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(54) **Metal detector with display.**

(57) A metal detector having a receive signal responsive to detected metal objects and having a display panel (139) that can simultaneously display a plurality of phase angles (205) on one scale associated with the receive signal. Additionally, the display panel can simultaneously display on the other scale (210) a second variable associated with the receive signal at each particular phase angle. The second variable is user selectable and can be either (1) a count of the number of times when the signal amplitude exceeds a predetermined threshold level at a particular phase angle or (2) the signal amplitude when the signal is at a particular phase angle.

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Field of Invention

The present invention relates to the field of metal detectors, and more particularly to a means of graphically displaying signal information that reflects signal characteristics responsive to metal objects which pass beneath a search head of the metal detector.

Background of the Invention

As induction balanced metal detector, of the type used to locate coins, rings and other treasure buried in soil within a few feet of the surface, has a search head that houses a transmit coil and receive coil. The metal detector has circuitry that transmits a periodic signal to the transmit coil as the search head is manually swept over a ground surface to detect buried metal objects. When the transmit coil passes over a metal object, a signal is generated in the receive coil due to pertubations in the magnetic field which cause the AC inductive coupling between the transmit and receive coils to become unbalanced. These receive coil signals are responsive to target characteristics such as size, depth below the ground surface, orientation with respect to the search head, and type of metal. In order to provide the user with information about the target's characteristics, (e.g., to distinguish coins from nails), some metal detectors measure the phase angle between the transmitted signal and the received signal. This phase angle is typically displayed to the user as a number on an output device such as an analog meter or a liquid crystal display (LCD). Under ideal conditions this phase angle can provide the user with accurate information regarding the the target.

However,, in actual practice the phase angle information is materially affected by ground mineralisation and can also be affected by the target's orientation with respect to the search head. Under either of these conditions a single sweep of the search head can, with conventional displays, produce multiple phase angle readings and thereby result in an indecipherable output. In response to this problem some metal detector designers have also provided an audio output of the received signal where the tone's frequency corresponds to the phase angle of the signal and the tone's volume corresponds to the signal strength. An example of the prior art which uses a numeric LCD to display phase angle information and which also has an audio output is Maulding, U.S. Patent No. 4,868,910, assigned to the assignee of this invention. This recent prior art approach provides the user with more complete information regarding phase angle and signal strength, but suffers in that the information cannot be latched for careful analysis and it also depends upon the user's audio memory and ability to discern frequencies in order to determine the target's characteristics.

Summary of the Invention

The present invention solves the above problems by providing a bivariate visual display of two variables that are associated with a signal induced in the receive coil of a metal detector.

The two variables are preferably:

(1) the receive signal's phase angle (with respect to the transmit signal) and

(2) either (a) a count of the number of occurrences in which the signal amplitude exceeds a predetermined amplitude (hereinafter, the signal count) or (b) the signal amplitude.

The apparatus is preferably operable so that the user has the choice of (a) or (b). The bivariate information is displayed on a suitable graphic device such as an LCD.

The method and apparatus of the invention permit the metal detector operator to readily make a visual discrimination between valid phase angle readings that represent good target information and those that are due to extraneous, non-target magnetic field pertubations.

According to the invention there is provided a metal detector having a bivariate visual display of two signal characteristics that are representative of a target object.

The preset invention further provides an improved metal detector in which (a) the phase angle between the transmit and receive signals is determined only when the signal strength exceeds a predetermined level and (b) the number of times the signal amplitude exceeds the predetermined level at a predetermined range of phase angles is counted, and then simultaneously displays both the phase angle and signal count on a visual display device.

The present invention further provides a metal detector that measures the phase angle between the transmit signal and receive signal when the signal strength exceeds a predetermined level and displays the phase angle and received signal strength simultaneously on a visual display device.

The invention and other objectives, features and advantages of the present invention will be more readily understood upon consideration of the following detailed description of an example of an embodiment of the invention taken in conjunction with the accompanying diagrammatic drawings.

Brief Description of the Drawings

FIGURE 1 is a block diagram of a portion of an exemplary metal detector circuit of the present invention.

FIGURES 2a-2g show exemplary embodiments of a bivariate graphic display of the present invention showing signal information associated with a metal detector.

FIGURE 3 is an abridged flow diagram of an exemplary software routine for processing the signals associated with the metal detector.

