APPENDIX

COMPUTER SOFTWARE

In this appendix, we simply list the computer simulation programs used for the simulation results given in the report. The programs are essentially self-explanatory via the comment and format statements. The 15 routines, BPSK0-BPSK14, simulate the receiver structure given in Figure 8. The programs are all similar and differ from each other only slightly to make use of different noise processes and different nonlinearities and various combinations of these. The programs are easily modified for other signaling and noise situations. For example, the second BPSK14 program given is a modified BPSK14 program (first one given, constant signal) for a Rayleigh fading signal.

These programs were used on CYBER170/750 computers. The "normal" DO loop procedure used in the programs will not function properly for $N > 10^5$. An example of the required modification for $N = 10^6$ is shown in BPSK2.

```
Z     PROGRAM BPSK0(INPUT,OUTPUT)
C     THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C     PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C     SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C     AND NON GAUSSIAN NOISE.
C     HALL MODEL,THETA=4.,LINEAR RECEIVER,NOISE ENVELOPE RMS=1.
C     NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C     NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C     NTB IS THE TIME-BANDWIDTH PRODUCT
      COMPLEX Z
      PRINT 7
7     FORMAT(34H HALL, THETA = 4., LINEAR RECEIVER, /)
      PI=3.141592654
      PI2=PI*2.
      THETA=4.
      GAM=SQRT(2.)/2.
      NTB=10 $ NSY=100000 $ NER=100
      PRINT 6, NTB, NSY, NER
6     FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
      RNP=0.5
C     REAL NOISE POWER=0.5*ENVELOPE POWER.
      SIGSQ=RNP
      SIG=SQRT(SIGSQ)
C     USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
      DO 90 I=1,15
      SNR=-25.+I*5.-10.*ALOG10(FLOAT(NTB))
      RSP=10.**(SNR/10.)
      SP=SQRT(RSP)
      ERS=0.
      DO 80 N=1,NSY
      SUM=0.
      DO 60 J=1,NTB
      PHI=PI2*RANDN(D)
      R=RANDN(D)
      E=-(2.0/(THETA-1.))
      T=SIG*GAM*SQRT((R**E)-1.)
      Y=SP+T*COS(PHI)
      SUM=SUM+Y
60    CONTINUE
C     CHECK FOR AN ERROR
      IF(SUM.LE.0.) ERS=ERS+1.
      NERS=ERS
      IF(NERS.EQ.NER) GO TO 85
80    CONTINUE
85    PE=ERS/N
      VAR=PE*(1.-PE)/N
      PRINT 8, SNR,PE,ERS,VAR,N
90    CONTINUE
 8    FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
      END
```

```
%       PROGRAM BPSK1(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=2.,BASEBAND
C       HARD LIMITER (NO FILTERING).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(37H HALL, THETA=2  BASEBAND HARD LIMITER,/)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=10 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(5H NTB=,I3,6H  NSY=,I9,6H  NER=,I3,/)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=7,8
        SNR=-55.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        IF(SP+T*COS(PHI)) 10,20,20
   10   SUM=SUM-1.
        GO TO 60
   20   SUM=SUM+1.
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
```

```
%       PROGRAM BPSK2(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=2.,COMPLEX
C       PROCESSING (BANDPASS),OPTIMUM NONLINEARITY.
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H HALL, THETA = 2., OPT NL, BANDPASS, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=10 $ NSY=1000000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
C        DO 90 I=1,12
C        SNR=-55.+I*5.-10.*ALOG10(FLOAT(NTB))
        SNR = -29.
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
C        DO 80 N=1,NSY
        N=1
 1001   SUM=0.
        N=N+1
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        ZMAG=CABS(Z)
        Y=(2.*ZMAG)/(ZMAG*ZMAG+GAM*GAM)
C       REAL PART OF NONLINEARLY PROCESSED SIGNAL PLUS
C       NOISE VECTOR
        YY=Y*(SP+T*COS(PHI))/ZMAG
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
        IF(N.LT.10000000) GO TO 1001

   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
-
```

```
Z       PROGRAM BPSK3(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=2.,LINEAR RECEIVER.
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(34H HALL, THETA = 2., LINEAR RECEIVER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=1 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,18
        SNR=-45.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Y=SP+T*COS(PHI)
        SUM=SUM+Y
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
```

```
%       PROGRAM BPSK4(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL NOISE ENVELOPE=1.,THETA=2.,IDEAL BANDPASS
C       LIMITER,(HARD LIMITER PLUS FILTER).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H HALL, THETA = 2., BANDPASS LIMITER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=1 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,13
        SNR=-55.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        YY=REAL(Z)/CABS(Z)
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK5(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=2.,REAL PROCESSING,
C       OPT NONLINEARITY.
