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VALIDATION OF THE MULTI-DOPPLER QUADRATURE CORRELATOR (MDQC).(U)

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TECHNICAL NOTE

VALIDATION OF THE MULTI-DOPPLER QUADRATURE CORRELATOR (MDQC)

by

Dr. D. B. Doan

Submitted to

Commanding Officer and Technical Director
Naval Undersea Research and Development Center
San Diego Division
San Diego, California 92132

Attn: Mr. Louis Strauss, Code 603

7 January 1970

SAN DIEGO LABORATORY

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1. INTRODUCTION

This report validates and documents the operation of the Multi-Doppler Quadrature Correlator (MDQC). A previous technical note[1] described the analytic technique utilized in the development of the MDQC.

Section 2 of this report describes the method used to validate the results obtained from the MDQC. Included in this section are the expected theoretical values and a summary of the actual results. The computer program used in the validation is found in Appendix A.

Appendices B, C, D, and E contain descriptions and program listings of the special TIMFAX Black Boxes required in order to use the Multi-Doppler Quadrature Correlator.

[1] TRACOR Document No. SD/69-008-U, "A Technique for a Multi-Doppler Quadrature Correlation Processing Scheme," 5 August 1969.

2. VALIDATION OF THE MULTI-DOPPLER QUADRATURE CORRELATOR (MDQC)

The operation of the Multi-Doppler Quadrature Correlator was validated by using the MDQC routine to correlate a linear FM slide. Because of the range-Doppler ambiguity of an LFM pulse, correlation peaks are obtained in all channels. The relative delay, Δt, between adjacent channels depends on the bandwidth, B, and pulse length, T, of the signal, and is given by

$$\Delta t = \Delta f \; T/B, \qquad (1)$$

where Δf is the channel spacing. For the LFM up-slide, which was used in the validation program, the peaks in the up-Doppler channels will occur later than the ones in the zero-Doppler channel. The peaks in the down-Doppler channels will occur earlier.

Since neither the signal nor the reference have been time-compressed, there is no dilation loss involved here. The amplitude of the correlation peaks, relative to the zero Doppler channel, is determined by the overlap loss, and is given by

$$L = 1 - \left|\frac{\Delta t}{T}\right| = 1 - \left|\frac{\Delta f}{B}\right| . \qquad (2)$$

The validation program consists of the TIMFAX topology shown in Figure 1. The Black Box, PGEN1, generates an LFM slide from 100 to 200 Hz, sampled at 1000 Hz. The pulse is 1 second long. CORGN1 and CORGN2 generate, respectively, sine and cosine representations of the same LFM signal. The references from the two uses of CORGN are each broken into 7 pieces by the two uses of MSCAT. MSCAT also clips the references, and reformats them into a form suitable for MDQC. The 7 output channels from MDQC are processed through 7 uses of LOCAL and 7 uses of LOCPR to extract and print the maximum value in each channel and the time at which it occurred.

MDQC1 uses an 8 point Fast Fourier Transform to produce 7 Doppler channels. The spacing between the channels is thus 7/8

Hz. The effect of low-pass filtering prior to comb filtering which is inherent in the design of MDQC is given in Equation 12 of Reference 1 as

$$I = \frac{\sin \frac{\omega_o T}{2N}}{\frac{\omega_o T}{2N}} \qquad (3)$$

where ω_o is the Doppler offset (in radians/second), T is the pulse length in seconds and N is the number of pieces in the reference. Since the channel spacing is 7/8 Hz,

$$\omega_o = 2\pi \frac{7}{8} n, \qquad (4)$$

where n is the channel number, measured from the zero-Doppler channel. The filter loss on the nth channel is thus

$$I_n = \frac{\sin \frac{\pi n}{8}}{\frac{\pi n}{8}}$$

(Note that this factor can usually be ignored. However, the test case violates the restriction given by Equation 1 of Reference 1, resulting in higher than normal filter loss.)

The results of the validation program are predicted to be as follows:

(a) The amplitude of the zero Doppler channel for a clipped reference will be equal to the average absolute value of the input signal. Since PGEN1 produces a sinusoid with a peak amplitude of 1, the peak in the zero-Doppler channel will be $2/\pi = .6366$.

(b) The amplitude of the nth channel will be modified by Equations 2 and 5 and will be

$$R_n = \frac{2}{\pi}\left(1 - \left|\frac{7n}{800}\right|\right)\left(\frac{\sin\frac{\pi n}{8}}{\frac{\pi n}{8}}\right) . \qquad (6)$$

(c) The time of the peak in the nth channel will be

$$t_n = 1 + \frac{7n}{800} , \qquad (7)$$

where $n > 0$ represents the nth up-Doppler channel and $n < 0$ represents the nth down-Doppler channel.

The results predicted by Equations 6 and 7 are tabulated in TABLE I, together with the actual results obtained from exercising the MDQC routine. The agreement is excellent.

TABLE I

COMPARISON OF THEORETICAL VALUE WITH COMPUTED RESULTS FROM MDQC

Channel	Measured Amplitude	Theoretical Amplitude	Measured Time	Theoretical Time
-3	.4868	.4861	.973	.9737
-2	.5619	.5631	.983	.9825
-1	.6171	.6149	.991	.9913
0	.6359	.6366	.999	1.0000
1	.6139	.6199	1.008	1.0088
2	.5690	.5631	1.016	1.0175
3	.4957	.4861	1.025	1.0263