FIGURE 4 is a flow diagram of an exemplary software routine that writes phase angle and signal count to the graphic display of FIGURE 2.

FIGURE 5 is a flow diagram of an exemplary software subroutine that selects a shorter bar character associated with the graphic display device of FIGURE 2.

FIGURE 6 is a flow diagram of an exemplary software routine that writes phase angle and amplitude information to the graphic display device of FIGURE 2.

Appendix A is a source code listing of the subroutine REPORT.

Description of a Preferred Embodiment

This invention pertains to improvements in the display of signal information generated within induction balance type metal detectors. A metal detector of this type is fully described in Maulding, U.S. Patent No. 4,868,910 which is incorporated herein by reference for purposes of providing a complete disclosure. Before proceeding to the preferred embodiment of the present invention, it is first necessary to generally describe the operation of an induction-balanced metal detector which will be done with reference to Maulding.

An induction-balanced metal detector generally has a search head with two AC coupled, electrically conductive coils: a transmit coil and a receive coil. Maulding describes a search head with three coils; transmit, receive and a feedback coil; however, the feedback coil is not relevant to the present disclosure. (See Maulding, FIGURE 1, Nos. 22, 24 and 26.) To search for buried targets, a periodic signal is applied to the transmit coil as the search head is swept over an area of ground. Under ideal conditions, i.e. proper induction balance and no magnetic field perturbations, there is no signal in the receive coil. However, when the search head passes over a target it causes a disturbance in the transmit coil's magnetic field, thereby inducing a signal in the receive coil. The transmit and receive signals are then electronically processed and applied to various output devices in an effort to measure and communicate various target characteristics. As exemplified in Maulding, the signals are processed into six components, XD, XF, YD, YF, GD and GF. Only the filtered signals XF, YF and GF are relevant to the present application. XF and YF are DC phase quadrature components of the receive and transmit signals and GF is a filtered DC signal representation of the ground mineralisation effects. (See Maulding, FIGURE 1, where 52, 56 and 78 represent signals XF, YF and GF, respectively.) From the XF and YF components, a receive signal phase angle is measured which is representative of the target's characteristics. (Maulding , FIGURES 2, 3; Col. 9, lines 35-50; and Col. 21, lines 27-50). This phase angle information discloses characteristics such as type of metal, size, orientation of a ferromagnetic object with respect to the search head, and ground mineralisation.

FIGURE 1 of this application shows the components of Maulding's circuit which are also in the present invention. (The reference numbers in FIGURE 1 correspond to Maulding reference numbers for identical component blocks.) All the reference elements in FIGURE 1 are also represented in Maulding with the important exception of LCD 139 which is materially distinct from Maulding's LCD 138.

With reference to FIGURE 1, it can be seen that signals XF and YF emerge from respective band pass filters 42, 46 and are applied to respective track and hold circuits 50 and 54. Thereafter, signals XF and YF are applied to a multiplexor (MUX) 82. The signal GF emerges from a band pass filter 74 and is thereafter applied directly to MUX 82.

Reading a signal is a two-step process and fully described in Maulding (Col. 18, line 25 to Col. 19, line 3). In essence, the main processor 116 simultaneously commands track and hold circuits 50, 54 to hold the respective XF and YF signals so that the signals which are later sequentially input into the MUX represent XF and YF signals that are sampled at the same instant in time. The main processor 116 then directs MUX 82 to route selected signals to the MUX output in a predetermined sequence at a fixed sampling rate of approximately 7.5 milliseconds. The signals coming out of the MUX are applied to an analog-to-digital converter system 100 and then applied to the main processor 116. At this point the present apparatus and method are different from Maulding in that the main processor is arranged to write the information to LCD 139 in a suitable format using onboard software programming described hereinafter.

FIGURE 2a represents a preferred embodiment of the bivariate graphical display of the present invention showing two variables of signal information displayed on LCD 139. There is a horizontal scale that is divided into a series of evenly-spaced divisions 205, each division represents a range of phase angles. A preferred embodiment of the present invention that is generally commercially available is a LCD having a 4 x 20 character display, which means that the horizontal axis can display 20 characters and the vertical scale can display four characters, with each character representing a range of values.

In the preferred embodiment of the display shown in each of FIGURES 2a-2g, the horizontal scale represents the relative phase angle. Each division represents a range of phase angles: where the possible range of phase angles is 180° then each division along the horizontal scale of a 4 x 20 LCD would represent a 9° range of phase angles. The vertical scale 210 represents a second variable which is either (a) a signal count or (2) an amplitude of the receive signal.

