Technical Memo 16, "ELINT Sensor Parameterization and Definition, Interim Report #1."

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This memo describes the modeling of the superheterodyne radar receiver and defines the parameters of interest. The modeling details are included. Both a flow chart and source code (FORTRAN) for the model are included. The report ends with documentation of the model testing and validation.
U.S. ARMY INTELLIGENCE CENTER AND SCHOOL
Software Analysis and Management System

ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT # 1

EAAF

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Interim report #1 describes progress to date of the ELINT Parameterization and Definition Study. The introduction describes the purpose of the study and explains why it was decided to model a superheterodyne receiver and defines the parameters of interest. A description of the model follows in section 2. A flow diagram and the source code of the model are included in sections 3 and 4 respectively. The report is concluded with documentation of results and conclusions in section 5.
EXECUTIVE SUMMARY

This Technical Memorandum was prepared originally as part of the Generic ELINT/COMINT Sensor Report (FY-85/FY-86) which was eliminated under the FY-87 statement of work (SOW #2), undated (delivered to JPL 19 November 1986).

The purpose of the Generic ELINT/COMINT Sensor Report, of which this paper was intended (in its final form) to become part of, was to establish a basic superheterodyne receiver based sensor model and perform simulations with it to determine the shaping or coloring of the statistical distributions of the radar free-space signal parametrics by a typical sensor prior to reaching the self-correlation processes. It was also intended for incorporation into the algorithm test bed so algorithms could be tested with realistic distorted data rather than unrealistic stastically pure data.

This work was originated in support of unanswered questions from previous self-correlation studies. The modeling and simulation approach was used because "live date" could not be obtained.

This paper is being published because it was completed in FY-86 with FY-86 funds and still serves a useful function.

There were no unexpected results at this stage of the models development - the model has been verified as valid. The second stage of this study is to analyze the shaping or coloring of the radar free-space signal parametrics and may not be completed due to the restrictions of the current JPL Task Plan.
ELINT SENSOR PARAMETERIZATION AND DEFINITION
INTERIM REPORT #1

0.0 EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 RECEIVER MODEL DEVELOPMENT

2.1 SQUARE LAW DETECTOR AND LOW PASS DETECTOR
2.2 VIDEO AMPLIFIER
2.3 CONSTANT FALSE ALARM RATE (CFAR)
2.4 PULSE DETECTOR
2.5 LIMITER
2.6 DISCRIMINATOR

3.0 RECEIVER PROGRAM FUNCTIONAL FLOWCHART

4.0 SOURCE CODE

5.0 RESULTS AND CONCLUSIONS
1.0 INTRODUCTION

The purpose of this report is to define the statistics of the observed parameters of interest of a generic ELINT sensor. The approach chosen was to "build" a computer model of a typical ELINT receiver and excite it with input signals of known distributions and then measure the resulting output distributions.

1.1 THE "SUPERHET"

The superheterodyne receiver has many advantages to offer for the gathering of electronic intelligence. It is the most widely used receiver design for nearly all uses including ELINT applications. A basic functional block diagram is shown in Figure 1.1. The idea is to use a local oscillator to convert the incoming signal to a fixed intermediate frequency (IF) by the mixing process called heterodyning. Thus the IF amplifier need operate at only one (lower) frequency and it's operating characteristics may be carefully and more economically controlled. Bandwidths for typical narrowband ELINT receivers are approximately 20 MHz for BRF or BF and 10 MHz for BV. This ensures good pulse fidelity for nominal radar pulsewidths of 1 microsecond or greater. The simple receiver of Figure 1.1 has been used with great success since World War II. Recent innovations have greatly increased the basic capability of the superhet. By rapidly sweeping the local oscillator in frequency an amplitude versus frequency display may be generated thus creating an RF spectrum analyzer. Very rapid sweeping creates a rapid sweep superhet that is useful for detecting high duty cycle, low power signals in the presence of low duty cycle interfering signals*. In addition heterodyning techniques are used in the implementation of compressive and microscan receivers and many instantaneous frequency measurement (IFM) receiver designs utilize superhet frontends.

So we see that the study of superhet receivers is a good place to begin.