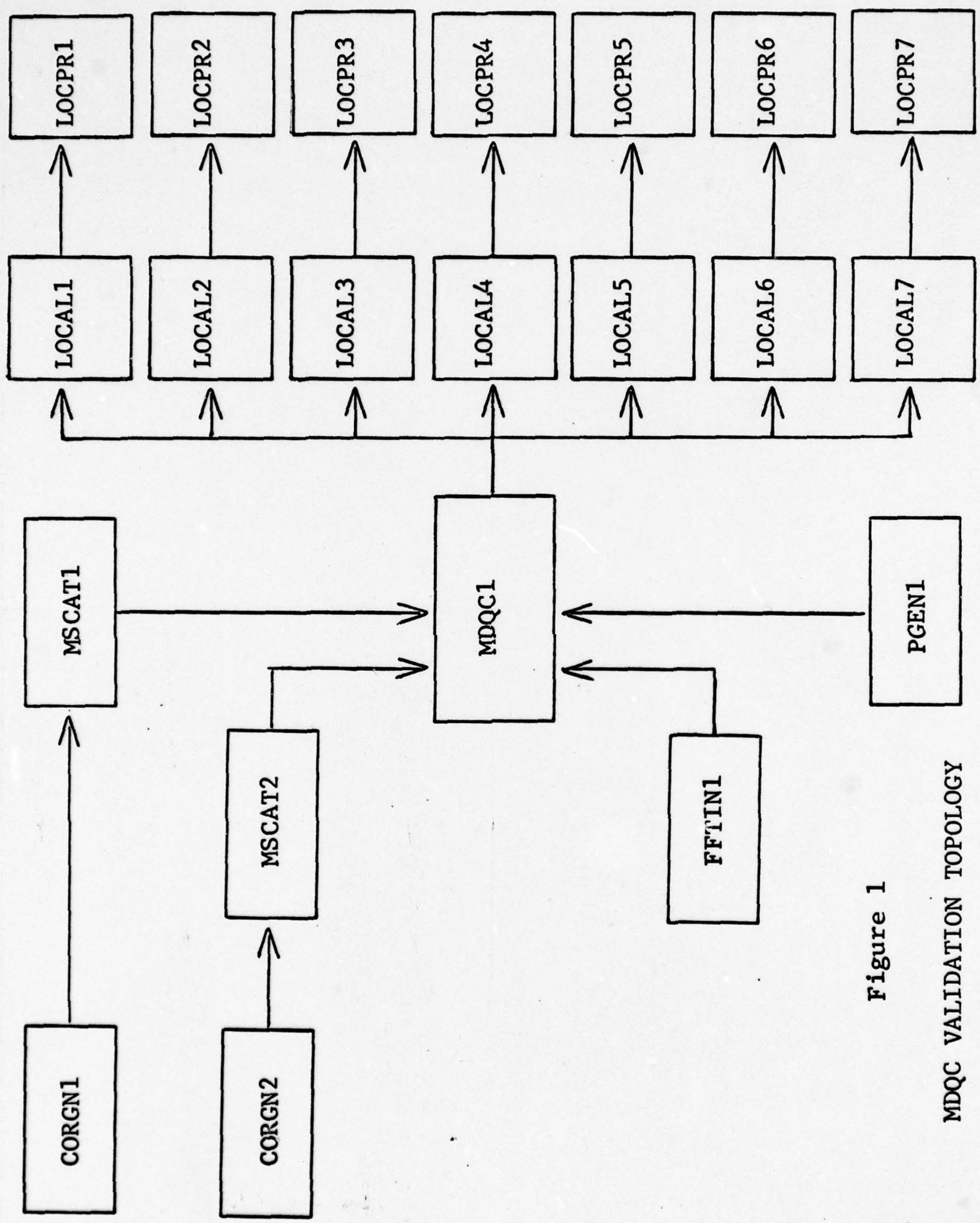

Figure 1

MDQC VALIDATION TOPOLOGY

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APPENDIX A

VALIDATION COMPUTER PROGRAM FOR MDQC

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APPENDIX A

VALIDATION COMPUTER PROGRAM FOR MDQC

TIMFAX TOPOLOGY

```
15    CORGN1
      CORGN2
      MSCAT1          CORGN1
      MSCAT2          CORGN2
      FFTIN1
13    PGEN1,A
      MDQC1,BCDEFGH MSCAT1,MSCAT2,FFTIN1,PGEN1
      LOCAL1          MDQC1B
      LOCAL2          MDQC1C
      LOCAL3          MDQC1D
      LOCAL4          MDQC1E
      LOCAL5          MDQC1F
      LOCAL6          MDQC1G
      LOCAL7          MDQC1H
11    LOCPR1          LOCAL1A,LOCAL1B
      LOCPR2          LOCAL2A,LOCAL2B
      LOCPR3          LOCAL3A,LOCAL3B
      LOCPR4          LOCAL4A,LOCAL4B
      LOCPR5          LOCAL5A,LOCAL5B
      LOCPR6          LOCAL6A,LOCAL6B
      LOCPR7          LOCAL7A,LOCAL7B
```

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TIMFAX DATA CARDS

```
PGEN1=      1000.,  1.,    1.,    100.,  200.,  P24=1000.  ,  P26=105.
CORGN1=      100.,  200.,  .001,  -1000.
CORGN2=      100.,  200.,  .001,  -1000.,        P7=1.
MSCAT1=      7,     1000,  1
MSCAT2=      7,     1000,  1
FFTIN1=      8
MDGC1=       7,     7,     7,     1.0,   1000,  105
LOCAL1=      3.,    9.
LOCAL2=      3.,    9.
LOCAL3=      3.,    9.
LOCAL4=      3.,    9.
LOCAL5=      3.,    9.
LOCAL6=      3.,    9.
LOCAL7=      3.,    9.
LOCPR1=      .001,  0.,    1.
LOCPR2=      .001,  0.,    1.
LOCPR3=      .001,  0.,    1.
LOCPR4=      .001,  0.,    1.
LOCPR5=      .001,  0.,    1.
LOCPR6=      .001,  0.,    1.
LOCPR7=      .001,  0.,    1.
   END OF DATA.SET        1
```

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TIMFAX PRINTOUT

```
                                                          SCRATCH STORAGE=  772
MDQC1       P(3) CHANGED TO     8
MDQC1       PIECES STORED IN AJ=     7, AI=     7, SCRATCH=     0, TOTAL PIECES=   14,
MSCAT1      N=  143, K=   19, L= 5, S= 1      PIECE   1
MSCAT1      N=  143, K=   12, L= 4, S= 1      PIECE   2
MSCAT1      N=  143, K=   20, L= 4, S= 1      PIECE   3
MSCAT1      N=  143, K=   20, L= 3, S= 1      PIECE   4
MSCAT1      N=  143, K=   16, L= 3, S= 1      PIECE   5
MSCAT1      N=  143, K=   16, L= 3, S= 1      PIECE   6
MSCAT1      N=  142, K=   20, L= 5, S= 0      PIECE   7
MSCAT1      FIELD STORAGE AVAILABLE= 1005, USED=  172
MSCAT2      N=  143, K=   20, L= 5, S= 1      PIECE   1
MSCAT2      N=  143, K=   12, L= 4, S= 1      PIECE   2
MSCAT2      N=  143, K=   20, L= 4, S= 1      PIECE   3
MSCAT2      N=  143, K=   20, L= 3, S= 1      PIECE   4
MSCAT2      N=  143, K=    8, L= 3, S= 1      PIECE   5
MSCAT2      N=  143, K=   16, L= 3, S= 1      PIECE   6
MSCAT2      N=  142, K=   19, L= 5, S= 0      PIECE   7
MSCAT2      FIELD STORAGE AVAILABLE= 1005, USED=  170
```

```
LOCPR1         CYCLE      1
    PEAK AT WORD        903,TIME =     .9030SEC., S/N= -16.3759DB, PK.=    .1518
    PEAK AT WORD        973,TIME =     .9730SEC., S/N=  -6.2538DB, PK.=    .4868
    PEAK AT WORD       1043,TIME =    1.0430SEC., S/N= -10.4048DB, PK.=    .3018
LOCPR2         CYCLE      1
    PEAK AT WORD        983,TIME =     .9830SEC., S/N=  -5.0073DB, PK.=    .5619
    PEAK AT WORD        996,TIME =     .9960SEC., S/N= -15.8265DB, PK.=    .1617
    PEAK AT WORD       1052,TIME =    1.0520SEC., S/N= -13.7684DB, PK.=    .2049
LOCPR3         CYCLE      1
    PEAK AT WORD        991,TIME =     .9910SEC., S/N=  -4.1931DB, PK.=    .6171
    PEAK AT WORD       1006,TIME =    1.0060SEC., S/N= -16.1501DB, PK.=    .1558
    PEAK AT WORD       1061,TIME =    1.0610SEC., S/N= -19.7597DB, PK.=    .1028
LOCPR4         CYCLE      1
    PEAK AT WORD        999,TIME =     .9990SEC., S/N=  -3.9322DB, PK.=    .6359
    PEAK AT WORD       1014,TIME =    1.0140SEC., S/N= -16.4843DB, PK.=    .1499
    PEAK AT WORD       1026,TIME =    1.0260SEC., S/N= -21.3370DB, PK.=    .0857
LOCPR5         CYCLE      1

    PEAK AT WORD        940,TIME =     .9400SEC., S/N= -20.7679DB, PK.=    .0915
    PEAK AT WORD       1008,TIME =    1.0080SEC., S/N=  -4.2381DB, PK.=    .6139
    PEAK AT WORD       1024,TIME =    1.0240SEC., S/N= -17.3109DB, PK.=    .1363
LOCPR6         CYCLE      1
    PEAK AT WORD        946,TIME =     .9460SEC., S/N= -14.5449DB, PK.=    .1874
    PEAK AT WORD       1016,TIME =    1.0160SEC., S/N=  -4.8974DB, PK.=    .5690
    PEAK AT WORD       1032,TIME =    1.0320SEC., S/N= -18.5037DB, PK.=    .1188
LOCPR7         CYCLE      1
    PEAK AT WORD        955,TIME =     .9550SEC., S/N= -10.8150DB, PK.=    .2879
    PEAK AT WORD       1025,TIME =    1.0250SEC., S/N=  -6.0962DB, PK.=    .4957
    PEAK AT WORD       1094,TIME =    1.0940SEC., S/N= -17.3225DB, PK.=    .1361
```

