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Program for calculating loudness according to DIN 45631 (ISO 532B)

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The method for calculating loudness level proposed by Zwicker is standardized in ISO 532B. This is a graphical procedure and it can be tedious to calculate loudness level by this procedure. Recently, DIN 45631 has been revised including a computer program for calculating loudness level in BASIC which runs on IBM-compatible PC's. Since the NEC PC-9801 series computers are popular in Japan, the program has been modified for the NEC PC-9801 series computers and is introduced in this paper.

Keywords: Loudness, Loudness level

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For the calculation of loudness, a graphical procedure has been proposed which was published in a German (DIN 45631)[1] and in an International Standard (ISO 532B).[2] In order to facilitate the sometimes tedious procedure significantly, and to increase its applicability, computer programs in FORTRAN[3] and in BASIC[4] were published. Recently, in a revision of DIN 45631, a computer program in BASIC has been included in the German standard which runs on IBM-compatible PC's. Since the software of the NEC PC-9801 series computers used in Japan shows slight modifications compared to that of the usual IBM standard, we were asked to publish a version of the loudness calculation program that runs on NEC PC-9801 series computers.

In the following, the listing of a program is printed that gives exactly the same values for loudness in sone and loudness level in phon as the program published in the German standard DIN 45631. Since this standard is largely identical to ISO 532B, values calculated by the program also are in line with this international standard.

By using the computer program described, loudness of stationary sounds can be calculated in excellent agreement with subjective evaluation. For sounds with strong temporal variations, however, special nonlinear temporal weightings have to be applied as described in Zwicker *et al.*[5] and Fastl.[6]

The program described here has been successfully applied so far in Europe (see references in Fastl[6]), in the United States (e.g. Hellman and Zwicker[7]) as well as in Japan (e.g. Namba and Kuwano,[8] Kuwano *et al.*[9,10], Suzuki *et al.*[11] and Tachibana *et al.*[12]). In all cases, a good correlation between subjective evaluation and physical evaluation by means of the computer program was found.

The listing of the program is the following.

† He passed away suddenly on 22nd November 1990. We highly esteem his great achievements and his passing has been hard to accept.

LIST OF THE PROGRAM

```
'*****************************************************************
'*
'*     LOUDNESS CALCULATION ACCORDING TO DIN 45631 (ISO 532B)
'*
'*
'*                TECHNICAL UNIVERSITY MUNICH
'*               INSTITUTE OF ELECTROACOUSTICS
'*
'*****************************************************************
'*
'*  PROGRAMMING LANGUAGE: N88-BASIC(MS-DOS)
'*
'*****************************************************************
'*
'*
'*  PROGRAMMING NOTE : THIS PROGRAM CALCULATES THE LOUDNESS
'*                     AND THE LOUDNESS LEVEL FROM THE 1/3
'*                     OCTAVE BAND LEVELS OF A SOUND
'*
'*
'*  INPUT PARAMETERS : LT   FIELD OF 28 ELEMENTS WHICH REPRESENT
'*                          THE 1/3 OCTAVE BAND LEVELS IN dB WITH
