the data. Dr. Young's analysis shows the residues to be < 1 cm, with a standard deviation of 5 mm. But the data still shows significant discrepancies between runs taken at the same speaker separation. The peaks vary as much as 13 time points, corresponding to a distance of 2.3 cm.

Fig. 4 is a plot of the delay time based on the correlation peak versus the speaker separation. Because the errors are so small, it looks to be a nice straight line. The computed speed of sound is 345.8 m/s. The book value is 343 m/s at 20 degrees C.

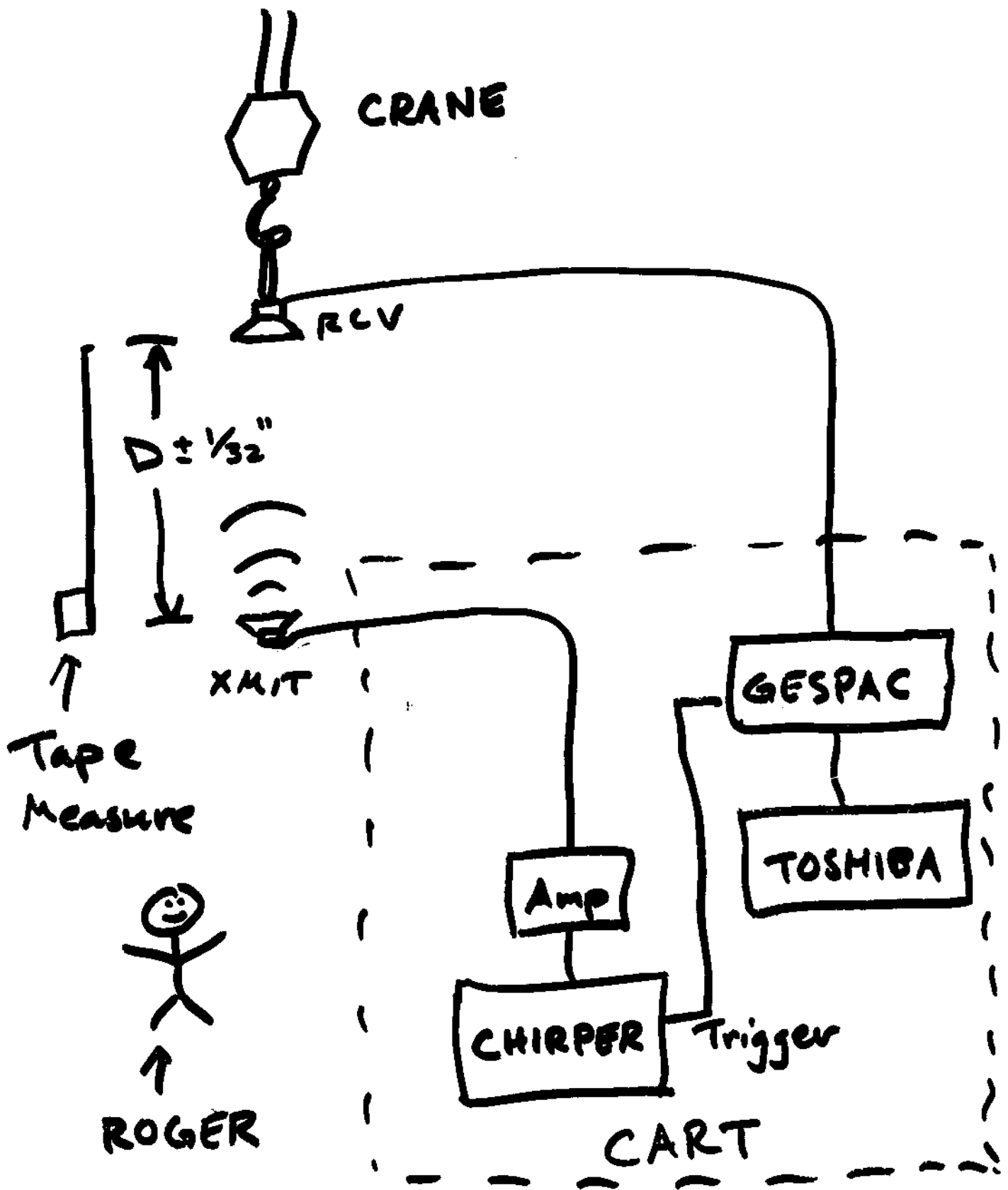
The remaining plots are correlograms with expanded views of the peak.