APPENDIX B

MDQC BLACK BOX DESCRIPTION

APPENDIX B

MDQC BLACK BOX DESCRIPTION

PROGRAM NAME:	MDQC
NATURE OF WORK:	Black Box
PROGRAMMER's NAME:	David Doan
DATE:	October 25, 1969
COMPUTER LANGUAGE:	FORTRAN V

PROBLEM DEFINITION

MDQC is a Multi-Doppler Quadrature Correlator. The Cooley-Tuckey Fast Fourier Transform is used as a comb filter to produce the effect of a number of frequency shifted channels. The output of each filter is processed through an ideal envelope detector.

OPERATING INSTRUCTIONS

1. Topology Card:

The topology card requires four input channels as follows:

MDQCi MSCATj,MSCATk,FFTINℓ,SOURCEm

The first two fields must be produced by MSCAT; the first one is the real part of the reference, and the second, the imaginary part. The third field, which must be produced by FFTIN, contains the cosine reference required by the Fast Fourier Transform. The time function, indicated above by SOURCEm, is the input signal channel.

2. Data Input:

All P-array entries are fixed point unless noted.

P(1) = Number of outputs (teeth) from comb filter

P(2) = Number of output channels, ≤ P(1)

P(3) = Size of Fast Fourier Transform,
≧ P(1)
≧ P(1) of MSCAT
= P(1) of FFTIN
= a power of 2

P(4) = Output scale factor, SV = 1.0 (floating point)

P(5) = Estimated length of correlator reference ≧ actual length

P(6) = Estimated input record length ≧ actual record length

P(7) = Number of pieces into which reference is broken. SV provides automatic transfer of this value from MSCAT. See Note below. Must equal P(1) of MSCAT.

P(8) = 0 for fixed point time function input
= 1 for floating point time function input. SV provides automatic transfer of this value from MSCAT. See Note below. Must equal P(3) of MSCAT.

NOTE: If the fields from MSCAT are input directly to MDQC, value for P(7) and P(8) need not be supplied. If the fields are being read from the drum or tape, P(7) and P(8) must be supplied.

See Section 8, Program Conditions and limitations for a further discussion of the P-array values required.

3. Input Fields:

The input fields must be produced by the boxes shown in (1) above. The topology for generation of the complex references should be one or the other of the following to provide for Doppler shift which increases with channel number.

If the references are directly generated, as for instance with CORGN, then the topology should be

```
05  CORGN1     <------------ sine wave
    MSCAT1     CORGN1
    CORGN2     <------------ cosine wave
    MSCAT2     CORGN2
03

    MDQC1      MSCAT1,MSCAT2,FFTIN1, . . .
```

If the references are to be obtained by quadrature heterodyning, the topology should be

```
13  - - -
    PGEN1      <------------ cosine
    PGEN2      <------------ sine
    TMUL1      PGEN1,SOURCEn
    TMUL2      PGEN2,SOURCEn
    FLTPL1     FSET1,TMUL1
    FLTPL2     FSET1,TMUL2
    RFEXT1     FLTPL1B
    RFEXT2     FLTPL2B
05  MSCAT1     RFEXT1
    MSCAT2     RFEXT2
03  - - -
    MDQC1      MSCAT1,MSCAT2,FFTIN1, . . .
```

4. Output Fields:

Channel A is used as a scratch field. It should not be referenced by any other Box. It can be overlayed by fields not used in the Section 3 containing MDQC.

5. Input Time Function:

The input time function may be either fixed or floating point. The mode requested is determined by P(8).

6. Output Time Functions:

The output time functions are floating point. P(2) channels are produced. If P(1) > P(2), the channels are block-multiplexed in the following manner:

Channels 1 through P(2) - 1 are multiplexed by a factor of

$$M_1 = \text{Int}\left[\frac{P(1) + P(2) - 1}{P(2)}\right] .$$

Channel P(2) is multiplexed by a factor of

$$M_2 = P(1) - (P(2) - 1) \cdot M_1 \quad .$$

Note that some combinations of P(1) and P(2) will cause M_2 to be zero. This situation should be avoided, since extra storage is reserved which will not be used.

Block multiplexing means that a full record (equal in length to the input record) is output for each multiplexed channel, followed by a full record of the next multiplexed channel. This is in contrast to the sample by sample multiplexing used by MPX and DEMPX. The block-multiplexed output must be demultiplexed by BDMPX.

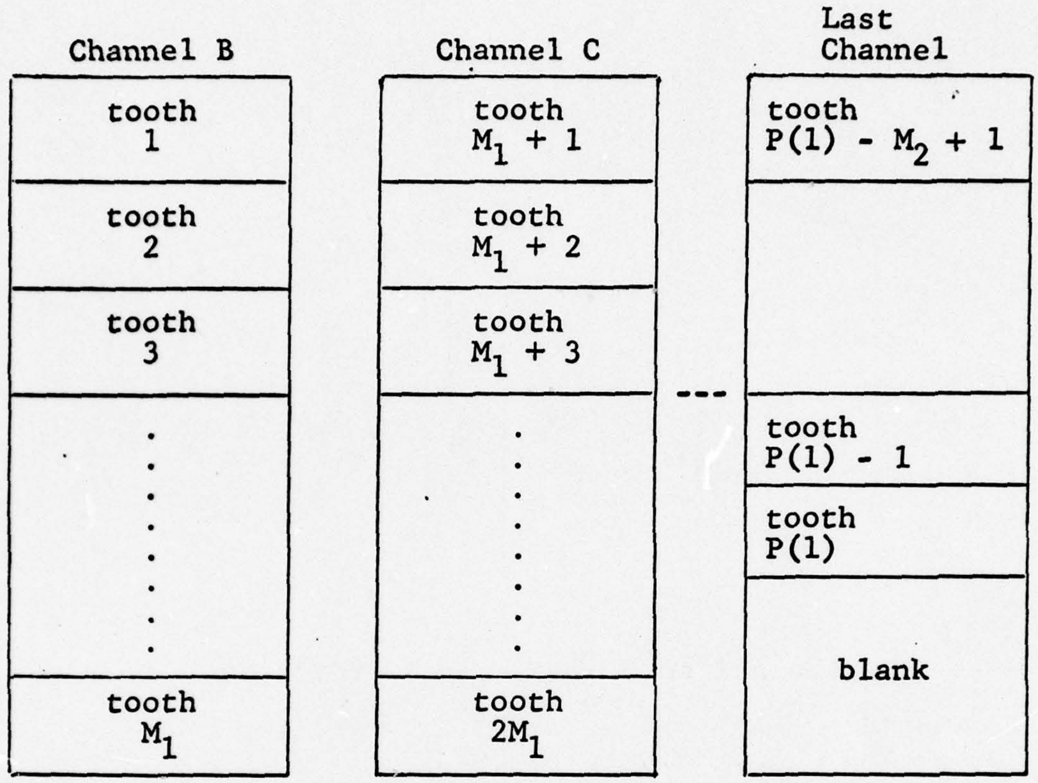
If the output is to be held in floating point, P(2) must be less than or equal to 17.