'*                          CENTER FREQUENCY FROM 25 Hz TO
'*                          12.5 kHz
'*
'*                     M$   VARIABLE TO DISTINGUISH THE TYPE
'*                          OF SOUND FIELD ( FREE / DIFFUSE )
'*
'*
'*  OUTPUT PARAMETERS: N    LOUDNESS IN SONE G
'*
'*                     LN   LOUDNESS LEVEL IN PHON G
'*
'*
'*  VARIABLES        : FR   CENTER FREQUENCIES OF 1/3 OCTAVE
'*                          BANDS
'*
'*                     RAP  RANGES OF 1/3 OCTAVE BAND LEVELS
'*                          FOR CORRECTION AT LOW FREQUENCIES
'*                          ACCORDING TO EQUAL LOUDNESS CON-
'*                          TOURS
'*
'*                     DLL  REDUCTION OF 1/3 OCTAVE BAND LEVELS
'*                          AT LOW FREQUENCIES ACCORDING TO
'*                          EQUAL LOUDNESS CONTOURS WITHIN THE
'*                          EIGHT RANGES DEFINED BY RAP
'*
'*                     LTQ  CRITICAL BAND RATE LEVEL AT ABSOLUTE
'*                          THRESHOLD WITHOUT TAKING INTO AC-
'*                          COUNT THE TRANSMISSION CHARACTERIS-
'*                          TICS OF THE EAR
'*
'*                     AO   CORRECTION OF LEVELS ACCORDING TO
'*                          THE TRANSMISSION CHARACTERISTICS OF
'*                          THE EAR
'*
'*                     DDF  LEVEL DIFFERENCE BETWEEN FREE AND
'*                          DIFFUSE SOUND FIELDS
'*
'*                     DCB  ADAPTATION OF 1/3 OCTAVE BAND LEVELS
'*                          TO THE CORRESPONDING CRITICAL BAND
'*                          LEVEL
'*
'*****************************************************************
'*****************************************************************
'*
'*                     ZUP  UPPER LIMITS OF APPROXIMATED CRITI-
'*                          CAL BANDS IN TERMS OF CRITICAL BAND
'*                          RATE
'*
'*                     RNS  RANGE OF SPECIFIC LOUDNESS FOR THE
'*                          DETERMINATION OF THE STEEPNESS OF
'*                          THE UPPER SLOPES IN THE SPECIFIC
'*                          LOUDNESS - CRITICAL BAND RATE PAT-
'*                          TERN
'*
'*                     USL  STEEPNESS OF THE UPPER SLOPES IN
'*                          THE SPECIFIC LOUDNESS - CRITICAL
'*                          BAND RATE PATTERN FOR THE RANGES
'*                          RNS AS A FUNCTION OF THE NUMBER OF
'*                          THE CRITICAL BAND
'*
'*****************************************************************
'
'--------------------------- PREFACE -----------------------------
'
WIDTH 80,25: CONSOLE 0,25,0,1: CLS 3
SR1$ = "*********************************"
LOCATE 8, 3: COLOR 6
PRINT SR1$; SR1$
LOCATE 8, 4: PRINT "*": LOCATE 71, 4: PRINT "*"
LOCATE 8, 5: PRINT "*": LOCATE 71, 5: PRINT "*"
LOCATE 13, 5
PRINT "LOUDNESS CALCULATION ACCORDING TO DIN 45631 (ISO 532B)"
LOCATE 8, 6: PRINT "*": LOCATE 71, 6: PRINT "*"
LOCATE 8, 7:
PRINT SR1$; SR1$
'
LOCATE 16, 10: COLOR 4
PRINT "This program calculates, according to the graphic"
'
LOCATE 16, 11
PRINT "procedure by Zwicker (DIN 45631), the loudness N as"
'
LOCATE 16, 12
PRINT "well as the loudness level LN from the 1/3 octave"
'
LOCATE 16, 13
PRINT "band levels of a sound."
'
LOCATE 16, 15
PRINT "The result is given numerically, as Loudness N"
'
LOCATE 16, 16
PRINT "in sone, as well as Loudness Level LN in phon."
'
LOCATE 16, 18
PRINT "Input each 1/3 oct. band level in dB"
'
LOCATE 16, 19
PRINT "and push <RETURN> key to enter."