### Comments

The replica was missing its first few data points. That is, there were no leading zeros at the front of the waveform. This truncation could bias the location of the correlation peak.

Time jitter is also a significant problem. The temporal location of the waveform relative to the trigger pulse varies by as much as 30  $\mu$ s (6 samples). This is reasonable in light of the hardware used, and probably accounts for most of the variation in the data taken at identical speaker separation.

Both of these problems should be solved by the next generation digital chirping circuit.

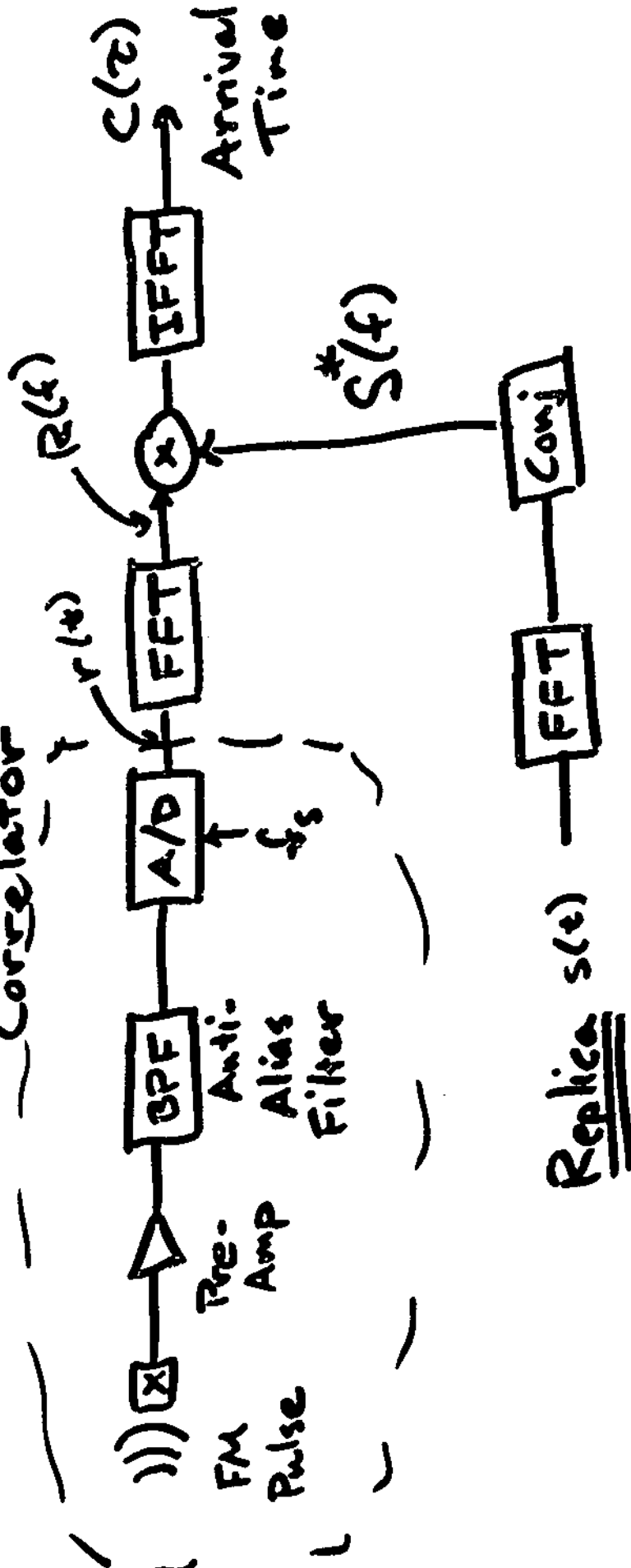


In-Air Chirping Apparatus

Fig. 1

# Frequency Domain Matched Filter

## Correlator



Correlation Function  $c(\tau) = \int r(t) s(t-\tau) dt = \mathcal{F}^{-1} \{ R(f) S^*(f) \}$