The first time function output is on Channel B. The Doppler shift associated with each output from the filter is

$$f = \frac{\overline{P(1)}}{P(3)T}\left[n - \text{Int}\,\frac{P(1)}{2}\right] ,$$

where $\overline{P(1)}$ is the P(1) input to MSCAT, f is the Doppler shift in Hertz, T is the pulse length in seconds, and n is the "tooth" number prior to multiplexing. P(3) in this expression will be a power of 2. If P(1) is even, there will be one more up-Doppler channels than there are down-Doppler channels.

The format of the output time function is as follows:



7. Printer Output:

One line of print is always produced:

MDQCn PIECES STORED IN AJ = ___, AI = ___, SCRATCH = ___,
TOTAL PIECES = ___, SCRATCH STORAGE = ___

This message indicates the allocation of temporary storage within the Box.

If P(3) is not a power of 2, the message

MDQCn P(3) CHANGED TO ____________

will be produced, indicating that P(3) has to be set to the next higher power of 2.

The following messages indicate fatal errors. The run is aborted if any of them appear.

MDQCn UNBALANCED REFERENCES

NO. OF PIECES j,k

T-F MODE l,m

The number of pieces or the time function mode was not the same for both references.

MDQCn UNBALANCED REFERENCES

SHORT REF LENGTH j,k
NO. LONG REFERENCES l,m

The length of the two references was not the same.

MDQCn OVERFLOW IN AI/PC STORAGE, REAL/IMAG PIECE j

LAST REQUEST = k, l available

Probably caused by too small a value for P(6), the estimated record length.

MDQCn P(3) = ___ IS ILLEGAL

is produced if P(3) < P(1)

MDQCn INCREASE P(5) BY AT LEAST ___

P(5) is less than the total length of the reference supplied.

MDQCn PARAMETER ERROR
EXPECTED PIECES = ___, REAL = ___, IMAG = ___
EXPECTED MODE = ___, REAL = ___, IMAG = ___
P(7) is not equal to P(1) of MSCAT or
P(8) is not equal to P(3) of MSCAT.

MDQCn WRONG FFTIN FIELD
_____ EXPECTED, ____ SUPPLIED

P(3) does not agree with P(1) of FFTIN

THE FIELD FROM _____ OR _____
IS AN ILLEGAL INPUT TO MDQCn UNLESS P(7) AND
P(8) ARE MANUALLY SET.

If the references are recorded on tape or drum, the parameters P(7) and P(8) must be supplied in the data input. If they are not supplied, the first two input fields must be supplied directly from MSCAT.

The following diagnostics were included for check-out purposes and should not occur:

MDQCn CORR RECORD TOO LONG, PIECE ___
MDQCn REFERENCE ERROR, I = ___
NRR = ___, REALF = ___
NIR = ___, IMAGF = ___

ERROR, REFERENCE LENGTH SUPPLIED TO MDQCn IS SMALLER
THAN THE LENGTH OF THE REFERENCE SUPPLIED

8. Program Limitations or Conditions:

MDQC must be in Section 3.

The parameters for MDQC and MSCAT are as follows: (P-array values are for MDQC, unless indicated by an over-score. Over-scored values are for MSCAT.)

a. Determine the maximum Doppler shift, fmax, from other data known about the problem (relative velocities, range of interest, etc.). This value may not exceed

$$fmax_{-1} = \frac{.89\ fo}{BT} \quad \text{for 1 dB dilation loss, or} \qquad (1)$$

$$fmax_{-3} = \frac{1.59\ fo}{BT} \quad \text{for 3 dB dilation loss,} \qquad (2)$$

where fo is the center frequency of the signal in the water, B is the bandwidth, and T is the pulse length.

b. The number of pieces is limited by

$$\overline{P(1)} \geq 4\ fmax\ T. \qquad (3)$$

c. The frequency resolution is given by

$$\Delta f = \frac{\overline{P(1)}}{P(3)\ T} \quad . \qquad (4)$$

To minimize splitting loss,

$$\Delta f \leq \frac{1}{2T}\ \text{, or} \qquad (5)$$

$$P(3) \geq 2\ \overline{P(1)}\ . \qquad (6)$$

d. P(3) must be a power of 2.

e. Juggle $\overline{P(1)}$ and P(3) to satisfy Equations (3) and (6), and to provide a convenient value of Δf.

f. The total number of outputs teeth is then

$$P(1) = \frac{2\ fmax\ T\ P(3)}{\overline{P(1)}} + 1 \quad . \qquad (7)$$

The input references must be constructed in accordance with the description in Section 3, above. Otherwise, the sign of the Doppler shift may be changed.

WARNING: If P(1) and P(2) are such that the time function outputs are multiplexed, the outputs must be demultiplexed by using BDMPX before writing the output to tape or drum. This requirement exists because the output record length from a tape - or drum - read Box is not necessarily the same as the record length at the input to the tape - or drum - write Box. Under these conditions, the subsequent demultiplex operation will be hopelessly confused.

9. Storage:

2771_8 or 1529_{10} words

10. Subroutines Referenced:

CORR2, CORR3, FIXTST, FLTTST, TWOPOW, BBNAME, PVAL, CALSAL, CTFFT, EREXIT, NPRT$, NI01$, NI02$, SQRT, NERR3$, CBNAME.

PROCESSING METHOD

MDQC is a digital simulation of the type of correlator in which a comb filter follows the multiplier. The general arrangement of such a correlator is shown in Figure 1.