'
LOCATE 16, 22: COLOR 6
PRINT "Push <RETURN> key to start ! ";
'
GOSUB 5370
'
COLOR 7: RE$ = INPUT$(1)
IF RE$ = CHR$(13) THEN GOSUB 5370 ELSE 2220
CLS
'
'
'*****************************************************************
'
'---------------------------- TABLES -----------------------------
'
'
' CENTER FREQUENCIES OF 1/3 OCT. BANDS (FR)
'
DATA  25, 31.5,40 ,50 ,63 ,80 ,100,125 ,160,200
DATA 250, 315 ,400,500,630,800,1.0,1.25,1.6,2
DATA 2.5, 3.15,4  ,5  ,6.3,8  ,10 ,12.5
'
'
' RANGES OF 1/3 OCT. BAND LEVELS FOR CORRECTION AT LOW FREQUENCIES
' ACCORDING TO EQUAL LOUDNESS CONTOURS (RAP)
'
DATA 45,55,65,71,80,90,100,120
'
'
' REDUCTION OF 1/3 OCT. BAND LEVELS AT LOW FREQUENCIES ACCORDING TO
' EQUAL LOUDNESS CONTOURS WITHIN THE EIGHT RANGES DEFINED BY RAP (DLL)
'
DATA -32,-24,-16,-10,-5,0, -7,-3,0, -2,0
DATA -29,-22,-15,-10,-4,0, -7,-2,0, -2,0
DATA -27,-19,-14, -9,-4,0, -6,-2,0, -2,0
DATA -25,-17,-12, -9,-3,0, -5,-2,0, -2,0
DATA -23,-16,-11, -7,-3,0, -4,-1,0, -1,0
DATA -20,-14,-10, -6,-3,0, -4,-1,0, -1,0
DATA -18,-12, -9, -6,-2,0, -3,-1,0, -1,0
DATA -15,-10, -8, -4,-2,0, -3,-1,0, -1,0
'
'
' CRITICAL BAND LEVEL AT ABSOLUTE THRESHOLD WITHOUT TAKING INTO
' ACCOUNT THE TRANSMISSION CHARACTERISTICS OF THE EAR (LTQ)
'
DATA 30,18,12, 8, 7, 6, 5, 4
DATA  3, 3, 3, 3, 3, 3, 3, 3
DATA  3, 3, 3, 3
'
'
' CORRECTION OF LEVELS ACCORDING TO THE TRANSMISSION CHARACTERISTICS
' OF THE EAR (AO)
'
DATA  0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
DATA  0.0, 0.0,-0.5,-1.6,-3.2,-5.4,-5.6,-4.0
DATA -1.5, 2.0, 5.0,12.0
'
'
' LEVEL DIFFERENCE BETWEEN FREE AND DIFFUSE SOUND FIELDS (DDF)
'
DATA 0.0,0.0,0.5, 0.9, 1.2, 1.6, 2.3,2.8
DATA 3.0,2.0,0.0,-1.4,-2.0,-1.9,-1.0,0.5
DATA 3.0,4.0,4.3, 4.0
'
'
' ADAPTATION OF 1/3 OCT. BAND LEVELS TO THE CORRESPONDING CRITICAL
' BAND LEVEL (DCB)
'
DATA -.25,-0.6,-0.8,-0.8,-0.5,0.0,0.5,1.1
DATA  1.5, 1.7, 1.8, 1.8, 1.7,1.6,1.4,1.2
DATA  0.8, 0.5, 0.0,-0.5
'
'
' UPPER LIMITS OF APPROXIMATED CRITICAL BANDS IN TERMS OF CRITICAL
' BAND RATE (ZUP)
'
DATA  0.9, 1.8, 2.8, 3.5, 4.4, 5.4, 6.6, 7.9
DATA  9.2,10.6,12.3,13.8,15.2,16.7,18.1,19.3
DATA 20.6,21.8,22.7,23.6,24.0
'
'
' RANGE OF SPECIFIC LOUDNESS FOR THE DETERMINATION OF THE STEEPNESS
' OF THE UPPER SLOPES IN THE SPECIFIC LOUDNESS - CRITICAL BAND RATE
' PATTERN (RNS)
'
DATA 21.5,18.0,15.1,11.5, 9.0, 6.1,.4.4,3.1
DATA 2.13,1.36,0.82,0.42,0.30,0.22,0.15,0.10
DATA 0.035,0.0
'
'
' STEEPNESS OF THE UPPER SLOPES IN THE SPECIFIC LOUDNESS - CRITICAL