$$\sum_n r(n) s(n-j\epsilon)$$

Fig. 2

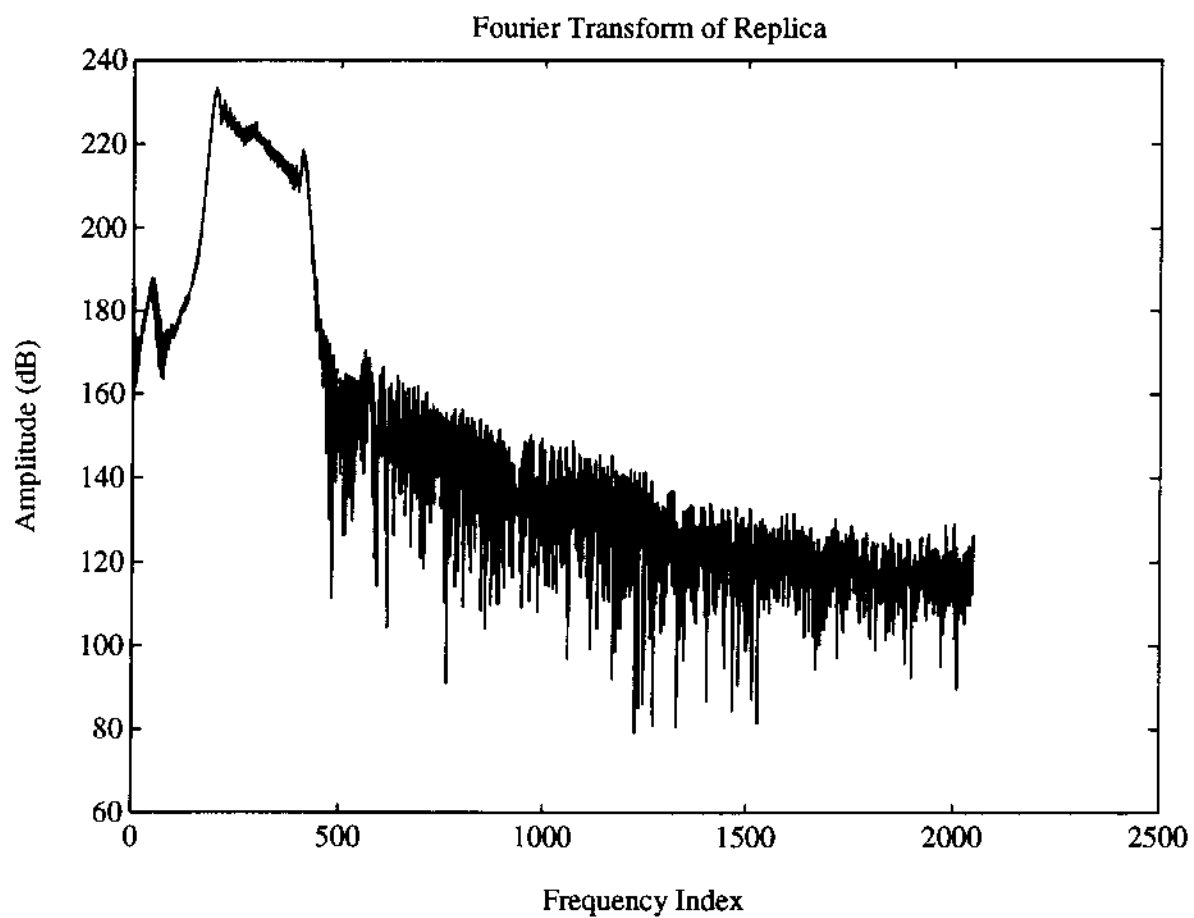
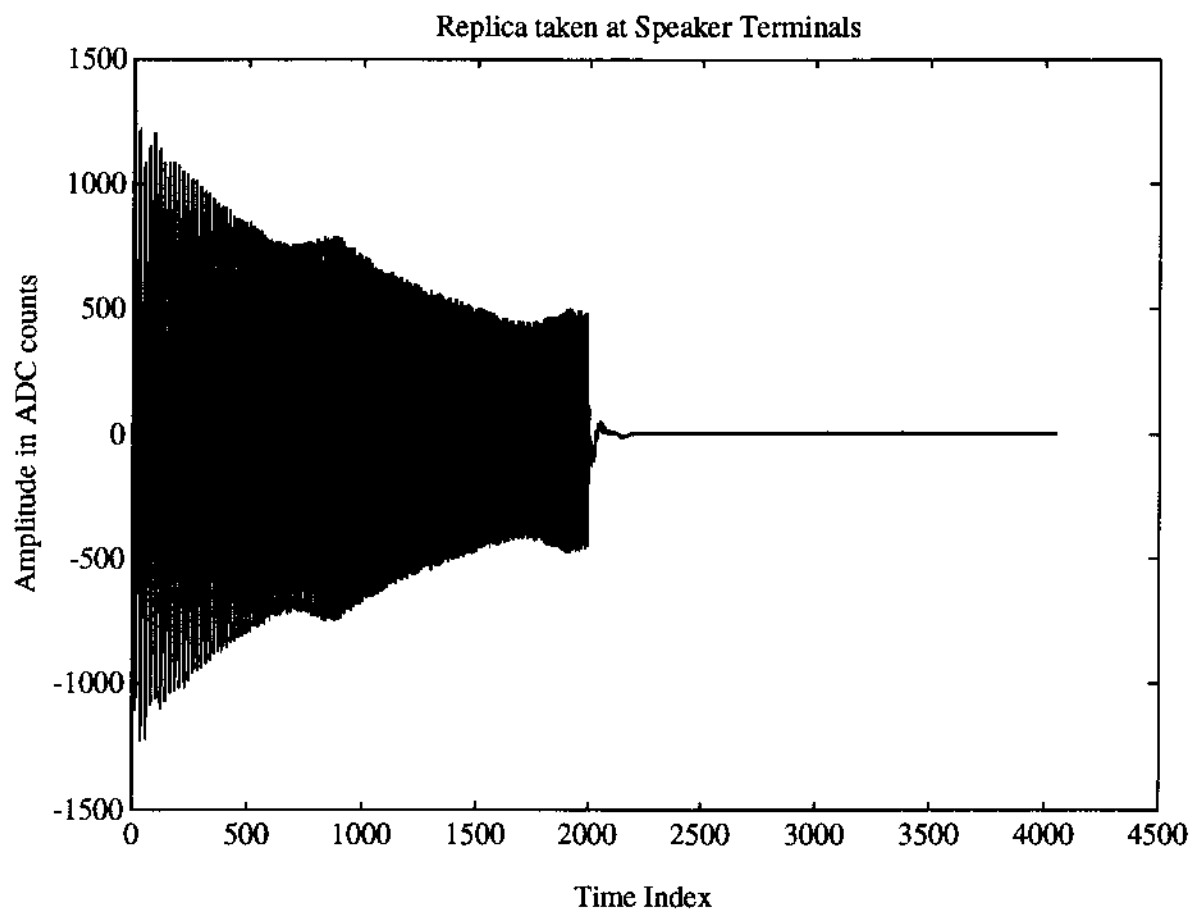