The signal count is a running tabulation of the number of times that a signal having a particular phase angle exceeds a predetermined threshold amplitude (e.g., the number of times that a signal with a phase angle between +20 and +29 exceeds a signal strength of 0.08 volts). Either the user or the main processor 116 selects the threshold amplitude to filter out weak signals. Each time a signal amplitude exceeds the threshold amplitude the associated phase angle is measured and the signal count for that phase angle is incremented.

The alternate variable displayed on the vertical scale is the amplitude of the receive signal. Only information associated with phase angles whose amplitude exceeds the predetermined threshold level is displayed.

The individual characters 212 used to represent the bivariate information are user definable characters which are bit-mapped into a five by eight matrix within the main processor 116 and downloaded to the LCD. The standard configuration displays the signal information as a bar graph, with a bar at respective phase angle ranges and the height of the bar is proportional to the signal count or signal amplitude (the bar height is zero where no signals correspond to a given range of phase angles).

FIGURES 2b-2g are examples of the LCD display when the search head encounters various buried metals. FIGURES 2b-2d represent the display in response to "good targets", that is, targets that the metal detector user may want to dig up. Good target displays are characterised by a tight grouping of bars within a narrow range of phase angles, or optimally at a single phase angle range as shown in FIGURE 2b. Additionally, good targets are characterised by groupings in the positive portion of the graph; i.e., the area between the "0" and "(+)" symbols. The exemplary embodiments of FIGURES 2b-2d also show other information on the LCD such as the VDI, which is a numeric representation of the phase angle, and a textual estimate of the target, e.g. "quarter" in FIGURE 2b.

FIGURES 2e-2g are exemplary embodiments of the display when the search head encounters undesirable (i.e., non-valuable) metal targets. These graphs display signal information having phase angles that are predominantly in the negative portion of the graph (between "0" and "(-)") and which typically show a signal response at a wide range of phase angles rather than the tight grouping associated with goods targets. The bivariate display is particularly helpful in deciphering those signals that are spread across a wide range of phase angles, as is shown in FIGURE 2f. If the display were monovariate (e.g., a numeric LCD), the user would not be able to distinguish good targets from bad because the numeric LCD would be as likely to show a phase angle associated with a good target as with a bad one. But the bivariate display of the present invention shows the signal information as a "smear" across the display, thereby clearly communicating to the user that the target is not desirable.

The advantage of the bivariate display is also apparent in a comparison of FIGURE 2g with FIGURE 2d. A monovariate display would likely indicate the same phase angle for each of these targets, namely the phase angle associated with the division 250 to the immediate right of the centre because the largest bar is at that location. However the bivariate display of the present invention shows information on multiple phase angles and the good target FIGURE 2d has a bar to the positive side whereas the undesirable target FIGURE 2g has a bar to the negative side of the largest bar. A user familiar with these displays will recognise the more positive phase angles as indicative of a good target.

FIGURE 3 is an abridged software flow diagram representing the steps performed by the main processor during operation of the metal detector. A more complete flow diagram showing steps necessary for operation of a metal detector is shown in Maulding, FIGURE 11. Continuing with FIGURE 3 of the present invention, steps 302 and 304 represent channel selection and signal reading wherein the main processor 116 instructs the MUX 82 to route a selected channel to the MUX output pin. After reading the signals 304, the next step calls software subroutine PEAK 306, which determines whether signal GF has reached a local maximum value. (Subroutine PEAK is exemplar shown in Maulding FIGURE 16). A "Local maximum" is one that occurs within a predetermined period of time. When the main processor determines that GF has reached a local maximum, a flag "PK" is set. The next step, subroutine GETPHASE 308, calculates the phase of the receive signal from XF and YF and stores the result in a memory register "PHASE". (GETPHASE is exemplar shown in Maulding, FIGURE 18). After GETPHASE, the software calls subroutine REPORT 310 which checks the status of flag PK and writes the signal information to the LCD when flag PK is set. (The subroutine REPORT 310 is novel to this invention and has no equivalent in Maulding). Software module REPORT utilises one of two, preferably user selectable, routines AVERG (FIGURES 4 and 5) or NORM (FIGURE 6).