* R. G. WILEY, ELECTRONIC INTELLIGENCE: THE INTERCEPTION OF RADAR SIGNALS
2.0 SENSOR MODEL DEVELOPMENT

Figure 2.1 is a functional block diagram of the simple receiver to be modeled. We first assume that the received signal is a narrowband process that is statistically unaltered by the downconversion to the IF frequency, $\omega_{\text{IF}}$. Thus, the signal at the input of the detector and limiter is

$$ r(t) = s(t) \cos((\omega_c - \omega_o)t + \Phi(t)) + n(t) $$

where

- $s(t)$ = transmitted pulse envelope as modified by the transmission channel characteristics
- $\omega_c$ = carrier frequency
- $\omega_o$ = LO frequency assumed to be noiseless
- $\omega_{\text{IF}} = \omega_c - \omega_o$ = IF frequency
- $\Phi(t)$ = signal phase at output of IF amplifier
- $n(t)$ = additive receiver noise plus input noise.
FIGURE 2.1: SIMPLIFIED RECEIVER MODEL
2.1 SQUARE LAW DETECTOR AND LOW PASS FILTER

Figure 2.2 depicts functionally a square law detector. Squaring the input, (1) above, we obtain

\[ r^2(t) = s^2(t) \cos^2[2\pi f_{IF} t + \phi(t)] + 2s(t) \{ \cos[2\pi f_{IF} t + \phi(t)] \} n(t) 
+ n^2(t) \]  

(1.1)

where \( f_{IF} = 2\pi(\omega_c - \omega_0) \) is the receiver IF frequency.

Now, using

\[ \cos^2 x = \frac{1}{2} (1 + \cos 2x) \]

(1.1) becomes

\[ r^2(t) = \frac{1}{2} s^2(t) + \frac{1}{2} s^2(t) \cos 2[2\pi f_{IF} t + \phi(t)] + 
2s(t) \{ \cos[(2\pi f_{IF})t + \phi(t)] \} n(t) + n^2(t) \]  

(1.2)
Hence, by multiplying the received signal by itself we have obtained $\frac{1}{2}$ the square of the modulation waveform $s(t)$ plus higher frequency terms consisting of cross products of the noise and the signal at the fundamental and second harmonic frequencies and the noise term $n^2(t)$. Now, by low pass filtering the output of the square law device as depicted in the above figure with a filter sufficiently wide to pass $s(t)$ while rejecting those frequencies above the lowest component of $s(t)$ that is of interest. One obtains at the output of the detector low pass filter the signal

$$ r_v^2(t) = \frac{1}{2} s^2(t) + n^2(t) $$

where $n^2(t)$ represents the low frequency components of the noise process $n^2(t)$. For the purpose of this simulation the output filter of the detector will determine the bandpass response of the video channel. Good pulse fidelity requires that the filter have a bandpass adequate to pass the 12th harmonic with less than 75% attenuation. Thus the filter is required to have a 3db bandwidth $B_{3\text{db}}$ greater than or equal to 12 Mhz, assuming that the received pulse width is greater than or equal to 1μsec.

* R. G. WILEY, ELECTRONIC INTELLIGENCE: THE ANALYSIS OF RADAR SIGNALS
2.2 VIDEO AMPLIFIER

The video amplifier provides additional gain and bandpass shaping if required. For this simulation, the gain will be set to $K$ with an infinite frequency response. Thus, the bandpass response of this portion of the receiver is determined by the low pass filter of the detector and

$$A(\omega) = K$$

where $K$ is selectable as an user input into the simulation and defaults to the value required to provide unity gain to the detector and, thereby, simplifying later calculations.

2.3 CONSTANT FALSE ALARM RATE (CFAR)

The CFAR is a circuit that maintains a reference voltage level proportional to the received in-band noise. Thus, it may be used to vary the threshold of the pulse detection circuitry in such a way to prevent false alarms due to varying noise levels at the input of the receiver. The CFAR constant $C$, is adjusted to provide a desired false alarm rate (FAR). The results reported herein were based upon a calculated FAR = $10^{-4}$.