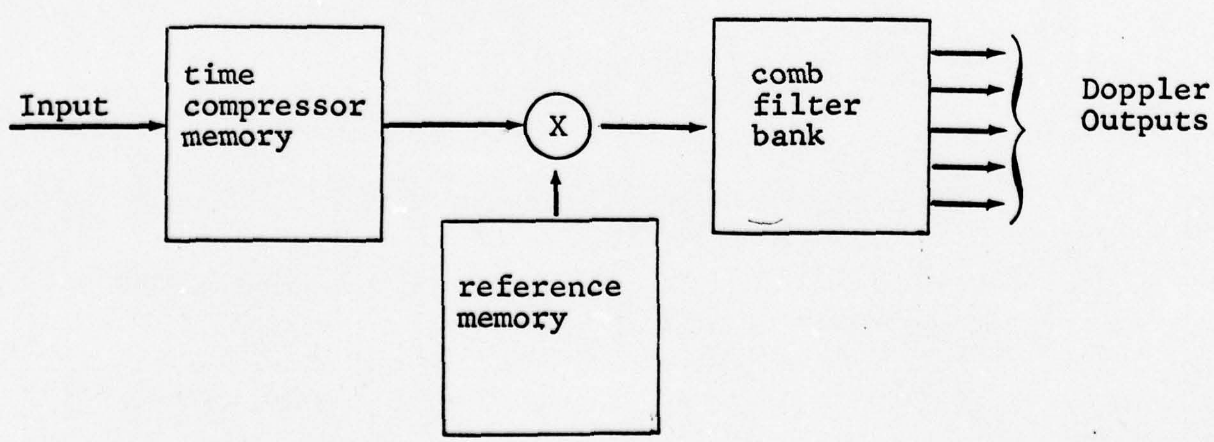


Figure 1

There are two problems in directly simulating the simple method shown in Figure 1. The sampling rate at the input to the comb filter, which is equal to the input sampling rate times the time compression factor, is extremely high. This makes simulation of the filter very time consuming. The method shown is unable to distinguish between positive and negative Doppler, since the pass band of an ordinary filter depends only on the absolute value of the frequency.

These problems are solved in the following way:

(1) The reference is replaced by a quadrature (complex) reference.

(2) The multiplier is followed by an "integrate-and-dump" low pass filter.

(3) The comb filter is simulated by using the Fast Fourier Transform (FFT).

This arrangement is shown in Figure 2.

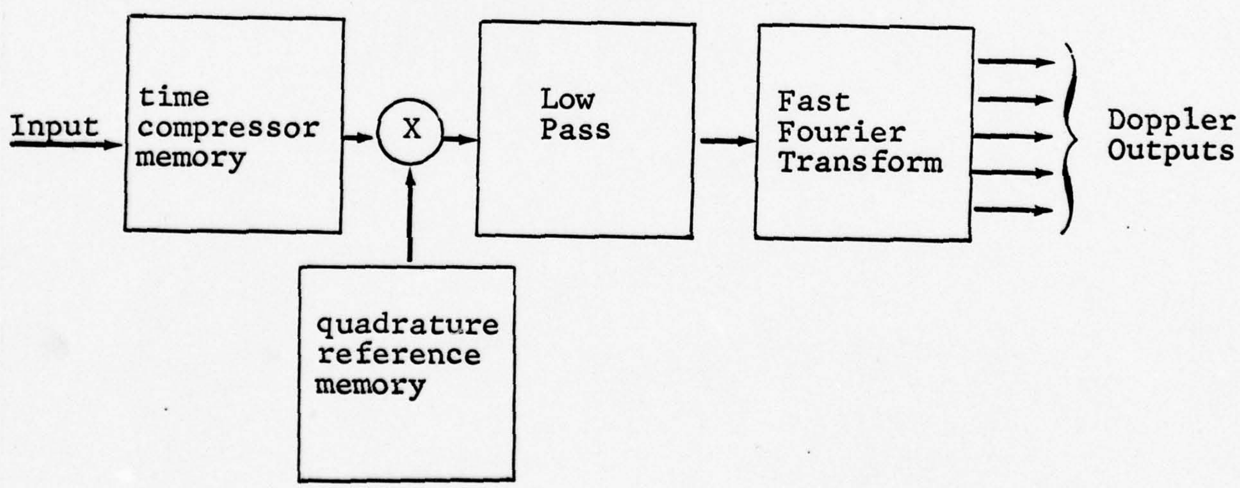


Figure 2

The integrate-and-dump low pass filter greatly reduces the sampling rate at the FFT ("comb filter"), thus reducing the running time. The use of a quadrature reference in combination with the Fast Fourier Transform provices a method for retaining Doppler sense.

Mathematically, the Multi-Doppler Quadrature Correlator consists of the evaluation of the equations given below.

The output of the low pass filter is given by

$$I_n(k) = \frac{N}{K} \sum_{m=\frac{Kn}{N}}^{\frac{K(n+1)}{N}} X_{k+m}\, r_m \,, \qquad (1)$$

where N = the number of pieces into which the reference is broken

K = the number of samples in the complete reference

X_k = the signal input (real)

amd r_m = the complex reference.

The output of the comb filter is given by

$$\rho(k,\ell) = \left| \frac{1}{N} \sum_{n=0}^{N_o-1} I_n(k) e^{-j\frac{2\pi \ell n}{N}} \right| \,, \qquad (2)$$

which is just the discrete Fourier Transform of $I_n(k)$. N_o is a power of 2, greater than or equal to N.

The parameter, k, is the sample number of the output time function. The parameter, ℓ, is the Doppler parameter. It is related to the Doppler shift at the center frequency by

$$f = \frac{\ell N}{TN_o} \quad , \qquad (3)$$

where T is the length of the pulse, and ℓ may be either positive or negative.

The absolute value indicated in Equation (2) performs the function of an ideal envelope detector. No further rectification or averaging is required.

For a more complete mathematical treatment of this process, see D. B. Doan, "A Technique for a Multi-Doppler, Quadrature Correlation Processing Scheme," TRACOR Document No. SD/69-008-U, August 1969.