The REPORT subroutine checks a flag "MP" to determine whether the user has selected the display mode which shows the signal count or the signal amplitude. If the user selects the signal count display, then the subroutine REPORT will branch to a routine AVERG (FIGURE 4). Alternatively, if the user selects the amplitude display, then REPORT will branch to the routine NORM (FIGURE 6). AVERG and NORM could be subroutines, but in the preferred embodiment they are code within the subroutine REPORT.

FIGURE 4 is an exemplary flow diagram of AVERG 400 which writes signal information to the LCD. This routine determines whether a local maximum in the signal amplitude has occurred at step 410 by testing whether flag PK has been set. If PK is not set then the routine exits at 412. If flag PK is set then the routine gets the phase angle in step 420 from the memory register PHASE> In step 425 the routine converts the phase angle into an LCD "write" address. As explained above, the preferred embodiment includes a 4 x 20 matrix LCD display device and the phase angle is represented along the 20-character axis. Therefore, the software program converts the phase angle into a "write" address corresponding to the LCD axis by multiplying the phase angle by 20 and dividing the result by 180, effectively creating 20 ranges of phase angles of nine degrees each. The routine then reads the height of the bar at the LCD address corresponding to the "write" address at step 430 and in step 435 determines whether the bar has reached a maximum height. If the bar has not reached a maximum height then the routine writes the next taller bar character in step 445. Alternatively, if the bar is at a maximum height then the routine calls FADE at step 440.

FADE 460, FIGURE 5, decrements the height of all bars that are at addresses other than the "write" address. FADE loops through 20 iterations, step 465, to read the height of the bar at each address, step 470. If the height of the bar is zero then the subroutine does nothing and loops to the next bar, step 485. If the height of the bar is not zero then the subroutine selects the next shortest bar character at step 480. The subroutine loops through all the bars until each bar other than the "write" address bar is decremented (or skipped, in the case of zero height bars) at step 485. After completing the 20 iterations the subroutine FADE returns control to AVERG which terminates at step 490.

FIGURE 6 is an exemplary flow diagram representation of the routine NORM 500. Upon entering NORM, the program first determines whether a local maximum in the receive signal has occurred at step 502 by testing for the flag PK. If flag PK is not set, the routine terminates at step 526. If flag PK is set, the program gets, at step 504, the phase angle of the receive signal from the memory register and converts the phase angle to an LCD "write" address 1 to 20, step 506, in the same manner as described above for routine AVERG. In the next step, the program runs a subroutine BYTE(GF) to calculate a compressed eight-bit datum representing the GF level which correlates to the receive signal amplitude. (BYTE is exemplarily disclosed in Maulding, FIGURE 14). Thereafter, the routine, at steps 510, 512 and 514, respectively, tests the eight-bit representation of the GF level against three preset, respectively decreasing thresholds designated thresholds 1, 2, and 3. If the GF level is greater than the first threshold 510, then the routine selects all four segments of the bar at step 516. If the GF level is less than threshold 1 but greater than the next lowest threshold 2, step 512, then the routine selects three of the four bar characters at step 518. If the GF level is less than threshold 2 but greater than the lowest threshold 3, step 514, then the routine selects two bar characters at step 520. If the GF level is less than threshold 3 then the routine selects one bar character at step 522. The routine then writes the information to the "write" address at step 524 and exits the subroutine at step 526.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognised that the scope of the invention includes and provides any metal detector or method incorporating any novel constructional or operational feature, step or process disclosed herein or in the accompanying drawings.