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H HALL, THETA = 2., OPT NL, BASEBAND, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=1 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,14
        SNR=-55.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Y=SP+T*COS(PHI)
        YY=(2.*Y)/(Y*Y+GAM*GAM)
        SUM=SUM+YY
  60    CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
  80    CONTINUE
  85    PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
  90    CONTINUE
   8    FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK6(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       GAUSSIAN NOISE,LINEAR RECEIVER(OPTIUM).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TIME-BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(26H GAUSSIAN, LINEAR RECEIVER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=1 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = ,I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,6
        SNR=-14.+I*4.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        T=SQRT(-2.*SIGSQ*ALOG(1.-R))
        SUM=SUM+SP+T*COS(PHI)
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK7(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       GAUSSIAN NOISE,IDEAL BANDPASS LIMITER
C       (HARD LIMITER PLUS FILTER).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TIME-BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(33H GAUSSIAN, IDEAL BANDPASS LIMITER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=10 $ NSY=100000 $ NER=1000
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,2
        SNR=-90.+I*4.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        T=SQRT(-2.*SIGSQ*ALOG(1.-R))
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        ZMAG=CABS(Z)
        YY=(SP+T*COS(PHI))/ZMAG
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK8(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       GAUSSIAN NOISE,BASEBAND HARD LIMITER (NO FILTERING).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(32H GAUSSIAN, BASEBAND HARD LIMITER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=10 $ NSY=100000 $ NER=10000
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,2
        SNR=-30.+I*4.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        T=SQRT(-2.*SIGSQ*ALOG(1.-R))
        IF(SP+T*COS(PHI)) 10,10,20
   10   SUM=SUM-1.
        GO TO 60
   20   SUM=SUM+1.
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK9(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       GAUSSIAN NOISE,HALL THETA=2. NONLINEARITY, BASEBAND
C       (NO FILTERING).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H GAUSSIAN, THETA = 2., NL, BASEBAND, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=10 $ NSY=100000 $ NER=10000
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,1
        SNR=-30.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        T=SQRT(-2.*SIGSQ*ALOG(1.-R))
        Y=SP+T*COS(PHI)
        SUM=SUM+(2.*Y)/(Y*Y+GAM*GAM)
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
%       PROGRAM BPSK10(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       GAUSSIAN NOISE,HALL THETA=2. NONLINEARITY,
C       BANDPASS(WITH FILTERING).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H GAUSSIAN, THETA = 2., NL, BANDPASS, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=2.
        GAM=SQRT(2.)/200.
C       THIS VALUE OF GAMMA RESULTS IN APD SATURATION USED
C       IN PREVIOUS ANALYTICAL WORK.
        NTB=1 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,9
        SNR=-15.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        T=SQRT(-2.*SIGSQ*ALOG(1.-R))
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        ZMAG=CABS(Z)
        Y=(2.*ZMAG)/(ZMAG*ZMAG+GAM*GAM)
        YY=Y*(SP+T*COS(PHI))/ZMAG
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
```

```
Z     PROGRAM BPSK11(INPUT,OUTPUT)
C     THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C     PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C     SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C     AND NON GAUSSIAN NOISE.
C     HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=4.,
C     REAL PROCESSING,OPTIMUM NONLINEARITY.
C     NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C     NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C     NTB IS THE TIME BANDWIDTH PRODUCT
      COMPLEX Z
      PRINT 7
 7    FORMAT(35H HALL, THETA = 4., OPT NL, BASEBAND, /)
      PI=3.141592654
      PI2=PI*2.
      THETA=4.
      GAM=SQRT(2.)/2.
      NTB=10 $ NSY=100000 $ NER=1000
      PRINT 6, NTB, NSY, NER
 6    FORMAT(5H NTB=,I3,6H  NSY=,I9,6H  NER=,I4,/)
      RNP=0.5
C     REAL NOISE POWER=0.5*ENVELOPE POWER.
      SIGSQ=RNP
      SIG=SQRT(SIGSQ)
C     USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
      DO 90 I=1,2
      SNR=-45.+I*5.-10.*ALOG10(FLOAT(NTB))
      RSP=10.**(SNR/10.)
      SP=SQRT(RSP)
      ERS=0.