2.4 PULSE DETECTOR

The pulse detector circuitry compares the output of the video amplifier to the threshold determined by the CFAR circuit and strobes a pulse present signal to the parameter estimation circuit when the video signal is greater than the threshold. A threshold is chosen to provide a desired probability of detection ($P_D$).
A functional block diagram of a hard limiter is depicted in Figure 2.3. The limiter conditions the input signal to the frequency discriminator by amplifying and clipping an I.F. output signal to provide essentially a square wave input to the discriminator at the frequency of the IF signal. If the input to a hard limiter is \( x(t) \) then the output, \( y(t) \), is

\[
y(t) = \begin{cases} 
1 & x(t) \geq 0 \\
-1 & x(t) < 0
\end{cases}
\]
2.8 DISCRIMINATOR

The discriminator provides the frequency estimation function for the receiver. It consists of a zero crossing counter that counts and stores the number of zero crossings during the pulse. When the threshold circuit detects a pulse it provides a strobe that initializes and starts the zero crossing counter. At the end of the pulse the contents of the counter are read and the average frequency of the I.F. pulse is calculated based upon the estimated pulsewidth.
3.0 SENSOR MODEL FUNCTIONAL FLOW CHART
$r(k) = s(k) \cos(2\pi f_1 k \Delta t + \phi_k) + n(k)$

**FIGURE 3a: RECEIVER SIMULATION FLOW CHART**
\[ r(k) = s(k)\cos(2\pi f_1 k \Delta t + \phi) + n(k) \]
\[ m \rightarrow \frac{1}{K} \sum_{k=1}^{K} \hat{s}(k) \]

**LIMITER/DISCRIMINATOR**

\[
\begin{align*}
  r(k) &= 100r(k) \\
  &\quad \text{if } r(k) > 0 \\
  &\quad \text{then } r(k) = 1 \\
  &\quad \text{else } r(k) = -1 \\
  &\quad \text{if } r(k) > r1(k) \\
  &\quad \text{then } \text{IFR} = \text{IFR} + 1 \\
  &\quad r1(k) = r(k)
\end{align*}
\]

**PARAMETER ESTIMATION**

\[
\begin{align*}
  \hat{s}(k) &\geq T \\
  &\quad \text{YES PULSE PRESENT} \\
  &\quad \text{NO PULSE NOT PRESENT}
\end{align*}
\]

**CFAR**

\[
\begin{align*}
  M &\rightarrow \frac{1}{M} \sum_{m=1}^{M} \hat{s}(k)
\end{align*}
\]

**Figure 3c: Receiver Simulation Flow Chart (continued)**

13
I TO W
LMT SUIPLE OF PULSE
IFEPWOI)
IPP = 0

\[ S(k-1) \]
WAS LAST SAMPLE
OF PULSE
\[ PW(1) = IPW \times A(k-1) \]
\[ FREQ(1) = IFR / PW(1) \]
\[ k = k + 1 \]
\[ IPP = 0 \]
\[ IFR = 0 \]

\[ k = k_{TOTAL} \]

FIGURE 3d: RECEIVER SIMULATION FLOW CHART (CONTINUED)
4.0 SOURCE CODE LISTING
THIS PROGRAM SIMULATES A SIMPLE SUPERHETERODYNE RECEIVER THAT UTILIZES A
SQUARE LAW DETECTION PROCESS. THE IF OUTPUT SIGNAL IS FIRST GENERATED AS-
SUMING THAT THE RECEIVED SIGNAL IS A PULSED RADAR SIGNAL OF CONSTANT
FREQUENCY, RANDOM PHASE, AND CORRUPTED BY AN ADDITIVE GAUSSIAN NOISE CHAN-
NEL.