APPENDIX A

```
2500 A.D. 6805 CROSS ASSEMBLER   -   VERSION 3.01d
-------------------------------------------------

          INPUT  FILENAME :  REPORT.ASM
          OUTPUT FILENAME :  REPORT.OBJ


                                  NAM    REPORT   07 FEB 89/modified 7/28/89  MDR
                          **********************************************
                          *OUT:TARGET DATA DISPLAYED IN AUDIO AND LCD.
                          *CRITERION FOR LEARN = PK
                          *CRITERION FOR AUDIO = GFLEV
                          **********************************************
                            PUBLIC REPORT
                            EXTERN AUDIO ;DOK & GOUT TO AUDW
                            EXTERN DISFLT ;DISCRIMINATE FILTER->DOK
                            EXTERN SET,CLR ;LEARN ROUTINES
                            EXTERN VDI,VDIAV,AVCOUNT,DISTABL,GDC,GCOUNT,IDTONE
                            EXTERN PAGE0 STATE,PAGE0 GHOT,PAGE0 DISPTR,PAGE0 KEY
                            EXTERN PAGE0 STAT ;7=LRNREJ,6=LRNACC       IN
                                              ;2=PK,3=TRIG,5=DISC      IN
                                              ;0=DOK                  OUT
                            EXTERN PAGE0 FLAGA ;3=DON:SET IF ACCEPT   OUT
                                               ;4=DOK:SET IF DISC ON  OUT
                                               ;2=ATH                  IN
                            EXTERN PAGE0 FLAGB ;6=ZDON                OUT
                                               ;4=SIGN BIT            INT
                                               ;5=ATIME RUNNING       INT
                            EXTERN PAGE0 FLAGP ;0=ac overload
                            EXTERN PAGE0 GFLEV ;DATA FROM PEAK         IN
                            EXTERN PAGE0 GFAMP ; abs(compressed(GF))
                            EXTERN PAGE0 DISLEV ;DISC. DATA TO AUDIO  OUT
                            EXTERN PAGE0 ACSENS ;USED FOR SHIFTS       IN
                            EXTERN PAGE0 PHASE ;SB                     IN
                            EXTERN PAGE0 PHRAC
                            EXTERN PAGE0 TEMA  ;STASH                 INT
                            EXTERN PAGE0 OPTST ;RAM TEST ADDRESS       IN
                            EXTERN PAGE0 ATIME ;RECOVERY HOLD OFF     INT
                            EXTERN PAGE0 RECOV ;user adj. hold off
                            EXTERN PAGE0 VDISENS,PAGE0 FADERATE,PAGE0 FADECOUNT
                            EXTERN PAGE0 BCREJ
                            EXTERN PAGE0 SIGBAL
                            EXTERN PAGE0 STATTABL
                            EXTERN PAGE0 TFREQ
                            EXTERN PAGE0 FLAG4
                            EXTERN DIVIDE
                            EXTERN CLRDATA,FADE,LABEL,CLRVDI
                          **********************************************
0000   07 00 7D           REPORT BRCLR  3,STAT,SEARCH *GO IF NO TRIGGER

                          **********************************************
                          * TRIGGER PRESSED (PINPOINTING MODE)          *
                          **********************************************
0003   B6 00                        LDA    DISPTR
0005   A1 1C                        CMP    #28
```

```
REPORT   07 FEB 89/modified 7/28/89  mDR

0007  26 69                BNE    JWR
0009  B6 00                LDA    SIGBAL
000B  44                   LSRA
000C  44                   LSRA
000D  40                   NEGA
000E  AB 14                ADD    #20
0010  97                   TAX                     ;x in range 17 -- 20
0011  B6 00                LDA    TFREQ
0013  A0 04                SUB    #4
0015  2A 02                BPL    SCALE2
0017  40                   NEGA
0018  5C                   INCX
0019  27 04     SCALE2     BEQ    SCALE3
001B  5C                   INCX
001C  4A                   DECA
001D  20 FA                BRA    SCALE2
001F  0A 07 03  SCALE3     BRSET  5,STATTABL+7,SCALE4
0022  5C                   INCX
0023  5C                   INCX
0024  5C                   INCX
0025  B6 00     SCALE4     LDA    SHOT
0027  2A 01                BPL    SCALEIT
0029  4F                   CLRA
002A  A1 78     SCALEIT    CMP    #120
002C  25 04                BLO    SCALIT2
002E  A6 13                LDA    #19
0030  20 0B                BRA    SHOWIT
0032  42        SCALIT2    MUL
0033  BF 00                STX    TEMA
0035  AE 07                LDX    #7
0037  34 00     SCLOOP     LSR    TEMA
0039  46                   RORA
003A  5A                   DECX
003B  26 FA                BNE    SCLOOP
003D  A1 13     SHOWIT     CMP    #19
003F  23 02                BLS    INDXOK
0041  A6 13                LDA    #19
0043  97        INDXOK     TAX
0044  A6 02                LDA    #2
0046  D7 00 0F             STA    DISTABL+15,X
0049  BF 00                STX    TEMA
004B  5C        MRKRLOOP   INCX
004C  A3 14                CPX    #20
004E  24 10                BHS    BARIT
0050  D6 00 0F             LDA    DISTABL+15,X
0053  A1 20                CMP    #32
0055  27 09                BEQ    BARIT
0057  A6 A1                LDA    #A1H
0059  D7 00 0F             STA    DISTABL+15,X
005C  A3 13                CPX    #19
005E  25 EB                BLO    MRKRLOOP
0060  5F        BARIT      CLRX
0061  A6 02                LDA    #2
0063  B3 00     BARLOOP    CPX    TEMA
0065  27 06                BEQ    DCPTST
0067  D7 00 0F             STA    DISTABL+15,X
006A  5C                   INCX
```