      DO 80 N=1,NSY
      SUM=0.
      DO 60 J=1,NTB
      PHI=PI2*RANDN(D)
      R=RANDN(D)
      E=-(2.0/(THETA-1.))
      T=SIG*GAM*SQRT((R**E)-1.)
      Y=SP+T*COS(PHI)
      YY=(THETA*Y)/(Y*Y+GAM*GAM)
      SUM=SUM+YY
 60   CONTINUE
C     CHECK FOR AN ERROR
      IF(SUM.LE.0.) ERS=ERS+1.
      NERS=ERS
      IF(NERS.EQ.NER) GO TO 85
 80   CONTINUE
 85   PE=ERS/N
      VAR=PE*(1.-PE)/N
      PRINT 8, SNR,PE,ERS,VAR,N
 90   CONTINUE
  8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
      END
Z
```

```
%       PROGRAM BPSK12(INPUT,OUTPUT)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=4.,
C       IDEAL BANDPASS LIMITER (HARD LIMITER PLUS FILTER).
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
7       FORMAT(35H HALL, THETA = 4., BANDPASS LIMITER, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=4.
        GAM=SQRT(2.)/2.
        NTB=100 $ NSY=100000 $ NER=100
        PRINT 6, NTB, NSY, NER
6       FORMAT(5H NTB=,I3,6H  NSY=,I9,6H  NER=,I3,/)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=6,6
        SNR=-25.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        YY=REAL(Z)/CABS(Z)
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        PRINT 8, SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,E8.2,2X,F7.1,2X,E8.2,2X,I9)
        END
%
```

```
      PROGRAM BPSK13(INPUT,OUTPUT)
C     THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C     PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C     SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C     AND NON GAUSSIAN NOISE.
C     HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=4.,
C     BASEBAND HARD LIMITING (NO LILTERING).
C     NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C     NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C     NTB IS THE TINE BANDWIDTH PRODUCT
      COMPLEX Z
      PRINT 7
    7 FORMAT(38H HALL, THETA=4. BASEBAND HARD LIMITING,/)
      PI=3.141592654
      PI2=PI*2.
      THETA=4.
      GAM=SQRT(2.)/2.
      NTB=10 $ NSY=10000 $ NER=100
      PRINT 6, NTB, NSY, NER
    6 FORMAT(5H NTB =,I3,6H NSY =,I9,6H NER =,I3,/)
      RNP=0.5
C     REAL NOISE POWER=0.5*ENVELOPE POWER.
      SIGSQ=RNP
      SIG=SQRT(SIGSQ)
C     USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
      DO 90 I=1,8
      SNR=-25.+I*5.-10.*ALOG10(FLOAT(NTB))
      RSP=10.**(SNR/10.)
      SP=SQRT(RSP)
      ERS=0.
      DO 80 N=1,NSY
      SUM=0.
      DO 60 J=1,NTB
      PHI=PI2*RANF(D)
      R=RANF(D)
      E=-(2.0/(THETA-1.))
      T=SIG*GAM*SQRT((R**E)-1.)
      IF(SP+T*COS(PHI)) 10,20,20
   10 SUM=SUM-1.
      GO TO 60
   20 SUM=SUM+1.
   60 CONTINUE
C     CHECK FOR AN ERROR
      IF(SUM.LE.0.) ERS=ERS+1.
      NERS=ERS
      IF(NERS.EQ.NER) GO TO 85
   80 CONTINUE
   85 PE=ERS/N
      VAR=PE*(1.-PE)/N
      PRINT 8, SNR,PE,ERS,VAR,N
   90 CONTINUE
    8 FORMAT(5X,F5.1,2X,1PE12.5,2X,0PF7.1,2X,1PE12.5,2X,I6)
      END
 3■
```

```
%       PROGRAM BPSK14(INPUT,OUT14,TAPE6=OUT14)
C       THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C       PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C       SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C       AND NON GAUSSIAN NOISE.
C       HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=4.,
C       COMPLEX PROCESSING (BANDPASS),OPTIMUM NONLINEARITY.
C       NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C       NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C       NTB IS THE TINE BANDWIDTH PRODUCT
        COMPLEX Z
        PRINT 7
    7   FORMAT(35H HALL, THETA = 4., OPT NL, BANDPASS, /)
        PI=3.141592654
        PI2=PI*2.
        THETA=4.
        GAM=SQRT(2.)/2.
        NTB=10 $ NSY=10000 $ NER=100
        PRINT 6, NTB, NSY, NER
    6   FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
        RNP=0.5
C       REAL NOISE POWER=0.5*ENVELOPE POWER.