* GENERATE THE RECEIVER IF SIGNAL

*DECLARATIONS

INTEGER K, IPP, J, I, IFR, CPRI, IPW, L,O,01 ,O
Integer*4 TICKCOUNT, TICK1, TICK2, toolbox
REAL Y(4200),X(4200),R(4200), PRI(1000), PW(1000), FREQ(1000)
REAL H(32),HL(24), RDET(4200)
PARAMETER (TICKCOUNT = '97580000') ! toolbox definitions
DATA (H(I), I=1,16)/-57534121E-02, .99027196E-02,1.75733545E-02,
```plaintext
1.65141192E-02, .13960525E-01, .22951469E-02,
1.19994067E-01, .71369560E-02,
1.39657363E-01, .11260114E-01, .66233643E-01,
1.10497223E-01, .85136133E-01, .12024993E-00,
1.29678577E00, .30410917E00/
DATA (HL(I), I=1,12)/0.33740917E-02, 0.14938299E-01,
10.10569630E-01,
10.25415067E-02, -0.15929992E-01, -0.34085343E-01,
1.0.38112177E-01, -0.14629169E-01,
10.40089541E-01, 0.11540713E00, 0.1350752E00,
10.23354606E00/
*   PRINT *, 'PULSE PULSEWIDTH PRI FREQUENCY
* 1 SNR'
* PRINT *, PREETEC
* PULSE POSTDETECTION'
* OPEN(UNIT=18,FILE = 'RCVDATA')
  DO 111 1=17,32
    L=33-I
    H(I)= H(L)
111 CONTINUE
  DO 101 1=13,24
    L=25-I
    HL(I)= HL(L)
101 CONTINUE
98 WRITE(9,*)) 'ENTER NUMBER OF PULSES, MINIMUM SNR, MAXIMUM SNR'
***********************INITIALIZE COUNTERS AND FLAGS***********************
READ(9,*) O,SNRMIN,SNR
TICK 1 = tickbx(TICKCOUNT)
DELT = 2.5E-08
F1 = 10.E06
KTOTAL = 4000
PWID = 20.E-06
97 O=0
Q=0.
SNSUM = 0.
SNSUM 1 = 0.
PM=0.
I1 = 1
99 IPP = 0
IPW = 0
J1 = 1
IFR = 0
PWRSIG = 0.
```
PWRNOS = 0.
PRESIG = 0.
PRENOS = 0.
KF=5555
* WRITE(9,*) 'ENTER SAMPLE INTERVAL,I.F. FREQUENCY,NUMBER OF
* ISAMPLES'
* READ(9,*) DELT,F1,KTOTAL
PI = 3.141593
*GENERATE RANDOM PHASE PHI
SIGMA = 1./SQRT(SNR)
PHI = RAND(0) ! SEED THE RANDOM NUMBER GENERATOR
PHI = (RAND(1) -.5)*2.0*PI
IDELAY = 2000
L = INT(PWID/DELT)
DO 11 K=1,KTOTAL+130
TN = RAND(1)-5
XN = SQRT(LOG(1./(TN*TN)))
XN = XN - (2.30753 + .27064*XN)/(1. + .99229*XN + .04481*XN*XN)
XN = XN*SIGMA
IF(TN.LT.0) XN=-XN
*GENERATE PULSED IF SIGNAL
IF (K.LE.IDELAY-32 OR K.GE.L+IDELAY) THEN
R(K) = XN
ELSE
R(K) = 1.4142*COS(2*PI*F1*K*DELT + PHI) + XN
END IF
11 CONTINUE
* BANDLIMITED ZERO MEAN WHITE GAUSSIAN NOISE
* BANDPASS NOISE TO +/- F1/2
* FINITE IMPULSE RESPONSE (FIR) LINEAR PHASE BANDPASS DIGITAL FILTER
* -10DB POINTS ARE .14 AND .39 OF THE NYQUIST FREQUENCY
DO 102 K=32,KTOTAL+130
Y(K) = 0.
DO 102 J = 0,32
102 Y(K) = Y(K) + H(J)*R(K-J+1) !BANDPASS LIMITED PULSE I.F. PLUS NOISE
DO 21 K=1,KTOTAL+99
Y(K) = Y(K+31)*Y(K+31) !PERFORM SQUARE LAW DETECTION
IF(K.LE.IDELAY-32 OR K.GE.IDELAY+L) THEN
PRENOS = PRENOS + Y(K)*Y(K)/(KTOTAL + 67 - L)
ELSE
PRESIG = PRESIG + Y(K)*Y(K)/L
END IF
21 CONTINUE
PRESNR = PRESNR/PRESNR
PRESNR = PRESNR
PSNRDB = 10*LOG10(PRESNR)

*****************************************************************************
LOW PASS FILTER DETECTOR OUTPUT*****************************************************************************