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APPENDIX C

MDQC PROGRAM LISTING

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APPENDIX C

MDQC PROGRAM LISTING

```
      SUBROUTINE MDQCO (N,P)
      DIMENSION P(1),REALF(1),IMAGF(1),AI(1),COREF(1),PC(1),IOUTT(1),
     1   NOUT(1),AJ(1),NAME(2), JNAME(2), KNAME(2)
      IMPLICIT INTEGER (A-Z)
      REAL B, AI, AJ, PC, COREF, Z
      PARAMETER PTQ=8
      DEFINE Q(I)=P(I+PTQ)
C        THE VARIABLE Q(I) IS THAT PORTION OF THE P-ARRAY USED
C        FOR INTERNAL SCRATCH STORAGE
      DEFINE AAI(I)=AI(I)
      DEFINE AAJ(I)=AJ(I)
      DEFINE PPC(I)=PC(I)
      EQUIVALENCE (NRR,NAME(1)), (NIR,NAME(2))
      EXTERNAL CORR2, CORR3
      N=13
      P(4)=BOOL(1.0) @ STD VALUE FOR SCALE FACTOR
      P(7)=-1 @ SV FOR AUTOMATIC
      P(8)=-1 @ SV PARAMETER TRANSFER
      RETURN
      ENTRY MDQC1 (P,INPF,INPT,KINPT,LAG,IOUTF,ISIZE,IOUTT,KOUTT,A,B)
      CALL FIXTST (P(1),P(3))
      CALL FLTTST (P(4),P(4))
      CALL FIXTST (P(5),P(8))
      NCT=TWOPOW (P(3), $720) @ IS P(3) A POWER OF 2
      IF(NCT .EQ. P(3)) GO TO 5 @ YES
      CALL BBNAME (NAME) @ NO, PRINT MSG AND SET TO NEXT HIGHER
      PRINT 1004, NAME, NCT @       POWER OF 2
      P(3)=NCT
    5 CALL CBNAME (1,JNAME)
      CALL CBNAME (2,KNAME)
      IF (AND(JNAME(1)-5HMSCAT,-63) .EQ. 0 .AND.
     1   AND ( KNAME(1) -5HMSCAT, -63 ) .EQ. 0 ) GO TO 6
      IF (P(7) .GT. 0 .AND. P(8) .GE. 0) GO TO 7 @ JUMP IF NOT AUTO
      CALL BBNAME (NAME)
      PRINT 1012,JNAME,KNAME,NAME
      CALL EREXIT
    6 P(7)=PVAL(1,1) @ NO. PIECES FROM REAL REF GENERATOR
      P(8)=PVAL(1,3) @ T-F MODE FROM REAL REF GENERATOR
      IF(P(7) .NE. PVAL(2,1)) GO TO 700 @ ERROR IF REAL AND IMAG
      IF(P(8) .NE. PVAL(2,3)) GO TO 700 @ PARAMS NOT THE SAME
    7 IF(P(7) .GT. P(3)) GO TO 720 @ FFT AREA TOO SMALL
      INPF=3
      INPT=1
      KINPT=P(8)
      LAG=P(5) + 55
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```
      IOUTF=1
      Q(2)=(P(1) + P(2) - 1)/P(2) @ OUTPUT MPX FACTOR
      B=Q(2)
      Q(3)=Q(2) * P(2) @ PIECES WHICH CAN BE STORED IN AJ
      NS=2*P(7) @ TOTAL PIECES
      LC=P(5)/P(7) @ PREDICTED SHORT REF
      LCC=MOD(P(5), P(7)) @ NO. LONG REFS
      Q(4)=0 @ COUNTER FOR PIECES IN AI
      NRR=0 @ COUNTER FOR AI AREA USED

      NIR=0  @ COUNTER FOR AI AREA AVAILABLE
      DO 10 I=1,NS  @  LOOP TO ALLOCATE STORAGE
      IF(I .LE. Q(3)) GO TO 9 @ JUMP IF IN AJ
      NRR=NRR + P(6) @ P(6) IS ESTIMATED INPUT RECORD LENGTH
      IF(NRR .GT. NIR) GO TO 15 @ JUMP IF TOO MUCH
      Q(4)=Q(4)+1 @ COUNT PIECES IN AI
    9 IF(AND(I,1) .NE. 0) GO TO 10
      NIR=NIR + LC @ RELEASE AFTER EACH PAIR
      IF((I+1)/2 .LE. LCC) NIR=NIR+1  @  INCR FOR LONG REF
   10 CONTINUE  @ END ALLOCATION LOOP
   15 NCT=NS-Q(3)-Q(4) @ PIECES LEFT TO STORE
      IF(NCT .LT. 0) NCT=0  @  PREVENT ACCIDENTS
      ISIZE=P(7)*108 + P(3)*2 + NCT*P(6) @ SCRATCH FIELD
      Q(5)=ISIZE @ SIZE SCRATCH FIELD
      CALL BBNAME (NAME)
      PRINT 1008, NAME, P(3+PTQ), P(4+PTQ), NCT, NS, ISIZE
      Q(4)=Q(4) + Q(3) @ TOTAL PIECES IN AI AND AJ
      IOUTT(1)=P(2) @ NO. OUPUT CHANNELS
      IOUTT(2)=1 @ MAY BE UNBALANCED
      KOUTT=1
      A=0
      RETURN
      ENTRY MDQC2 (P)
      Q(1)=1 @ INITIALIZATION FLAG
      RETURN
      ENTRY MDQC3 (P,KFLG,REALF,IMAGF,COREF,IM,INPT,AI,LAG,PC,JM,
     1   IOUTT,AJ,NOUT)
      JMC=IM - LAG @ NO. NEW SAMPLES
      IF (JMC .GT. 0)  GO TO 18
      JMC=0
      JM=0
      GO TO 145
   18 IF(Q(1) .NE. 1) GO TO 30 @ SKIP INITIALIZATION
      IF(REALF(4) .NE. P(7)) GO TO 760 @ PARAMETER ERROR
      IF(REALF(5) .NE. P(8)) GO TO 760 @ PARAMETER ERROR
      IF(IMAGF(4) .NE. P(7)) GO TO 760 @ PARAMETER ERROR
      IF(IMAGF(5) .NE. P(8)) GO TO 760 @ PARAMETER ERROR
      IF(REALF(2) .NE. IMAGF(2)) GO TO 701 @ ERROR IF REAL AND IMAG
      IF(REALF(3) .NE. IMAGF(3)) GO TO 701 @ REF LENGTHS ARE NOT EQUAL
      NCT=COREF(2) @ CHECK LENGTH OF FFT REF
      IF(P(3) .NE. NCT) GO TO 750 @ ABORT IF DOESN'T MATCH
```

```
      NS = 2 * P(7)  @  TOTAL PIECES IN BOTH REFS
      NCT=0 @ P ARRAY POINTER
      NRR=7 @ REFERENCE ARRAY POINTER
      Z=BOOL(P(4))/FLOAT(REALF(6))
      DO 20 I=1,NS
      PC(NCT+1)=BOOL(REALF(2)) @ P(1) FOR CORR, REF LENGTH
      IF(((I+1)/2.LE.REALF(3)) PC(NCT+1)=BOOL(BOOL(PC(NCT+1))+1) @ LONG
      PC(NCT+2)=FLOAT(REALF(NRR+1))*Z    @ P(2) FOR CORR, SCALE
      PC(NCT+3)=BOOL(P(8)) @ P(3) FOR CORR, T-F MODE
      CALL CALSAV (1,CORR2,PC(NCT+1)) @ INITIALIZE CORR
      IF(AND(I,1) .EQ. 0) NRR=NRR + REALF(NRR) + 1 @ INCR REF POINTER
   20 NCT=NCT + 54 @ INCR P ARRAY POINTER
      Q(1)=0 @ CLEAR INITIALIZATION FLAG
   30 LC=LAG - P(7)*REALF(2) - REALF(3) @ BASE LAG VALUE
      IF(LC .LT. 55) GO TO 730
      NCT=1 @ OUTPUT STORAGE SWITCH
      NCP=1 @ P ARRAY POINTER
      NRR=7 @ REAL REF POINTER
      NIR=7 @ IMAG REF POINTER
      NS=P(7) @ NO. PIECES IN EACH REFERENCE
      NOCT=1 @ AJ STORAGE POINTER
      NICT=1 @ AI STORAGE POINTER
      NSCT=P(7) * 108 + 1 @ PC STORAGE POINTER
      DO 100 I=1,NS @ BEGIN CORRELATION LOOP
      LCC=LC+1
      LC=LC + REALF(2) @ ADD REF LENGTH TO LAG
      IF(I .LE. REALF(3)) LC=LC+ 1 @ INCR IF LONG REF
