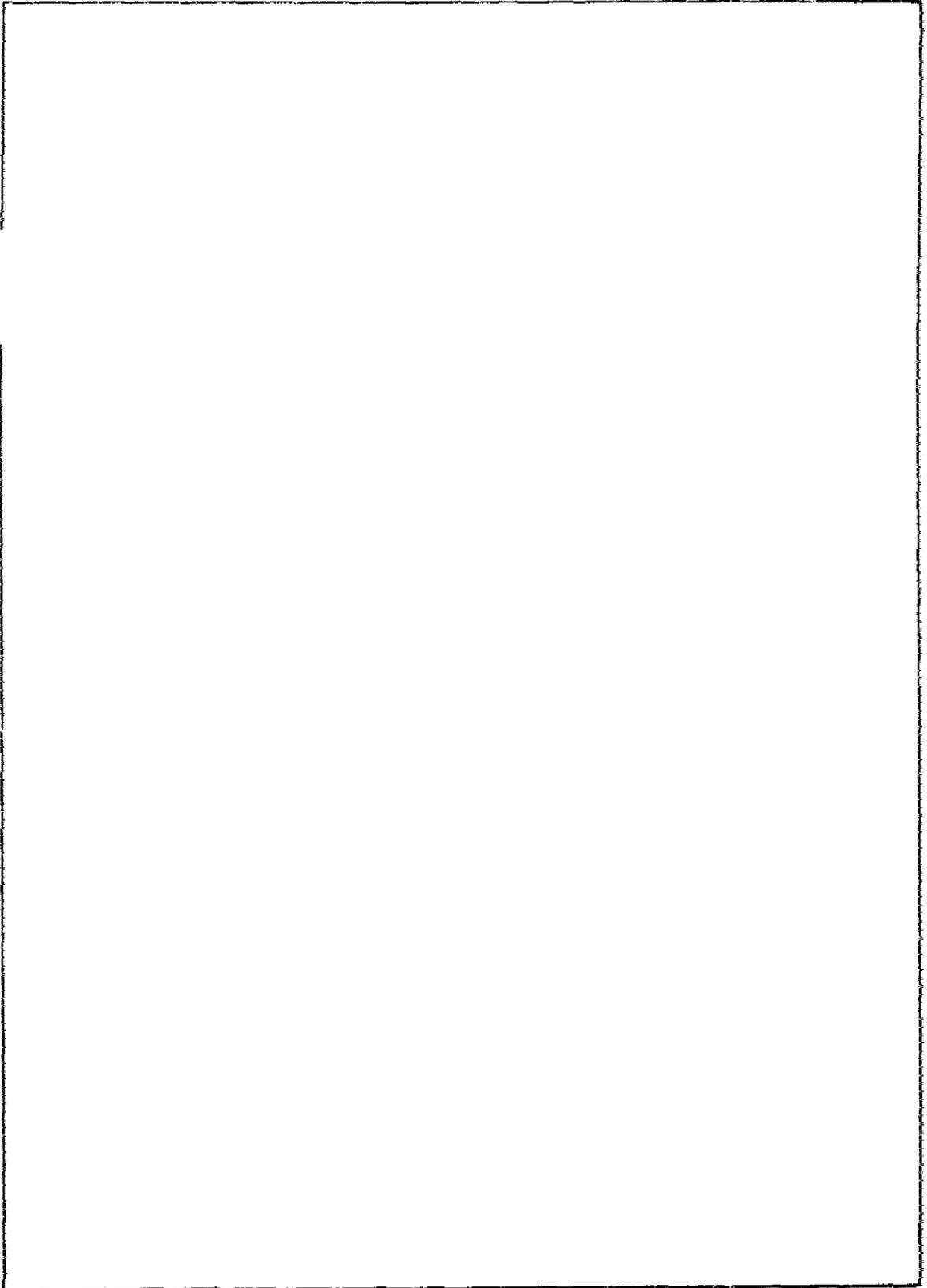


REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 8108	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SIDELOBE REDUCTION IN POLYPHASE CODES		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ben H. Cantrell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem R02-97 Project RR021-05-41 Program Element 61153N-21
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Office of Naval Research Arlington, Va. 22217		12. REPORT DATE April 13, 1977
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Signal Processing Pulse Compression Coding		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A means of reducing the sidelobes in Frank polyphase codes was obtained. This was achieved by applying a stepped amplitude weighting function across the length of the code. An example which reduces the sidelobes by about 10 dB for a code of length 256 is demonstrated.		

DD FORM 1473
1 JAN 73EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

1 SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



SIDELobe REDUCTION IN POLYPHASE CODES

INTRODUCTION

This report describes a means of reducing the sidelobes of a Frank polyphase code [1-3]. This is basically achieved by applying a stepped weighting across the code. The polyphase code is first reviewed, and then the means of weighting is described. Finally an example is given.