        SIGSQ=RNP
        SIG=SQRT(SIGSQ)
C       USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
        DO 90 I=1,8
        SNR=-25.+I*5.-10.*ALOG10(FLOAT(NTB))
        RSP=10.**(SNR/10.)
        SP=SQRT(RSP)
        ERS=0.
        DO 80 N=1,NSY
        SUM=0.
        DO 60 J=1,NTB
        PHI=PI2*RANDN(D)
        R=RANDN(D)
        E=-(2.0/(THETA-1.))
        T=SIG*GAM*SQRT((R**E)-1.)
        Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
        ZMAG=CABS(Z)
        Y=(THETA*ZMAG)/(ZMAG*ZMAG+GAM*GAM)
        YY=Y*(SP+T*COS(PHI))/ZMAG
        SUM=SUM+YY
   60   CONTINUE
C       CHECK FOR AN ERROR
        IF(SUM.LE.0.) ERS=ERS+1.
        NERS=ERS
        IF(NERS.EQ.NER) GO TO 85
   80   CONTINUE
   85   PE=ERS/N
        VAR=PE*(1.-PE)/N
        WRITE(6,8) SNR,PE,ERS,VAR,N
   90   CONTINUE
    8   FORMAT(F5.1,2X,1PE12.5,2X,0PF7.1,2X,1PE12.5,2X,I6)
        END
%
```

```
%     PROGRAM BPSK14(INPUT,OUT14,TAPE6=OUT14)
C     THIS IS ONE OF A SERIES OF SHORT PROGRAMS TO DETERMINE
C     PROBABILITY OF BINARY BIT ERROR FOR BINARY COHERENT PSK
C     SYSTEMS USING VARIOUS FORMS OF NONLINEAR PROCESSING
C     AND NON GAUSSIAN NOISE.
C     HALL MODEL,NOISE ENVELOPE RMS=1.,THETA=4.,
C     COMPLEX PROCESSING (BANDPASS),OPTIMUM NONLINEARITY.
C     NSY IS THE NUMBER OF SYMBOLS TRANSMITTED
C     NER IS THE NUMBER OF ERRORS DESIRED,MAXIMUM
C     NTB IS THE TINE BANDWIDTH PRODUCT
      COMPLEX Z
      PRINT 7
   7  FORMAT(35H HALL, THETA = 4., OPT NL, BANDPASS, /)
      PI=3.141592654
      PI2=PI*2.
      THETA=4.
      GAM=SQRT(2.)/2.
      NTB=10 $ NSY=10000 $ NER=100
      PRINT 6, NTB, NSY, NER
   6  FORMAT(7H NTB = , I3, 8H  NSY = , I9, 8H  NER = , I3, /)
      RNP=0.5
C     REAL NOISE POWER=0.5*ENVELOPE POWER.
      SIGSQ=RNP
      SIG=SQRT(SIGSQ)
C     USE VARIOUS SIGNAL TO NOISE RATIOS DEPENDING ON TBP
      DO 90 I=1,8
      SNR=-25.+I*5.-10.*ALOG10(FLOAT(NTB))
      RSP=10.**(SNR/10.)
      SP=SQRT(RSP)
      ERS=0.
      DO 80 N=1,NSY
      SUM=0.
      TT=RANDN(D)
      SP=SQRT(-2.*RSP*ALOG(1.-TT))
      DO 60 J=1,NTB
      PHI=PI2*RANDN(D)
      R=RANDN(D)
      E=-(2.0/(THETA-1.))
      T=SIG*GAM*SQRT((R**E)-1.)
      Z=CMPLX(SP+T*COS(PHI),T*SIN(PHI))
      ZMAG=CABS(Z)
      Y=(THETA*ZMAG)/(ZMAG*ZMAG+GAM*GAM)
      YY=Y*(SP+T*COS(PHI))/ZMAG
      SUM=SUM+YY
  60  CONTINUE
C     CHECK FOR AN ERROR
      IF(SUM.LE.0.) ERS=ERS+1.
      NERS=ERS
      IF(NERS.EQ.NER) GO TO 85
  80  CONTINUE
  85  PE=ERS/N
      VAR=PE*(1.-PE)/N
      PRINT 8, SNR, PE, ERS, VAR, N
  90  CONTINUE
   8  FORMAT(F5.1,2X,1PE12.5,2X,0PF7.1,2X,1PE12.5,2X,I6)
```