-10 DB POINT IS .05 OF THE NYQUIST FREQUENCY

RDET(1) = 0.
DO 202 K=1,100
RDET(1) = RDET(1) + .01*Y(K)
202 CONTINUE
DO 203 K=2,KTOTAL
RDET(K) = RDET(K-1) + .01*(Y(K+99)-Y(K-1))
IF(K.LE.IDELAY-130 .OR. K.GE.IDELAY+L) THEN
  PWRNOS = PWRNOS + RDET(K)*RDET(K)/(KTOTAL-L-130)
ELSE IF(K.GE.IDELAY-130 .AND. K.LE.IDELAY+L) THEN
  PWRSIG = PWRSIG + RDET(K)*RDET(K)/(L-130)
END IF
203 CONTINUE
SIGNOS = PWRSIG/PWRNOS
SIGNOS = SIGNOS - 1.0
SIGNOSDB = 10*LOG10(SIGNOS)
SNSUM = SNSUM + SIGNOS/O
SNSUM1 = SNSUM1 + PRESNR/O

*****************************************************************************PARAMETER ESTIMATION*****************************************************************************

T = SQRT(18.4*PWRNOS)
DO 400 K=1,KTOTAL
IF( RDET(K) .LT. T AND. IPP=0 .AND. K=KTOTAL) GO TO 206
IF( RDET(K) .GE. T AND. IPP=0 ) THEN
  KF=K
  T=T/2.
  ! FIRST SAMPLE OF NEW PULSE
  IPP=1
  IPW = IPW + 1
ELSE IF( RDET(K) .GE. T AND. IPP=1 ) THEN
  IPW = IPW + 1
ELSE IF( RDET(K) .LT. T AND. IPP=1 ) THEN
  PW(I1) = IPW*DELT*1000000.
  GO TO 401
END IF
400 CONTINUE
401 IF(KF.NE.5555) THEN
  DO 204 K=KF,KF+IPW
    IF(R(K).LT.0) THEN
      R(K) = -1.
  204 CONTINUE
END IF
ELSE
    R(K) = 1.
END IF

204 CONTINUE
END IF

DO 205 K = KF, K + PW
205 IF (R(K).NE.R(K + 1)) IFR = IFR + 1
    FREQ(11) = IFR/PW(11)/2.
    PRINT 5002,11,PW(11),PRI(11),FREQ(11),PSNRDB, SIGNOSDB
*5002 FORMAT(1X,14,3X,FI10.4,3X,FI0.4,8X,FI10.4,2X,FI10.4)
    GO TO 207
206 PM = PM + 1./0
*    PRINT 5003, 11,T,SIGNOSDB
*5003 FORMAT(1X,14,6X,16H MISSED DETECTION, 5X, 12HTHRESHOLD = , F10.4,
*     15X, 6HSNR = , F10.4)
207 I1 = I1 + 1
    O1 = O1 - 1
    IF (O1.GT.0) GO TO 99
    SNSUM = 10*LOG10(SNSUM)
    SNSUM1 = 10*LOG10(SNSUM1)
    WRITE(6,*)'AVERAGE PREDETECTION SNR = ', SNSUM1,';
    1AVERAGE POSTDETECTION SNR = ', SNSUM
    PD = (1. - PM)*100.
    WRITE(6,*)'PROBABILITY OF DETECTION = ', PD, ' PER CENT'
    TIME = FLOAT(TICK2 - TICK1)/60.
    WRITE(6,*)'ELAPSED TIME = ', TIME, ' SECONDS'
    SNR = SNR - .10
    IF (SNR - SNRMIN > 0.) GO TO 97
*    DO 91 K = 1,KTOTAL
*    X(K) = RDET(K)
*    Y(K) = 0.0
*91 CONTINUE
*    CALL FFT4(X,Y,4096,6)
*    NTOTAL = KTOTAL/2
*    DO 40 K = 1, NTOTAL
*    RDET(K) = X(K)*X(K) + Y(K)*Y(K)
*    RDET(K) = 10.*LOG10(RDET(K))
*40 CONTINUE

***********************************************************************
*                      AVERAGE ARRAY                                *
***********************************************************************
*    LTOTAL = NTOTAL/4
*    DO 50 K = 1, LTOTAL
*    Y(K) = 0.0

20
*50 CONTINUE
*    L=1
*    M=4
*    DO 60 K=1,LTOTAL
*    DO 70 J=L,M
*    Y(K) = Y(K) + RDET(J)/4.
*70 CONTINUE
*    L=L+4
*    M=M+4
*60 CONTINUE
*    WRITE(18,5010) (RDET(K),K=1,NTOTAL)
*5010 FORMAT(2X,F15.4)
*    WRITE(9,*) TENTER
'5010 ENTER 1 TO CONTINUE
READ(9,*) Q
IF(Q.1) GO TO 98
STOP
END