FRANK POLYPHASE CODE

The Frank polyphase code is probably most easily described by noting the elements of the code are the same as the elements in the argument portion of the discrete Fourier transform (DFT). The DFT is described by

$$S(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N}, \text{ for } k = 0, \dots, N-1. \quad (1)$$

This can be written in matrix form

$$S = W X, \quad (2)$$

where

$$S = \begin{bmatrix} S(0) \\ S(1) \\ \dots \\ S(N-1) \end{bmatrix}, W = \begin{bmatrix} W_{0,0} & W_{0,1} & \dots & W_{0,N-1} \\ W_{1,0} & W_{1,1} & \dots & \dots \\ \dots & \dots & \dots & \dots \\ W_{N-1,0} & \dots & \dots & W_{N-1,N-1} \end{bmatrix}, \text{ and } X = \begin{bmatrix} X(0) \\ X(1) \\ \dots \\ X(N-1) \end{bmatrix}$$

The elements $W_{k,n}$ are

$$W_{k,n} = e^{-j2\pi nk/N}. \quad (3)$$

The Frank polyphase code is obtained by sequentially reading the elements of W one row at a time from left to right starting from element $W_{0,0}$. For example for $N = 2$ the resulting code would be

$$W_{0,0} \ W_{0,1} \ W_{1,0} \ W_{1,1}.$$

The code is compressed by crosscorrelating the returned signal with the inverted-order complex conjugate of the code. The reverse-order complex conjugate would be obtained by reading the elements of W one row at a time from right to left starting from element $W_{N-1,N-1}$. For example for $N = 2$ the resulting code to crosscorrelate with is

$$W_{1,1}^* \ W_{1,0}^* \ W_{0,1}^* \ W_{0,0}^*.$$

Manuscript submitted February 7, 1977.

A circuit for performing the crosscorrelation is given in Fig. 1, which is a common correlator.

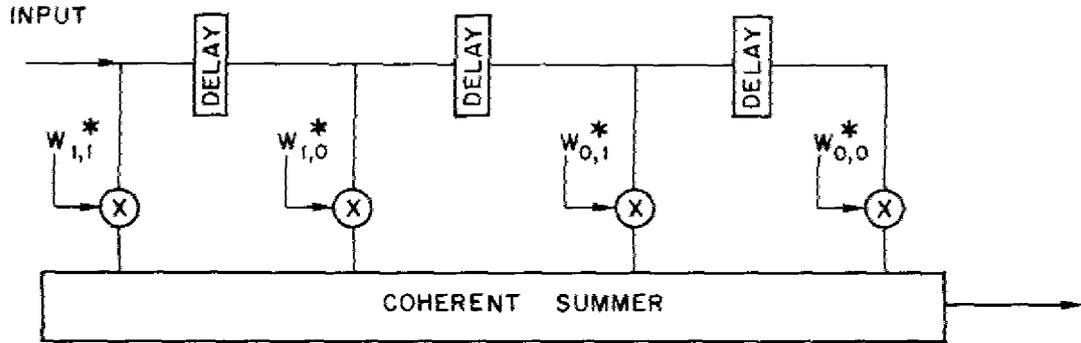


Fig. 1 -- Circuit for compressing an $N = 2$ Frank polyphase code

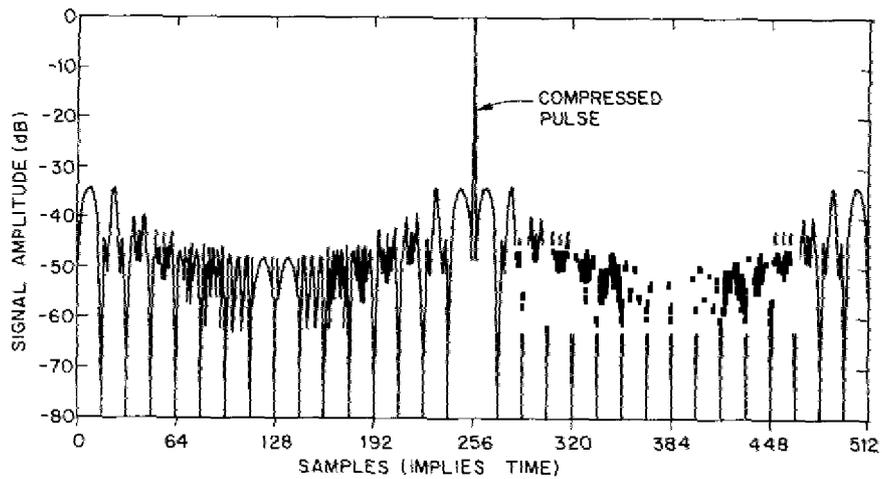


Fig. 2 -- Compressed waveform for $N = 16$ (uniform weighting)

The coherent summer adds the real and imaginary parts separately. The compressed pulse for $N = 16$, or a compression ratio of 256, is shown in Fig. 2. The results show peak sidelobes in the order of 33 dB.

