Simulation of Frequency Spectrum Measurement of Frequency Modulation Wave by Electronic Digital Computer

Simulation of Frequency Spectrum Measurement of Frequency Modulation Wave by Electronic Digital Computer ⫯

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Engineerings in recent years postulate the utilization of the electronic digital computer for the engineers. This paper reports the FORTRAN IV programming which simulates the frequency spectrum measurement of frequency modulation wave.

Frequency modulation wave may be written in the form[1]

$$\begin{aligned} e = \; & J_o(\delta) E_c \sin \omega ct \\ & + J_1(\delta) E_c [\sin(\omega_c + \omega_m)t - \sin(\omega_c - \omega_m)t] \\ & + J_2(\delta) E_c [\sin(\omega_c + 2\omega_m)t + \sin(\omega_c - 2\omega_m)t] \\ & + J_3(\delta) E_c [\sin(\omega_c + 3\omega_m)t - \sin(\omega_c - 3\omega_m)t] \\ & + \cdot \cdot \cdot \cdot \end{aligned} \tag{1}$$

where $J_n(\delta)$: Bessel function of the first kind and order n

E_c : Amplitude of unmodulated carrier wave

ωc : Angular frequency of unmodulated carrier wave

ω_m : Angular frequency of modulating signal

δ : Deviation ratio

Therefore, the computation of the absolute value of the Bessel function is necessary to obtain the frequency spectrum of the frequency modulation wave.

Normalized magnitude of the spectrum and plot of the spectral distribution are obtained as output.

The notation of the output is as follows: X denotes an index for the computation of the frequency spectrum. SZ denotes deviation ratio. XBESSL and YBESSL denotes the absolute value of the Bessel function actually computed by the electronic digital computer and shown in the form of the real number. PBESSL and QBESSL denotes assumed experimental data duplicated the table of Bessel function and fed to the electronic digital computer. ABESSL denotes the absolute value of the Bessel function computed in the form of double precision number. The last two digits and minus sign of ABESSL denotes the decimal place. For example, 1.4958289786495405D-06 denotes 0.0000014958289786495405.

The following is the FORTRAN IV programming.

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1. Samuel Seely, "Electron-Tube Circuits" McGraw-Hill Book Company, Inc., 1958, pp 603−608