' BAND RATE PATTERN FOR THE RANGES RNS AS A FUNCTION OF THE NUMBER
' OF THE CRITICAL BAND (USL)
'
DATA 13.00, 8.20, 6.30, 5.50, 5.50, 5.50, 5.50, 5.50
DATA  9.00, 7.50, 6.00, 5.10, 4.50, 4.50, 4.50, 4.50
DATA  7.80, 6.70, 5.60, 4.90, 4.40, 3.90, 3.90, 3.90
DATA  6.20, 5.40, 4.60, 4.00, 3.50, 3.20, 3.20, 3.20
DATA  4.50, 3.80, 3.60, 3.20, 2.90, 2.70, 2.70, 2.70
DATA  3.70, 3.00, 2.80, 2.35, 2.20, 2.20, 2.20, 2.20
DATA  2.90, 2.30, 2.10, 1.90, 1.80, 1.70, 1.70, 1.70
DATA  2.40, 1.70, 1.50, 1.35, 1.30, 1.30, 1.30, 1.30
DATA  1.95, 1.45, 1.30, 1.15, 1.10, 1.10, 1.10, 1.10
DATA  1.50, 1.20, 0.94, 0.86, 0.82, 0.82, 0.82, 0.82
DATA  0.72, 0.67, 0.64, 0.63, 0.62, 0.62, 0.62, 0.62
DATA  0.59, 0.53, 0.51, 0.50, 0.42, 0.42, 0.42, 0.42
DATA  0.40, 0.33, 0.26, 0.24, 0.22, 0.22, 0.22, 0.22
DATA  0.27, 0.21, 0.20, 0.18, 0.17, 0.17, 0.17, 0.17
DATA  0.16, 0.15, 0.14, 0.12, 0.11, 0.11, 0.11, 0.11
DATA  0.12, 0.11, 0.10, 0.08, 0.08, 0.08, 0.08, 0.08
DATA  0.09, 0.08, 0.07, 0.06, 0.06, 0.06, 0.06, 0.05
DATA  0.06, 0.05, 0.03, 0.02, 0.02, 0.02, 0.02, 0.02
'
'
'*****************************************************************
'
'------------- DIMENSION AND STORING OF VARIABLES ----------------
'
OPTION BASE 1
'
DIM LT(28), FR(28), CLT(28), CFR(28), GI(3), LTQ(20), LE(21)
DIM LCB(3), NM(21), RAP(8), NS(240), DLL(11, 8), AO(20)
DIM DCB(20), DDF(20), ZUP(21), RNS(18), USL(18, 8)
DIM TI(11), KOMM$(80), XP(10), XB(10), XX(10)
'
```

```
3460 RESTORE 2390
3470   FOR I = 1 TO 28
3480     READ FR(I)
3490   NEXT I
3500   FOR I = 1 TO 8
3510     READ RAP(I)
3520   NEXT I
3530   FOR J = 1 TO 8
3540     FOR I = 1 TO 11
3550       READ DLL(I, J)
3560     NEXT I
3570   NEXT J
3580   FOR I = 1 TO 20
3590     READ LTQ(I)
3600   NEXT I
3610   FOR I = 1 TO 20
3620     READ AO(I)
3630   NEXT I
3640   FOR I = 1 TO 20
3650     READ DDF(I)
3660   NEXT I
3670   FOR I = 1 TO 20
3680     READ DCB(I)
3690   NEXT I
3700   FOR I = 1 TO 21
3710     READ ZUP(I)
3720   NEXT I
3730   FOR I = 1 TO 18
3740     READ RNS(I)
3750   NEXT I
3760   FOR I = 1 TO 18
3770      FOR J = 1 TO 8
3780        READ USL(I, J)
3790      NEXT J
3800   NEXT I
3810 '
3820 '*************************************************************
3830 '*************************************************************
3840 '
3850 '----------------------- IN- AND OUTPUT --------------------------
3860 '
3870 '--- INPUT OF 1/3 OCT. BAND LEVELS
3880 '
3890 CLS : GOSUB 5370
3900 '
3910 X = 5
3920 '