SIDELOBE REDUCTION

The sidelobes of the code can be reduced by applying an additional weighting to the sequence used in the crosscorrelation process. The weights used in the crosscorrelation multiplier is specified by

$$Z_{k,n} = C_k W_{k,N} \tag{4}$$

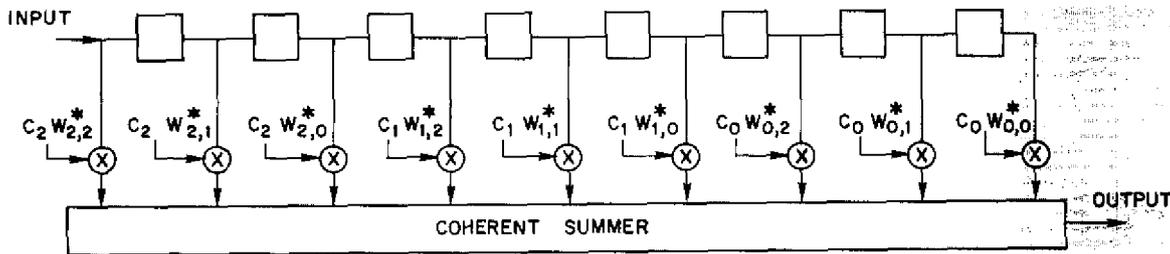


Fig. 3 -- Circuit for compressing an $N = 3$ Frank polyphase code with weighting for sidelobe reduction

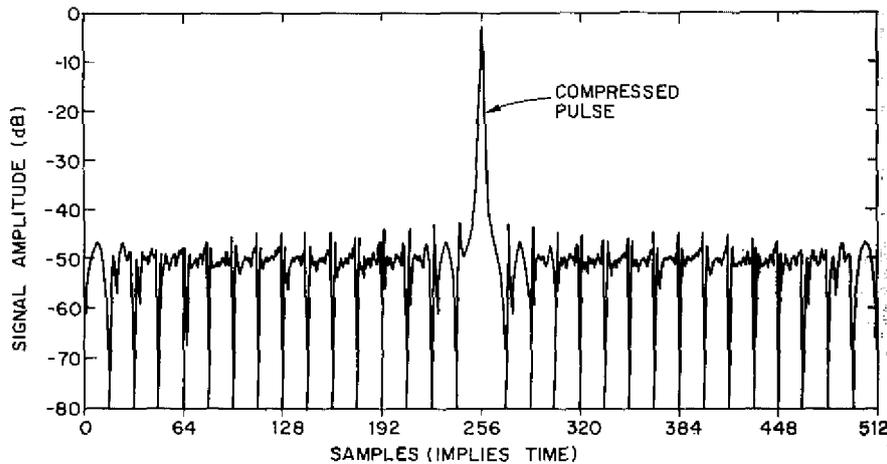


Fig. 4 -- Compressed waveform for $N = 16$ (weighted)

The weight C_k remains constant for each row of the W matrix. The weight C_k used is a Hamming weight [3]. The equation is

$$C_k = a + (1 - a) \cos \frac{\pi \left[\frac{k}{N-1} \right] - 1}{2} \quad (5)$$

where N is even and $k = 0, 1, 2, \dots, N - 1$. The crosscorrelator structure for $N = 3$ is shown in Fig. 3. The compressed pulse for $N = 16$ using the weighting specified by (4) and (5) for $a = 0.15$ is shown in Fig. 4. Comparing Figs. 2 and 4, we find the sidelobes have been reduced and the peak sidelobe has been reduced in the order of 10 dB.

SUMMARY

A means of weighting for reducing the sidelobe levels in the compressed pulse of a Frank polyphase code was obtained. This was achieved by using a stepped weighting such as a Hamming weighting across the code. The results showed improvements of the order of 10 dB in peak sidelobe levels.

ACKNOWLEDGMENTS

I thank Frank Kretschmer and Bernard Lewis for discussing the problem with me.

REFERENCES

1. R. L. Frank and S. A. Zadoff, "Phase Shift Pulse Codes with Good Periodic Correlation Properties," *IEEE Trans. (Correspondence)* IT-8, 381-382 (1962).
2. R. L. Frank, "Polyphase Codes with Good Nonperiodic Correlation Properties," *IEEE Trans.* IT-9, 43-45 (1963).
3. C. E. Cook and M. Bernfeld, *Radar Signals, An Introduction to Theory and Application*, New York, Academic Press, 1967.