REPORT 07 FEB 89/modified 7/28/89 MDR

```
0068  20 F6                BRA   BARLOOP
006D  B6 00      DCPTST    LDA   PHASE
006F  02 08 60             BRSET 1,STATTABL+8,SIGN?
0072  CC 01 EC   JWR       JMP   WRITE    ;UPDATE AUDIO & RTN
0075  A6 10      SETFADE   LDA   #16
0077  B0 00                SUB   FADERATE ;1 (min) - 15 (max)
0079  48                   LSLA
007A  48                   LSLA
007B  48                   LSLA
007C  48                   LSLA
007D  B7 00                STA   FADECOUNT
007F  81                   RTS
                 **********************************************
                 * TRIGGER RELEASED (SEARCH MODE)             *
                 **********************************************

0080  01 00 00   SEARCH BRCLR  0,STATE,NOFADE
0083  3D 00             TST    FADERATE
0085  27 09             BEQ    NOFADE
0087  3A 00             DEC    FADECOUNT
0089  26 05             BNE    NOFADE
008B  AD E8             BSR    SETFADE
008D  CD 00 00          JSR    FADE
0090  CD 00 00   NOFADE JSR    DISFLT   ;UPDATE DOK
                 ;check for valid time to do peak processes
0093  05 00 05          BRCLR  2,STAT,NOTPK ;GO,NOT PEAK
0096  07 00 02          BRCLR  3,FLAGA,NOTPK ;GO,NOT DOD
0099  20 12             BRA    PEAK
009B  CD 00 00   NOTPK  JSR    LABEL
009E  C6 00 00          LDA    VDI
00A1  A1 64             CMP    #100      ;if overload or low bat showing
00A3  24 05             BHS    JNP       ;..don't defeat label update
00A5  A6 66             LDA    #102      ;"no label" code
00A7  C7 00 00          STA    VDI
00AA  CC 01 70   JNP    JMP    NOTPK2
                 **********************************************
                 * PEAK PROCESSES: DO AT PEAK OF EACH WAVE    *
                 **********************************************
00AD  02 0A 0B   PEAK    BRSET 1,STATTABL+10,NOCLEAR    ;test single sweep/accum.
00B0  01 00 05           BRCLR 0,FLAG4,NOCLEAR
00B3  11 00              BCLR  0,FLAG4
00B5  CD 00 00           JSR   CLRDATA
00B8  AD BB      NOCLEAR BSR   SETFADE
00BA  B6 00              LDA   PHASE
00BC  C7 00 00           STA   VDI
00BF  C7 00 00           STA   IDTONE
00C2  0B 08 0D           BRCLR 5,STATTABL+8,SIGN?     ;skip test if vis. disc. off
00C5  00 00 0A           BRSET 0,STAT,SIGN?           ;accept targ.?
00C8  CD 00 00           JSR   CLRVDI
00CB  A6 67              LDA   #103
00CD  C7 00 00           STA   VDI
00D0  20 37              BRA   SPECTN
00D2  2A 08      SIGN?   BPL   POSVDI
00D4  40                 NEGA
00D5  AE 2D              LDX   #2DH
00D7  CF 00 01           STX   DISTABL+1
00DA  20 05              BRA   DOVNUM
```