FUNCTION Rand(IX)
*
* This random number generator is a variation on Tausworthe
* generator described in "Solution of Statistical Distribution
* Problems" by H. O. Hartley in Statistical Methods for Digital
* Computers Vol. III, edited by Enstein, Ralston, and Wilf
* (John Wiley and Sons 1977). The only modification of consequence
* is the ability to reseed the generator with the system tickcount.
* *
* The function returns a real value between 0 and 1.
* Rand(0) will reseed the random sequence using system tickcount.
* Rand(1) will use previous calls values as seeds for next number
* in the sequence. Always using Rand(1) will generate a specific
* random sequence based upon starting values internal to
* the function.
* *
Real*4 Factor,Ku 1,Ku2
Integer*4 toolbox,BITXOR,TICKCOUNT ! toolbox definitions
Integer*4 KU3,LU 1,EC,N2TM,N2TCM
Equivalence (KU2,KU3), (KU1,LU1)
PARAMETER (BITXOR=Z'85992000') ! toolbox definitions
PARAMETER (TICKCOUNT=Z'97580000') ! toolbox definitions
* Note that the parameter statement assigns a value to
* the indicated constant label. In this case, it is the indey

21
* into a table of trap addresses contained in TOOLBX.SUB which
* converts the call to a trap call. A list of these assignments
* is given in the file TOOLBX.PAR.
*
* You must explicitly tell MacFortran to save the values of
* local variables across successive calls of the subroutines.
* 
* SAVE
Data Factor/0.4656613e-9/
Data N2TCM/z'0000400000' /
Data KU1,KC,N2TM/z'400000003',z'7fffffff'z'000002000' /

* KU1 enters with U(I) uniform random variable
* KU2 leaves with U(I+1) uniform random variable
* KCU complement of KU1
* KCU2 complement of KU2
* KC complementing constant
* LXXX logical equivalences of above LXXX
* N2TM $2^{**}M$ where $M$ is shift factor
* n2TCM $2^{**}P-M$ where $P$ is word size
* Factor float value of $2^{**}P$
* XOR is the exclusive or operator

if (IX=0) KU1=toolbox(TICKCOUNT)
KU1=toolbox(BITXOR,KU1,LU1/N2TM)
KU2=toolbox(BITXOR,KU1,(LU1*N2TM) and. KC)
Rand=FLOAT(KU3)*Factor
KU1-KU2
RETURN
END

*******************************************************************************
C A COOLEY-TUKEY RADIX-4 DIF FFT PROGRAM
C COMPLEX INPUT DATA IN ARRAYS X AND Y
C
C C---------------------------------------------
SUBROUTINE FFT4 (X,Y,N,M)
REAL X(1024), Y(1024)
REAL*8 E
C--------------------------MAIN FFT LOOPS--------------------------
N2 = N

22
DO 10 K = 1,M
    N1 = N2
    N2 = N2/4
    E = 6.283185307179586/N1
    A = 0
    DO 20 J = 1,N2
    B = A + A
    C = A + B
    CO1 = COS(A)
    CO2 = COS(B)
    CO3 = COS(C)
    SI1 = SIN(A)
    SI2 = SIN(B)
    SI3 = SIN(C)
    A = J*E
    DO 30 I = J, N, N1
    I1 = I + N2
    I2 = I1 + N2
    I3 = I2 + N2
    R1 = X(I) + X(I2)
    R3 = X(I) - X(I2)
    S1 = Y(I) + Y(I2)
    S3 = Y(I) - Y(I2)
    R2 = X(I1) + X(I3)
    R4 = X(I1) - X(I3)
    S2 = Y(I1) + Y(I3)
    S4 = Y(I1) - Y(I3)
    X(I) = R1 + R2
    R2 = R1 - R2
    R1 = R3 - S4
    R3 = R3 + S4
    Y(I) = S1 + S2
    S2 = S1 - S2
    S1 = S3 + R4
    S3 = S3 - R4
    X(I1) = CO1*R3 + SI1*S3
    Y(I1) = CO1*S3 - SI1*R3
    X(I2) = CO2*R2 + SI2*S2
    Y(I2) = CO2*S2 - SI2*R2
    X(I3) = CO3*R1 + SI3*S1
    Y(I3) = CO3*S1 - SI3*R1
30 CONTINUE
20 CONTINUE
CONTINUE