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C       A CALCULATION OF MAGNITUDES OF FREQUENCY SPECTRUM BY USING
C       DOUBLE  PRECISION  BESSEL  FUNCTIONS
C
        DOUBLE  PRECISION       Z,  PFAC,  P,  TERM,  BESSL,  ZSQ,
      1 DENOM,  TERM1,  DENOM1,  ABESSL
        DIMENSION  GRAPH  (867) ,  PBESSL  (21) ,  QBESSL  (21) , X (21) ,
      1 PFAC  (21) ,  P  (21) ,  TERM  (21) ,  BESSL  (21) ,  DENOM  (21) ,
      2 TERM1  (11) ,  DENOM1 (11) ,  XBESSL (21) ,  ABESSL (21)
      3 ,  YBESSL (21)
C
    8   READ (5,  10) FREQDV,  FREQMD
   10   FORMAT (  2F10.2  )
        DELTA  =  FREQDV  /  FREQMD
        Z  =  DBLE  (  DELTA  )
        DATA (PBESSL (K) ,  K = 1, 21) /0.0000015,  0.0000123,  0.0000908,
      1 0.0005927,  0.0033669,  0.0162417,  0.0643070,  0.1981148,
      2 0.4309800,  0.5201853,  0.0025077,  0.5201853,  0.4309800,  0.1981148,
      3 0.0643070,  0.0162417,  0.0033669,  0.0005927,  0.0000908,  0.0000123,
      4 0.0000015  /
        X  (K)  =  K
        DATA  (QBESSL  (K) , K = 1, 21)  /  0.0025217,  0.0088335,  0.0273661,
      1 0.0734705,  0.1659740,  0.3009145,  0.3996515,  0.3000651,  0.0612322,
      2 0.3461043,  0.0688822,  0.3461043,  0.0612322,  0.3000651,  0.3996515,
      3 0.3009145,  0.1659740,  0.0734705,  0.0273661,  0.0088335,
      4 0.0025217  /
        X  (K)  =  K
        WRITE  (6,100)
  100   FORMAT  (1H1,  20X,  15H  JUNE  10,  1966  /
      1 20X,  40H  MEASUREMENT  OF  F.M.  FREQUENCY  SPECTRUM  ////
      2 25X,  6H  DATA  ///
      3 35X,  30H  CARRIER  FREQUENCY  =  109.0  MC  ////
      4 35X,  11H  FREQ.  DEV.,  10X,  11H  FREQ.  MOD.  ///
      5 10X,  15H  TOP  PICTURE,  10X,  6H  60  KC,  17X,  6H  25  KC ///
      6 10X,  15H  BOTTOM PICTURE, 9X, 7H 133 KC, 17X, 6H 25 KC //////////
      7 25X,  13H  ABBREVIATION  //
      8 30X,  33H  FREQ.  DEV.  =  FREQUENCY  DEVIATION  /
      9 30X,  34H  FREQ.  MOD.  =  FREQUENCY  MODULATION  )
        DO  967  K  =  1,  21
        X  (K)  =  K
        IF  (K-11)  111,  112,  113
  111   PFAC  (K)  =  11  -  K
        P  (K)  =  11  -  K
        TERM  (K)  =  ( 1 + K )  -  K
   25   TERM (K)  = TERM (K)  *  (Z / 2.0)  / PFAC (K)
        PFAC (K)  = PFAC (K)  - 1.0
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      IF  (PFAC (K)  .LE. 0.0)  GO TO 26
      GO  TO  25
 26   BESSL (K)  = TERM (K)
      ZSQ =  (Z / 2.0)  ** 2
      DENOM (K)  =  ( 1 + K)  - K
 28   TERM (K) = - (TERM (K) * ZSQ)  /  (DENOM (K) * (P (K) + 1.0) )
      BESSL (K) = BESSL (K)  + TERM (K)
      IF  (DABS  (TERM  (K) )  .LT. 1.OD-17  ) GO  TO  1966
      P  (K) = P  (K)  + 1.0
      DENOM (K)  = DENOM  (K)  + 1.0
      GO  TO  23
 112  TERM1 (K)  = K - 10
      DENOM1  (K)  =  ( 1 + K ) -K
      BESSL  (K)  = TERM1  (K)
      ZSQ =  ( Z / 2.0 )  ** 2
 120  TERM1 (K) = - (TERM1 (K) * ZSQ) / (DENOM1 (K)  ** 2)
      BESSL  (K) = BESSL  (K)  + TERM1  (K)
      IF  (DABS  (TERM1  (K) )  .LT. 1.OD-17)  GO  TO  1966
      DENOM1  (K)  = DENOM1  (K)  + 1.0
      GO  TO  120
 113  PFAC  (K)  = K - 11
      P   (K)  = K - 11
      TERM (K)  =  (1 + K)  - K
 225  TERM (K)  = TERM (K) *  ( Z / 2.0 )  / PFAC  (K)
      PFAC (K)  = PFAC  (K)  - 1.0
      IF  (PFAC (K)  .LE. 0.0) GO TO 226
      GO  TO  225
 226  BESSL (K)  = TERM  (K)
      ZSQ =  ( Z / 2.0 )  **  2
      DENOM (K)  =  ( 1 + K)  - K
 228  TERM (K) = - (TERM (K) * ZSQ) / (DENOM (K) *  (P (K) + 1.0) )
      BESSL (K) = BESSL (K) + TERM (K)
      IF (DABS  (TERM (K) )  .LT.  1.OD-17)  GO TO 1966
      P (K)  = P  (K)  + 1.0
      DENOM (K)  = DENOM  (K)  + 1.0
      GO  TO  223
1966  SZ = SNGL (Z)
      ABESSL  (K)  = DABS  (BESSL  (K) )
 967  XBESSL  (K)  = SNGL  (ABESSL (K) )
      IF  (SZ - 3.0)  303,  303,  304
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  303 WRITE (6, 301)
  301 FORMAT (1H1, 12X, 1HX, 10X, 2HSZ, 10X, 6HPBESSL , 8X, 6HXBESSL,
     1 12X, 6HABESSL)
      DO 411 K = 1, 21
  411 WRITE (6, 29) X (K) , SZ, PBESSL (K) , XBESSL (K) , ABESSL (K)
   29 FORMAT (5X, F10.0, 2X,F12.6, 2X, F12.7, 2X, F12.7, 1PD 26.16)
      IF (SZ .LT. 3.0) GO TO 402
  304 WRITE (6, 302)
  302 FORMAT (1H1, 12X, 1HX, 10X, 2HSZ, 10X, 6HQBESSL, 8X, 6HYBESSL,
     1 12X, 6HABESSL )
      DO 412 K = 1, 21
      YBESSL (K) = XBESSL (K)
  412 WRITE (6, 30) X (K) , SZ, QBESSL (K) , YBESSL (K) , ABESSL (K)
   30 FORMAT (5X, F10. 0, 2X, F12.6, 2X, F12. 7, 2X, F12. 7, 1 PD26.16)
C
C
C
  402 CALL PLOT2 (GRAPH, 21.0, 1.0, 1.00, 0.0)
      IF (SZ - 3.0) 305, 305, 306
  305 CALL PLOT3 ( 1HX, X (1) , XBESSL (1) , 21)
      WRITE (6, 60)
   60 FORMAT (1H1)
      CALL FPLOT 4 (34, 34H    MAGNITUDE OF FREQUENCY SPECTRUM    )
      WRITE (6, 61)
   61 FORMAT (/30X47H/   X=MAGNITUDE OF FREQUENCY SPECTRUM IN F.M./
     1 35X, 40H MODULATION --- CALCULATED FROM THEORY    )
      CALL PLOT3 ( 1HP, X (1) , PBESSL (1) , 21)
      WRITE ( 6, 64 )
   64 FORMAT ( 1H1 )
      CALL FPLOT 4 (34, 34H MAGNITUDE OF FREQUENCY SPECTRUM    )
      WRITE ( 6, 65 )
   65 FORMAT (/ 30X47H/ P = MAGNITUDE OF FREQUENCY SPECTRUM IN  F.M./
     1 37X, 39H MODULATION --- FROM EXPERIMENTAL DATA    )
      IF (SZ .LT. 3.0) GO TO 309
  306 CALL PLOT3 (1HY, X (1) , YBESSL (1) ,21 )
      WRITE ( 6, 62 )
   62 FORMAT ( 1H1 )
      CALL FPLOT 4 (34, 34H    MAGNITUDE OF FREQUENCY SPECTRUM    )
      WRITE ( 6, 63 )
   63 FORMAT (/30X47H/   Y=MAGNITUDE OF FREQUENCY SPECTRUM IN F.M./
     1 35X, 40H MODULATION --- CALCULATED FROM THEORY    )
      CALL PLOT3 ( 1HQ, X (1) , QBESSL (1) , 21 )
      WRITE ( 6, 66 )
   66 FORMAT ( 1H1 )
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      CALL FPLOT 4  (34, 34H    MAGNITUDE OF FREQUENCY SPECTRUM    )
      WRITE  ( 6, 67 )
   67 FORMAT (/30X47H/  Q=MAGNITUDE OF FREQUENCY SPECTRUM IN   F.M./
    1 37X, 39H MODULATION --- FROM EXPERIMENTAL DATA     )
  309 GO  TO  8
      END
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DATA