3930 FOR I = 1 TO 28
3940   X = X + 1
3950   IF X = 20 THEN CLS : X = 5
3960   LOCATE 1, 1: COLOR 4
3970   PRINT "Input 1/3 oct. band levels (format: ***.*) !"
3980   LOCATE 1, 2
3990   PRINT "Push <RETURN> key each time.
4000   LOCATE 18, X
4010   IF I < 17 THEN 4020 ELSE 4050
4020   PRINT "1/3 oct. band level at ";
4030   COLOR 6: PRINT USING "###.#"; FR(I); : COLOR 4: PRINT "  Hz: "
4040   GOTO 4070
4050   PRINT "1/3 oct. band level at ";
4060   COLOR 6: PRINT USING "##.##"; FR(I); : COLOR 4: PRINT " kHz: "
4070   COLOR 7: LOCATE 52, X: INPUT LT(I)
4080   IF LT(I) = 0 THEN LT(I) = -60
4090   IF LT(I) < -60 OR LT(I) > 120 THEN 4100 ELSE 4170
4100   COLOR 2: LOCATE 1, 22
4110   PRINT "Attention !"
4120   LOCATE 1, 23
4130   PRINT "Input levels are accepted only between -60 dB and 120 dB !"
4140   BEEP:COLOR 7
4150   LOCATE 51, X: PRINT SPACE$(10)
4160   GOTO 4070
4170   COLOR 6: LOCATE 51, X: PRINT USING "#####.#"; LT(I):
4180   LOCATE 58, X: PRINT " dB     ": COLOR 7
4190 '
4200   GOSUB 5370
4210   '
4220 NEXT I
4230 '
4240 '--- SELECTION OF SOUND FIELD (FREE/DIFFUSE)
4250 '
4260 GOSUB 5370
4270 CLS
4280 COLOR 4: LOCATE 20, 11
4290 PRINT "Input of the type of sound field:"
4300 LOCATE 20, 13
4310 PRINT "free (F) or diffuse (D) sound field? "; : COLOR 7
4320 '
4330 M$ = INPUT$(1)
4340 '
4350 IF M$ = "F" OR M$ = "f" THEN M$ = "F": GOTO 4370
4360 IF M$ = "D" OR M$ = "d" THEN M$ = "D" ELSE GOTO 4330
4370 '
4380 '
4390 CLS
4400 COLOR 5: LOCATE 30, 12:
4410 PRINT "Now calculating..."
4420 COLOR 7: GOSUB 5510
4430 '
4440 '
4450 '--- END OF PROGRAM - OUTPUT OF RESULTS ON DISPLAY/PRINTER ---
4460 '
4470 CLS
4480 COLOR 6: LOCATE 9, 5:
4490 PRINT SR1$; SR1$
4500 LOCATE 9, 6: PRINT "*": LOCATE 72, 6: PRINT "*"
4510 LOCATE 9, 7: PRINT "*": LOCATE 21, 7:
4520 PRINT "LOUDNESS          N =    ";
4530 IF N <= 16 THEN PRINT USING "####.##"; N;
4540 IF N > 16 THEN PRINT USING "####.#"; N; : PRINT " ";
4550 PRINT "    sone G"; M$
4560 LOCATE 72, 7: PRINT "*"
4570 LOCATE 9, 8: PRINT "*": LOCATE 21, 8:
4580 PRINT "LOUDNESS LEVEL  LN =    "; : PRINT USING "###.#"; LN;
4590 PRINT "    phon G"; M$
4600 LOCATE 72, 8: PRINT "*"
4610 LOCATE 9, 9: PRINT "*": LOCATE 72, 9: PRINT "*"
4620 LOCATE 9, 10:
4630 PRINT SR1$; SR1$
4640 '
4650 GOSUB 5370
4660 '
4670 COLOR 4: LOCATE 24, 17: PRINT "Print out of the table above? (y/n) ";
4680 PR$ = INPUT$(1): COLOR 7
4690 '
4700 IF PR$ = "y" OR PR$ = "Y" THEN GOTO 4980
4710 IF PR$ = "n" OR PR$ = "N" THEN GOTO 4730 ELSE GOTO 4680
4720 '
4730 CLS : GOSUB 5370
4740 '
4750 COLOR 4: LOCATE 13, 12
4760 PRINT "Input of new 1/3 oct. band levels (y) or end (n)? ";
4770 NE$ = INPUT$(1): COLOR 7
4780 '
4790 IF NE$ = "y" OR NE$ = "Y" THEN 3850
4800 IF NE$ = "n" OR NE$ = "N" THEN 4820 ELSE GOTO 4770
4810 '
4820 CLS
4830 '