C----------------------DIGIT REVERSE COUNTER----------------------

J=1
N1 = N - 1
DO 104 I=1, N1
   IF (I.GE.J) GOTO 101
   R1  = X(J)
   X(J) = X(I)
   X(I) = R1
   R1  = Y(J)
   Y(J) = Y(I)
   Y(I) = R1
101  K = N/4
102  IF (K**3.GE.J) GOTO 103
      J = J - K**3
      K = K/4
      GOTO 102
103  J = J + K
104  CONTINUE
RETURN
END
5.0 RESULTS AND CONCLUSIONS

The previous pages of this report have documented the development of the Sensor model. In this section model validation and verification will be demonstrated. In order to validate the model a received signal disturbed only by Gaussian noise was assumed and the signal processing was examined at intermediate points within the model to see if the model was behaving as one would expect.

The assumed signal parameters for the validation runs were $F_{IF} = 10$ MHz and a pulsewidths of 10, 20, and 50 μsec.

A FFT routine was used to observe the output of the IF bandpass filter. The results of two runs of SNRs of 0 db and 10 db (SNR measured at input of IF filter) are depicted in Figure 5.1. As expected the output is a bandpass spectrum centered at 10 MHz with a spectral width of 10 MHz. Next the output of the detector lowpass filter was observed. This is illustrated in Figure 5.2. Again we see what one would hope to. A lowpass spectrum of spectral width of about 5 MHz (adequate to accurately reproduce pulsewidth of 2 μsec and greater) and the signal energy concentrated at the lower frequencies.

Figures 5.3, 5.4, and 5.5 depict time domain plots of the detector output. The received pulse SNR was 20 db, 13 db, and 3 db respectively in the IF bandwidth. The stronger pulses were detected and the pulsewidth of 50 μsec correctly measured. At a SNR = 3 db false detection occurred and pulsewidth was incorrectly measured. The plots as shown have been smoothed to facilitate the plotting process. This enhances the SNR as seen in the plots and the detector was working at a SNR of about 13 db less than one would estimate by looking at the plots alone.
Figure 5.1. Spectral plots of the signal at the output of the I.F. filter.
FIGURE 5.2. DETECTOR LOWPASS FILTER SPECTRAL OUTPUT.
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INTERIM REPORT # 1

DETECTED PULSE S/NR = 20 DB
PULSE WIDTH = 50 MICROSECS
MEASURED PULSEWIDTH = 50.225 MICROSECS

![Pulse with High S/NR](image)

**Figure 5.3. Detected Pulse with High S/NR**

DETECTED PULSE S/NR = 13 DB
PULSE WIDTH = 50 MICROSECONDS
MEASURED PULSEWIDTH = 50.275 MICROSECONDS

![Pulse with Lower S/NR](image)

**Figure 5.4. Detected Pulse of Lower S/NR.**

28
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INTERIM REPORT # 1

IMPROPERLY DETECTED PULSE SNR = 3
PULSE WIDTH = 50 MICROSECONDS
MEASURED PULSE WIDTH = .075 MICROSECONDS

FIGURE 5.5. PULSE OF LOW SNR THAT WAS NOT PROPERLY DETECTED
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The model was exercised many times with received signals of varying SNRs and then the measured probability of detection was compared to theoretical as documented in many standard references* A plot of SNR vs. Probability of Detection for this model is presented in Figure Eight.

As can be seen performance is comparable at high SNRs but degrades rapidly as SNR decreases. This is because the detection process modeled is not matched filter detection and is not optimum at lower SNRs but is instead designed to reproduce a detected pulse with sufficient fidelity to provide good pulse parameter measurement capability.

In conclusion, then, it can be said that the sensor model at its present state of development performs as expected when excited with signals plus Gaussian noise and will provide a tool by which the output distributions of other types of signals may be studied.

* SEE FOR INSTANCE "RADAR TARGET DETECTION HAND BOOK OF THEORY AND PRACTICE" BY MEYER AND MAYER
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