Fig. 3

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Using Chirper signal and convolution to find speed of sound

Lord60 is replica.

Work by R. Lord and B Egaas

120.88	76.13	36.38	12.31	4.31	distance(inches)
3.070352	1.933702	0.924052	0.312674	0.109474	distance(m)
1859	1195	607	254	146	time from convolut
1857	1190	618	253	150	
1847	1202	606	251	147	
1852	1189	608	261	140	
1853.75	1194	609.75	254.75	145.75	avg time
3.070352	1.933702	0.924052	0.312674	0.109474	distance
4.656984	5.147815	4.81534	3.76663	3.63146	std time

distance time(ct) time(sec)(pred-meas)x

0.109	145.8	0.000729	0.008868	Regression Output:	
0.313	254.8	0.001274	-0.00666	Constant	-0.13424
0.924	609.8	0.003049	-0.00381	Std Err of Y Est	0.00681
1.93	1194	0.00597	0.000355	R Squared	0.999977
3.07	1853.8	0.009269	0.001242	No. of Observations	5
				Degrees of Freedom	3

↑  
residue  
std = 5 mm

X Coefficient(s) 345.8283 velocity  
Std Err of Coef. 0.956759

0.002767 fract. er

del T	T (C)	T
5.314844	25.31484	77.56672

std T 2.781276

Datafiles are listed in lab notebook.

Table 1

Fig. 4