CARRIER FREQUENCY = 109.0 MC

	FREQ. DEV.	FREQ. MOD.
TOP PICTURE	60 KC	25 KC
BOTTOM PICTURE	133 KC	25 KC

ABBREVIATION

FREQ. DEV. = FREQUENCY DEVIATION

FREQ. MOD. = FREQUENCY MODULATION

X	SZ	PBESSL	XBESSL	ABESSL
1.	2.400000	0.0000015	0.0000015	1.4958289786495405D−06
2.	2.400000	0.0000123	0.0000123	1.2300243384487578D−05
3.	2.400000	0.0000908	0.0000908	9.0755997321446449D−05
4.	2.400000	0.0005927	0.0005927	5.9273974476902080D−04
5.	2.400000	0.0033669	0.0033669	3.3668925481798282D−03
6.	2.400000	0.0162417	0.0162417	1.6241723163365478D−02
7.	2.400000	0.0643070	0.0643070	6.4306954638122331D−02
8.	2.400000	0.1981148	0.1981148	1.9811479442648289D−01
9.	2.400000	0.4309800	0.4309800	4.3098003634831925D−01
10.	2.400000	0.5201853	0.5201853	5.2018527328971906D−01
11.	2.400000	0.0025077	0.0025077	2.5076956994271011D−03
12.	2.400000	0.5201853	0.5201853	5.2018527328971906D−01
13.	2.400000	0.4309800	0.4309800	4.3098003634831925D−01
14.	2.400000	0.1981148	0.1981148	1.9811479442648289D−01
15.	2.400000	0.0643070	0.0643070	6.4306954638122331D−02
16.	2.400000	0.0162417	0.0162417	1.6241723163365478D−02
17.	2.400000	0.0033669	0.0033669	3.3668925481798282D−03
18.	2.400000	0.0005927	0.0005927	5.9273974476902080D−04
19.	2.400000	0.0000908	0.0000908	9.0755997321446449D−05
20.	2.400000	0.0000123	0.0000123	1.2300243384487578D−05
21.	2.400000	0.0000015	0.0000015	1.4958289786495405D−06