REPORT 07 FEB 89/modified 7/28/89 MDR

```
00DC  AE 20      POSVDI  LDX    #32
00DE  CF 00 01           STX    DISTABL+1
00E1  AE 0A      DOVNUM  LDX    #10
00E3  CD 00 00           JSR    DIVIDE
00E6  AB 30              ADD    #30H
00E8  C7 00 02           STA    DISTABL+2
00EB  9F                 TXA
00EC  AB 30              ADD    #30H
00EE  C7 00 03           STA    DISTABL+3
00F1  A6 2E              LDA    #2EH
00F3  C7 00 04           STA    DISTABL+4
00F6  B6 00              LDA    PHRAC
00F8  AB 30              ADD    #30H
00FA  C7 00 05           STA    DISTABL+5
00FD  A6 1C              LDA    #28
00FF  B7 00              STA    DISPTR
0101  1F 00              BCLR   7,FLAG4
0103  07 00 03           BRCLR  3,STAT,SPECTM
0106  CC 01 EC           JMP    WRITE
0109  5F         SPECTM  CLRX
010A  B6 00              LDA    PHASE
010C  AB 60              ADD    #96             ;nm'lize to -96 @ 0
010E  B7 00              STA    TEMA
0110  4F                 CLRA
0111  AB 0A      VLOOP   ADD    #10
0113  B1 00              CMP    TEMA
0115  24 03              BHS    DISBAR
0117  5C                 INCX
0118  20 F7              BRA    VLOOP
011A  04 0A 21   DISBAR  BRSET  2,STATTABL+10,AVERG


                 ;"normal" mode -- scale bar height by gf amp.
011D  B6 00              LDA    GFAMP
011F  2A 01              BPL    COMP64
0121  40                 NEGA
0122  A1 6B      COMP64  CMP    #6BH
0124  25 04              BLO    COMP40
0126  A6 02              LDA    #2
0128  20 35              BRA    STASH
012A  A1 4B      COMP40  CMP    #4BH
012C  25 04              BLO    COMP18
012E  A6 03              LDA    #3
0130  20 2D              BRA    STASH
0132  A1 3B      COMP18  CMP    #3BH
0134  25 04              BLO    SHORT
0136  A6 04              LDA    #4
0138  20 25              BRA    STASH
013A  A6 5F      SHORT   LDA    #5FH
013C  20 21              BRA    STASH


                 ;"average" mode -- count hits and show distribution
013E  D6 00 0F   AVERG   LDA    DISTABL+15,X
0141  A1 20              CMP    #20H
0143  26 04              BNE    COMP5F
0145  A6 5F              LDA    #5FH
0147  20 16              BRA    STASH
0149  A1 5F      COMP5F  CMP    #5FH
```

```
REPORT   07 FEB 89/modified 7/28/89  MDR

0148   26 04                   BNE    COMP2
014D   A6 04                   LDA    #4
014F   20 0E                   BRA    STASH
0151   A1 02          COMP2    CMP    #2
0153   26 09                   BNE    NEXTSEG
0155   BF 00                   STX    TEMA
0157   CD 00 00                JSR    FADE
015A   BE 00                   LDX    TEMA
015C   A6 03                   LDA    #3
015E   4A             NEXTSEG DECA
015F   D7 00 0F       STASH    STA    DISTABL+15,X

                      LEARN ;modify memory based upon [phase]
0162   0D 0A 05              BRCLR  6,STATTABL+10,LRN1 ;GO NOT LRNREJ
0165   CD 00 00              JSR    SET
0168   20 06                 BRA    LRNEND
016A   0B 0A 03       LRN1   BRCLR  5,STATTABL+10,LRNEND ;GO,NOT LRNACC
016D   CD 00 00              JSR    CLR
0170                  LRNEND

0170                  NOTPK2
                      ************************************************
                      * THE FOLLOWING OCCURS EVERY CYCLE              *
                      ************************************************

                      ************************************************
                      * WEIGHT GFLEV FOR NORMAL OR HIGH GAIN         *
                      * IN:GFLEV (0-128)                             *
                      * OUT:A,TEMA=WEIGHTED GFLEV (0-128)            *
                      ************************************************
0170   B6 00                 LDA    GFLEV
0172   27 0A                 BEQ    WGFEND   ;STAY AT 0 IF 0
0174   BE 00                 LDX    ACSENS
0176   A3 41                 CPX    #65
0178   24 04                 BHS    WGFEND
017A   44                    LSRA
017B   26 01                 BNE    WGFEND
017D   4C                    INCA
017E   B7 00          WGFEND STA    TEMA
                      ************************************************
                      * ATIME CONTROL SYSTEM
                      * IN:2,FLAGA (ATH) RESETS ATIME
                      *OUT:5,FLAGB SET IF ATIME RUNNING
                      ************************************************
0180   1B 00                 BCLR   5,FLAGB  ;ASSUME NO ATIME
0182   05 00 07              BRCLR  2,FLAGA,NOATH
                      ;if ath detected, reset atime with app. value
0185   A6 32                 LDA    #50
0187   B0 00                 SUB    RECOV    ; 40 (max) - 1 (min)
0189   44                    LSRA            ;range: 5 - 24
018A   B7 00                 STA    ATIME
018C   3D 00          NOATH  TST    ATIME    ;CHECK IF RUNNING
018E   26 04                 BNE    DECIT
0190   10 00                 BSET   0,FLAG4
0192   20 04                 BRA    ATEND
0194   3A 00          DECIT  DEC    ATIME    ;SERVICE ATIME &
0196   1A 00                 BSET   5,FLAGB  ; SET FLAG
```