4840 SCREEN 0: CONSOLE ,,1.0
4850 LOCATE 37, 11: PRINT "End..."
4860 '
4870 LOCATE 0,0: END
4880 '
4890 '
4900 '*************************************************************
4910 '********************** SUBRQUTINES **************************
4920 '*************************************************************
4930 '
4940 '*************************************************************
4950 '********** SUBROUTINE TO OUTPUT THE RESULTS ON PRINTER **********
4960 '*************************************************************
4970 '
4980 COLOR 7: LOCATE 1, 17: PRINT SPACE$(79)
4990 '
5000 COLOR 4: LOCATE 29, 17
5010 PRINT "Ready?"
5020 LOCATE 29, 19
5030 PRINT "Push any key to start !"
5040 '
5050 GOSUB 5370: GOSUB 7240
5060 ON ERROR GOTO 7110
5070 '
5080 CLS
5090 '
5100 DT1$ = MID$(DATE$, 4, 2)
5110 DT2$ = LEFT$(DATE$, 2)
5120 DT3$ = RIGHT$(DATE$, 2)
5130 DT$ = DT2$ + "." + DT1$ + "." + DT3$
5140 '
5150 LPRINT
5160 LPRINT SPACE$(10); "*** DIN - LOUDNESS CALCULATION ***"
5170 LPRINT
5180 LPRINT SPACE$(12);
5190 LPRINT "DATE:"; " "; DT$; "  "; "TIME:"; " "; TIME$
5200 LPRINT
5210 LPRINT SPACE$(17);
5220 LPRINT "N  = ";
5230 IF N <= 16 THEN LPRINT USING "####.##"; N;
5240 IF N > 16 THEN LPRINT USING "####.#"; N; : LPRINT " ";
5250 LPRINT " sone G"; M$
5260 LPRINT SPACE$(17);
5270 LPRINT "LN =  "; : LPRINT USING "###.#"; LN;
5280 LPRINT "  phon G"; M$
5290 LPRINT
5300 COLOR 7: GOTO 4730
5310 '
5320 '
5330 '*************************************************************
5340 '************** SUBROUTINE TO CLEAR THE KEY BUFFER **************
5350 '*************************************************************
5360 '
5370 FOR W = 1 TO 50
5380   W$ = INKEY$
5390   IF LEN(W$) = 0 THEN RETURN
5400 NEXT W
5410 '
5420 '
5430 '*************************************************************
5440 '************** SUBROUTINE - LOUDNESS CALCULATION **************
5450 '*************************************************************
5460 '
5470 '--- CORRECTION OF 1/3 OCT. BAND LEVELS ACCORDING TO EQUAL LOUDNESS
5480 '    CONTOURS (XP) AND CALCULATION OF THE INTENSITIES FOR 1/3 OCT.
5490 '    BANDS UP TO 315 Hz
5500 '
5510 FOR I = 1 TO 11
5520   J = 1
5530   IF LT(I) <= RAP(J) - DLL(I, J) THEN GOTO 5560
5540   J = J + 1
5550   IF J < 8 THEN GOTO 5530
5560   XP = LT(I) + DLL(I, J)
5570   TI(I) = 10 ^ (.1 * XP)
5580 NEXT I
5590 '
5600 '
5610 '--- DETERMINATION OF LEVELS LCB(1), LCB(2) AND LCB(3) WITHIN THE
5620 '    FIRST THREE CRITICAL BANDS
5630 '
5640 DEF FNGI (I) = 10 * LOG(GI(I)) / LOG(10)
5650 GI(1) = TI(1) + TI(2) + TI(3) + TI(4) + TI(5) + TI(6)
5660 GI(2) = TI(7) + TI(8) + TI(9)
5670 GI(3) = TI(10) + TI(11)
5680 '
5690 FOR I = 1 TO 3
5700   IF GI(I) > 0 THEN LCB(I) = FNGI(I)
5710 NEXT I
5720 '
5730 '
5740 '--- CALCULATION OF MAIN LOUDNESS
5750 '
5760 FOR I = 1 TO 20
5770   LE(I) = LT(I + 8)
5780   IF I <= 3 THEN LE(I) = LCB(I)
5790   LE(I) = LE(I) - AO(I)
5800   NM(I) = 0