      IN=JMC + LC @ TOTAL SAMPLES TO CORR
      IF(NCT.GT.Q(3)) GO TO 40
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
     $     AJ(NOCT),NC)
      NOCT=NOCT + JMC @ INCR AJ STORAGE POINTER
      GO TO 60
   40 IF(NCT .GT. Q(4)) GO TO 50
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
     $     AI(NICT),NC)
      NICT=NICT + JMC @ INCR AI STORAGE POINTER
      IF(NICT .GT. LCC) GO TO 702 @ AI OVERFLOW
      GO TO 60
   50 CONTINUE
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,REALF(NRR),IN,1,AI,LC,JMC,1,
     $     PC(NSCT),NC)
      NSCT=NSCT + JMC @ INCR PC STORAGE POINTER
      IF(NSCT .GT. Q(5) - 2*P(3) + 1) GO TO 703 @ PC OVERFLOW
   60 IF(NC .GT. JMC) GO TO 706 @ CORR OUTPUT RECORD TOO LONG
      NRR=NRR + REALF(NRR) + 1 @ INCR REAL REF POINTER
      IF(NRR .GT. REALF(1) + 2) GO TO 740
      NCT=NCT + 1 @ INCR STORAGE SWITCH
      NCP=NCP + 54 @ INCR P ARRAY POINTER
      IF(NCT .GT. Q(3)) GO TO 70
```

```
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),;N,1,AI,LC,JMC,1,
     $     AJ(NOCT),NC)
      NOCT=NOCT + JMC @ INCR AJ STORAGE POINTER
      GO TO 90
   70 IF(NCT .GT. Q(4)) GO TO 80
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),;N,1,AI,LC,JMC,1,
     $     AI(NICT),NC)
      NICT=NICT + JMC @ INCR AI STORAGE POINTER
      IF(NICT .GT. LCC) GO TO 704 @ AI OVERFLOW
      GO TO 90
   80 CONTINUE
      CALL CALSAV (11,CORR3,PC(NCP),KFLG,IMAGF(NIR),;N,1,AI,LC,JMC,1,
     $     PC(NSCT),NC)
      NSCT=NSCT + JMC @ INCR PC STORAGE POINTER
      IF(NSCT .GT. Q(5) - 2*P(3) + 1) GO TO 705 @ PC OVERFLOW
   90 IF(NC .GT. JMC) GO TO 706 @ OUTPUT RECORD FROM CORR TOO LONG
      NIR=NIR + IMAGF(NIR) + 1 @ INCR IMAG REF POINTER
      IF(NIR .GT. IMAGF(1) + 2) GO TO 740
      NCT=NCT + 1 @ INCR STORAGE SWITCH
  100 NCP=NCP + 54 @ INCR P ARRAY POINTER
C        END OF CORRELATION LOOP
      NS=2*P(7)-1 @ TOTAL PIECES MINUS 1
      NSCT=Q(5) - 2*P(3) @ BASE OF FFT WORKING STORAGE
      NF1=NSCT+1 @ LIMITS FOR CLEARING FFT STORAGE
      NF2=Q(5)
      NICT=P(1) - 1 @ NO. TEETH IN FILTER MINUS 1
      NIR=P(1)/2 @ OFFSET FOR NEGATIVE FREQUENCIES
      DO 140 I=1,JMC @ SAMPLE LOOP
      DO 105 J=NF1,NF2
  105 PC(J)=0 @ CLEAR FFT WORKING STORAGE
      NCT=NSCT @ INITIALIZE FFT INPUT POINTER
      DO 130 J=0,NS @ PIECE LOOP
      NCT=NCT + 1 @ INCR FFT INPUT POINTER
      IF(J .GE. Q(3)) GO TO 110
      PC(NCT)=AAJ(I+J*JMC) @ GET SAMPLE FROM AJ
      GO TO 130
  110 IF(J .GE. Q(4)) GO TO 120
      PC(NCT)=AAI(I+(J-Q(3))*JMC) @ GET SAMPLE FROM AI
      GO TO 130
  120 PC(NCT)=PPC(I+(J-Q(4))*JMC+P(7)*108) @ GET SAMPLE FROM PC
  130 CONTINUE
      CALL CTFFT (PC(NSCT+1), COREF(4),P(3),2)
      DO 140 J=0,NICT @ OUTPUT STORAGE LOOP
      NOCT=J - NIR @ INDEX OFFSET FOR NEGATIVE FREQUENCIES
      IF(NOCT .LT. 0)NOCT=NOCT + P(3)
  140 AAJ(I+J*JMC)=SQRT(PPC(NSCT+2*NOCT+1)**2 + PPC(NSCT+2*NOCT+2)**2)
C        END OUTPUT LOOP
  145 NCT=IOUTT(1)
      DO 150 I=2,NCT @ SET NO. OUTPUT SAMPLES
  150 NOUT(I-1)=JM
```

```
      NOUT(NCT)=(P(1) - (P(2)-1)*Q(2)) * JMC
      RETURN
  700 NCT=PVAL(2,1)
      NCP=PVAL(2,3)
      PRINT 1000,          P(7), NCT, P(8), NCP
      GO TO 799
  701 PRINT 1001,         REALF(2), IMAGF(2), REALF(3), IMAGF(3)
      GO TO 799
  702 NOCT=4HREAL
      GO TO 710
  703 NOCT=4HREAL
      GO TO 711
  704 NOCT=4HIMAG
      GO TO 710
  705 NOCT=4HIMAG
      GO TO 711
  706 PRINT 1003,         I
      GO TO 799
  710 NRR=NICT-1
      NIR=LCC - 1
      NICT=2HAI
      GO TO 715
  711 NRR=NSCT - 1
      NIR=Q(5) - 2*P(3)
      NICT=2HPC
  715 PRINT 1002,          NICT, NOCT, I, NRR, NIR
      GO TO 799
  720 PRINT 1005,          P(3), P(7)
  730 NCT=55 - LC
      PRINT 1006,          NCT
      GO TO 799
  740 PRINT 1007,          I, NRR, REALF(1), NIR, IMAGF(1)
      GO TO 799
  750 PRINT 1009,          P(3), NCT
      GO TO 799
  760 PRINT 1010,          P(7), REALF(4), IMAGF(4), P(8), REALF(5),
     $  IMAGF(5)
      GO TO 799
  799 CALL BBNAME (NAME)
      PRINT 1011, NAME
      CALL EREXIT
 1000 FORMAT (1X,12X,'UNBALANCED REFERENCES'/' NO. OF PIECES',2I5/' T-F
     $MODE'5X,2I5)
 1001 FORMAT (1X,12X,'UNBALANCED REFERENCES'/' SHORT REF LENGTH',2I5/' N
     $O. LONG REFS',4X,2I5)
 1002 FORMAT (1X,12X,'OVERFLOW IN 'A3,'STORAGE, 'A5,,PIECE',I5/' LAST RE
     $QUEST='I5,',' I5,' AVAILABLE')
 1003 FORMAT (1X,12X,'CORR RECORD TOO LONG, PIECE',I5)
 1004 FORMAT(1X,2A6,'P(3) CHANGED TO 'I4)
 1005 FORMAT (1X,12X,'P(3)=',I4,' IS ILLEGAL FOR 'I4,' PIECES')
```

```
1006 FORMAT (1X,12X,'INCREASE P(5) BY AT LEAST 'I5)
1007 FORMAT (1X,12X,'REFERENCE ERROR, I='I5/' NRR='I5,', REALF(1)='I5/'
    S NIR='I5,', IMAGF(1)='I5)
1008 FORMAT (1X,2A6,'PIECES STORED IN AJ='I5,', AI='I5,', SCRATCH='I5,'
    S, TOTAL PIECES='I5,', SCRATCH STORAGE='I5)
1009 FORMAT (1X,12X,'WRONG FFTIN FIELD,'I5,' EXPECTED,'I5,' SUPPLIED')
1010 FORMAT(1X,12X,'PARAMETER ERROR'/' EXPECTED PIECES='I5,', REAL='I5,
    S', IMAG='I5/' EXPECTED  MODE ='I5,', REAL='I5,', IMAG='I5)
1011 FORMAT (1H+,2A6)
1012 FORMAT (' THE FIELD FROM 'A6,A1,' OR 'A6,A1,
    1    ' IS AN ILLEGAL INPUT TO 'A6,A1,
    2    ' UNLESS P(7) AND P(8) ARE MANUALLY SET. ' )
     END
```