5810   IF M$ = "D" OR M$ = "d" THEN LE(I) = LE(I) + DDF(I)
5820   IF LE(I) <= LTQ(I) THEN 5930
5830   LE(I) = LE(I) - DCB(I)
5840   '
5850   S = .25
5860   '
5870   MP1 = .0635 * 10 ^ (.025 * LTQ(I))
5880   MP2 = (1 - S + S * 10 ^(.1 * (LE(I) - LTQ(I)))) ^ .25 - 1
5890   NM(I) = MP1 * MP2
5900   '
5910   IF NM(I) <= 0 THEN NM(I) = 0
5920   '
5930 NEXT I
5940 NM(21) = 0
5950 '
5960 '
5970 '--- CORRECTION OF SPECIFIC LOUDNESS IN THE LOWEST CRITICAL BAND
5980 '    TAKING INTO ACCOUNT THE DEPENDENCE OF ABSOLUTE THRESHOLD
5990 '    WITHIN THIS CRITICAL BAND
6000 '
6010 KORRY = .4 + .32 * NM(1) ^ .2
```

```
6020 IF KORRY > 1 THEN KORRY = 1
6030 NM(1) = NM(1) * KORRY
6040 '
6050 '
6060 '--- START VALUES
6070 '
6080 N = 0
6090 Z1 = 0
6100 N1 = 0
6110 IZ = 1
6120 Z = .1
6130 '
6140 '
6150 '--- STEP TO FIRST AND SUBSEQUENT CRITICAL BANDS
6160 '
6170 FOR I = 1 TO 21
6180 '
6190   ZUP(I) = ZUP(I) + .0001
6200 '
6210   IG = I - 1
6220   IF IG > 8 THEN IG = 8
6230 '
6240 '
6250   IF N1 > NM(I) THEN GOTO 6560
6260   IF N1 = NM(I) THEN GOTO 6410
6270 '
6280 '
6290 '--- DETERMINATION OF THE NUMBER J CORRESPONDING TO THE RANGE
6300 '    OF SPECIFIC LOUDNESS
6310 '
6320       FOR J = 1 TO 18
6330           IF RNS(J) < NM(I) THEN 6410
6340       NEXT J
6350 '
6360 '
6370 '--- CONTRIBUTION OF UNMASKED MAIN LOUDNESS TO TOTAL LOUDNESS
6380 '    AND CALCULATION OF VALUES NS(IZ) WITH A SPACING OF
6390 '    Z = IZ * 0.1 BARK
6400 '
6410       Z2 = ZUP(I)
6420       N2 = NM(I)
6430       N = N + N2 * (Z2 - Z1)
6440 '
6450       FOR K = Z TO Z2 STEP .1
6460           NS(IZ) = N2
6470           IZ = IZ + 1
6480       NEXT K
6490       Z = K
6500       GOTO 6780
6510 '
6520 '
6530 '--- DECISION WHETHER THE CRITICAL BAND IN QUESTION IS COMPLETELY
6540 '    OR PARTLY MASKED BY ACCESSORY LOUDNESS
6550 '
6560       N2 = RNS(J)
6570       IF N2 < NM(I) THEN N2 = NM(I)
6580       DZ = (N1 - N2) / USL(J, IG)
6590       Z2 = Z1 + DZ
6600       IF Z2 <= ZUP(I) THEN 6680
6610       Z2 = ZUP(I)
6620       DZ = Z2 - Z1
6630       N2 = N1 - DZ * USL(J, IG)
6640 '
6650 '
```

```
6660 '--- CONTRIBUTION OF ACCESSORY LOUDNESS TO TOTAL LOUDNESS
6670 '
6680       N = N + DZ * (N1 + N2) / 2
6690       FOR K = Z TO Z2 STEP .1
6700           NS(IZ) = N1 - (K - Z1) * USL(J, IG)
6710           IZ = IZ + 1
6720       NEXT K
6730       Z = K
6740 '
6750 '
6760 '--- STEP TO NEXT SEGMENT
6770 '
6780       IF N2 <= RNS(J) AND J < 18 THEN J = J + 1: GOTO 6780
6790       IF N2 <= RNS(J) AND J >= 18 THEN J = 18
6800       Z1 = Z2
6810       N1 = N2
6820       IF Z1 < ZUP(I) THEN 6250
6830 '
6840 NEXT I
6850 '
6860 IF N < 0 THEN N = 0
6870 '
6880 IF N <= 16 THEN N = INT(N * 1000 + .5) / 1000
6890 IF N > 16 THEN N = INT(N * 100 + .5) / 100
6900 '
6910 '
6920 '--- CALCULATION OF LOUDNESS LEVEL FOR LN < 40 PHON
6930 '    OR N < 1 SONE
6940 '
6950 LN = 40 * (N + .0005) ^ .35
6960 IF LN < 3 THEN LN = 3
6970 '
6980 '