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APPENDIX D

MSCAT BLACK BOX DESCRIPTION

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APPENDIX D

MSCAT BLACK BOX DESCRIPTION

PROGRAM NAME: MSCAT
NATURE OF WORK: BLACK BOX
PROGRAMMER'S NAME: David Doan
DATE: August 25, 1969
COMPUTER LANGUAGE: FORTRAN V

PROBLEM DEFINITION

MSCAT produces a set of partial correlator references from a single input field for use with the Box, MDQC. The technique used by the Black Box, SCAT, is used to provide very efficient clipped-reference correlation.

OPERATING INSTRUCTIONS

1. Topology Card:

The topology card for MSCAT requires one floating point field such as that provided by CORGN or RFEXT.

2. Data Input:

All P-array entries are fixed point.

P(1) = number of pieces into which the reference is to be broken. See Section 8 of the MDQC write-up.

P(2) = length of output field. Initially, P(2) should be equal to the length of the input field. It may be possible to reduce this value to conserve storage. See Sections 5 and 6.

P(3) = 0(SV) for fixed point time function input to MDQC.
= 1 for floating point input to MDQC.

3. Input Fields:

The input field must contain a floating point correlator reference in the format produced by Boxes such as RFEXT or CORGN.

4. Output Field:

The output field contains the count word, and five constants, followed by P(1) subfields, each having the format of the field generated by SCAT. The field is shown below:

word 1	:	N
word 2	:	length of short reference
word 3	:	number of long references
word 4	:	P(1)
word 5	:	P(3)
word 6	:	total reference length
word 7	:	N_1
word 8 ⋮ word $N_1 + 7$	:	constants and machine instructions as generated by SCAT for piece 1
word $N_1 + 8$	:	N_2
word $N_1 + 9$ ⋮ word $N_1 + N_2 + 8$	:	constants and machine instructions as generated by SCAT for piece 2
⋮ etc.		

5. Printer Output:

One line is printed for each piece of the reference. The format of the line is

MSCATx N = ___, K = ___, L = ___, S = ___, PIECE y

where x is the use number, N is the number of samples in this partial reference, K, L, and S are parameters indicating the operating of SCAT (See SCAT write-up and SCAT/CORR process description), and y is the number of the partial reference. Following the above is a line with the following format:

MSCATx FIELD STORAGE AVAILABLE = ___, USED = ___

The storage available is P(2) + 5. The storage used is the total number of words in the output field including the count word.

6. Program Limitations and Conditions:

a. Each piece must contain at least 2 samples.

b. An error message is produced if the output field is too small and the run is aborted.

7. Storage Requirements:

447_8 or 295_{10} words.

8. Subroutines Referenced:

SCAT3, FIXTST, CALSAV, BBNAME, EREXIT, NPRT$, NIO1$, NIO2$, NERR3$.

PROCESSING METHOD

MSCAT breaks the reference supplied in the input field into P(1) pieces. If the input field contains N samples, then there are

$$n = N \bmod P(1)$$

long pieces and N-n short pieces.

The first n pieces have a length

$$\ell_1 = \text{Int}\,(N/P(1)) + 1,$$

and the remaining N-n pieces have a length

$$\ell_2 = \text{Int}\,(N/P(1)).$$

Each piece is converted to a series of add-subtract commands by SCAT3 (part of the Black Box, SCAT). The outputs from SCAT3 are stored in the output field.

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APPENDIX E

MSCAT PROGRAM LISTING

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APPENDIX E

MSCAT PROGRAM LISTINGS

```
SUBROUTINE MSCAT0 (N,P)
DIMENSION P(1), REF(1), OUT(1), NAME(2)
EQUIVALENCE (NS,NAME(1)), (OCT,NAME(2))
IMPLICIT INTEGER (A-Z)
REAL REF, SAVE
EXTERNAL SCAT3
N=6
P(3)=0 @ FIXED T-F IS STANDARD
RETURN
ENTRY MSCAT1 (P,INPF,INPT,KINPT,LAG,IOUTF,ISIZE,IOUTT,KOUTT,A,B)
INPF=1
IOUTF=1
ISIZE=P(2) + 5
CALL FIXTST (P(1),P(3))
RETURN
ENTRY MSCAT2 (P)
RETURN
ENTRY MSCAT3 (P,KFLG,REF,OUT)
NCT=REF(1) @ LENGTH OF REF SUPPLIED
OUT(2)=NCT/P(1) @ LENGTH OF SHORT REF
OUT(3)=MOD(NCT,P(1)) @ NO. OF LONG REFS
OUT(4)=P(1)  @  NO. OF PIECES
OUT(5)=P(3)  @  T-F MODE
OUT(6)=NCT     @ TOTAL REFERENCE LEN GTH
P(4)=P(2) @ P(1) FOR SCAT, LENGTH OF REF
P(5)=1 @ P(2) FOR SCAT, FLOATING POINT FIELD FLAG
P(6)=P(3)  @ P(3) FOR SCAT, T-F FLAG
NCT=1 @ INPUT FIELD POINTER
MCT=7 @ OUTPUT FIELD POINTER
NS=P(1) @ NO. OF PIECES
DO 10 I=1,NS
OCT=OUT(2)  @  LENGTH OF SHORT REF
IF(I .LE. OUT(3)) OCT=OCT+1 @ INCR FOR LONG REF
SAVE=REF(NCT) @ SAVE ORIG CONTENTS OF INPUT FIELD
REF(NCT)=OCT  @ SET REF LENGTH IN FIELD FOR PARTIAL REF
CALL CALSAV (4,SCAT3,P(4),KFLG,REF(NCT),OUT(MCT))
PRINT 1000, I @ ADD PIECE NO. TO SCAT MSG
REF(NCT)=SAVE @ RESTORE INPUT FIELD
NCT=NCT + OCT @ INCR INPUT POINTER
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   10 MCT=MCT + OUT(MCT) + 1 @ INCR OUTPUT POINTER
      IF(MCT-6 .GT. P(2)) GO TO 30 @ OUTPUT FIELD TOO SMALL, ERROR
      OUT(1)=MCT - 2 @ SET LENGTH OF OUTPUT FIELD
   20 NCT=P(2) + 5 @ STORAGE AVAILABLE
      MCT=MCT - 1  @ STORAGE USED
      CALL BBNAME (NAME)
      PRINT 1001, NAME, NCT, MCT
      IF(OUT(1) .LT. 0) CALL EREXIT @ ABORT RUN
      RETURN
   30 PRINT 1002
      OUT(1)=-1 @ SET ERROR FLAG
      GO TO 20
 1000 FORMAT (1H+,45X,'PIECE',I4)
 1001 FORMAT (1X,2A6,'FIELD STORAGE AVAILABLE=',I5,', USED=',I5)
 1002 FORMAT (/' ***ERROR***')
      END
```