6990 '--- CALCULATION OF LOUDNESS LEVEL FOR LN >= 40 PHON
7000 '    OR N >= 1 SONE
7010 '
7020 IF N >= 1 THEN LN = 10 * LOG(N) / LOG(2) + 40
7030 '
7040 RETURN
7050 '
7060 '
7070 '*************************************************************
7080 '*************** SUBROUTINE FOR ERRORS OF PRINTER ***************
7090 '*************************************************************
7100 '
7110 CLS
7120 COLOR 2: LOCATE 18, 12: PRINT "Printer is not ready."
7130 LOCATE 48, 12: PRINT "Try again !
7140 BEEP
7150 LOCATE 18, 14: PRINT "Push any key !"
7160 GOSUB 5370: GOSUB 7240
7170 RESUME 4470
7180 '
7190 '
7200 '*************************************************************
7210 '*************** SUBROUTINE TO WAIT FOR KEY INPUT ***************
7220 '*************************************************************
7230 '
7240 LET A$ = INKEY$
7250 WHILE A$ = "": LET A$ = INKEY$: WEND: RETURN
7260 '
7270 '
7280 '*************************************************************
7290 '*************************************************************
```


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REFERENCES

1) DIN 45631, "Berechnung des Lautstärkepegels und der Lautheit aus dem Geräuschspektrum. Verfahren nach E. Zwicker" (1990).
2) ISO 532B, "Acoustics—Method for calculating loudness level" (1975).
3) E. Paulus and E. Zwicker, "Programme zur automatischen Bestimmung der Lautheit aus Terzpegeln oder Frequenzgruppenpegeln," Acustica **27**, 253–266 (1972).
4) E. Zwicker, H. Fastl, and C. Dallmayr, "BASIC-Program for calculating the loudness of sounds from their 1/3-oct. band spectra according to ISO 532B," Acustica **55**, 63–67 (1984).
5) E. Zwicker, K. Deuter, and W. Peisl, "Loudness meters based on ISO 532B with large dynamic range," Proc. Inter-Noise 85 (II), 1119–1122 (1985).
6) H. Fastl, "Noise measurement procedures simulating our hearing system," J. Acoust. Soc. Jpn. (E) **9**, 75–80 (1988).
7) R. Hellman and E. Zwicker, "Measured and calculated loudness of complex sounds," Proc. Inter-Noise 87 (II), 973–976 (1987).
8) S. Namba and S. Kuwano, "Psychological study on L_{eq} as a measure of loudness of various kinds of noises," J. Acoust. Soc. Jpn. (E) **5**, 135–148 (1984).
9) S. Kuwano, S. Namba, and H. Miura, "Advantages and disadvantages of A-weighted sound pressure level in relation to subjective impression of environmental noise," Noise Control Eng. J. **33**, 107–115 (1989).
10) S. Kuwano, S. Namba, and T. Hashimoto, "On the psychological evaluation of amplitude-modulated sounds," Proc. Inter-Noise 89, 797–802 (1989).
11) Y. Suzuki, T. Sone, H. Sato, and S. Kono, "An experimental consideration on the tone correction (or adjustment) for environmental noise evaluation," Proc. Inter-Noise 86 (II), 849–854 (1986).
12) H. Tachibana, F. Sato, S. Kuwano, and S. Namba, "Comparisons of various kinds of noise assessment measures," Proc. Spring Meet. Acoust. Soc. Jpn., 415–416 (1987) (in Japanese).