REPORT   07 FEB 89/modified 7/28/89 MDR

```
0198                   ATEND
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ; DECREASE DISLEV UNLESS ATIME
                       ;OUT:DISLEV=0 IF ATIME OVER
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ;skip decrease if atime running
0198   0A 00 06              BRSET  5,FLAGB,DECEND  ;GO IF ATIME
019B   37 00                 ASR    DISLEV
019D   2A 02                 BPL    DECEND
019F   3C 00                 INC    DISLEV   ;FORCE NEG CONVERGENCE
01A1                   DECEND
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ; ADD GFLEV TO DISLEV                         ;
                       ; IN:  DISLEV (SB)                            ;
                       ; IN:TEMA=WEIGHTED, (OB)                      ;
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ;skip add if not atime
01A1   0B 00 37              BRCLR  5,FLAGB,ADDEND
                       ;get ready, and branch to appropriate routine
01A4   B6 00           ADDUP  LDA   DISLEV
01A6   AB 80                 ADD    #80H     ;A=DISLEV (OB)
01A8   00 00 16              BRSET  0,STAT,ACC ;GO IF ACCEPT
                       ;reject target... A=dislev-adj gflev,clip @ 0
01AB   00 00 0E              BRSET  0,FLAGP,SUBIT     ;test ac overload
01AE   0E 00 0B              BRSET  7,PHASE,SUBIT     ;don't bias pos. phase reponses
01B1   97                    TAX              ;x has dislev
01B2   B6 00                 LDA    BCREJ     ;1 (min) - 20 (max)
01B4   44                    LSRA             ;0 - 10
01B5   B1 00                 CMP    TEMA      ;clip?
01B7   25 02                 BLO    GFOK
01B9   B7 00                 STA    TEMA      ;clip above min. neg. excursion
01BB   9F              GFOK   TXA
01BC   B0 00           SUBIT  SUB   TEMA     ;A=DISLEV-ADJ GFLEV (OB)
01BE   24 17                 BCC    NOCLIP   ;CLIP IF OVERFLOW
01C0   4F                    CLRA             ;CLIP @ 0
                       ;accept target... A=dislev+adj gflev
01C1   00 00 0D        ACC    BRSET 0,FLAGP,ADDIT     ;test ac overload
01C4   97                    TAX              ;x has dislev
01C5   A6 18                 LDA    #24       ;bcrej: 1 (min) - 20 (max)..
01C7   B0 00                 SUB    BCREJ     ;23 - 4
01C9   48                    LSLA             ;46 (min) - 8 (max)
01CA   B1 00                 CMP    TEMA      ;clip?
01CC   22 02                 BHI    GFOK2
01CE   B7 00                 STA    TEMA      ;clip below max. pos. excursion
01D0   9F              GFOK2  TXA
01D1   BB 00           ADDIT  ADD   TEMA
                       ;clip at full scale
01D3   24 02                 BCC    NOFS      ;CLIP IF OVERFLOW
01D5   A6 FF                 LDA    #0FFH
01D7                   NOFS
                       ;finish processing A into dislev....
01D7                   NOCLIP
01D7   A0 80                 SUB    #80H      ;CONVERT SB
01D9   B7 00                 STA    DISLEV    ;POSSIBLY REDUNDANT
01DB                   ADDEND
                       ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                       ; RIG UP DON AND DOD FROM DISLEV              ;
```

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```
                     ; IN:   DISLEV                                  ;
                     ;OUT: DOD=1 IF |DISLEV|>VDISENS(DATA PRESENT);
                     ;OUT: DON=1 IF DISLEV >0 (ACCEPT)              ;
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
01DB  18 00                BSET   4,FLAGA  ;DON (SET IF ACCEPT)
01DD  17 00                BCLR   3,FLAGA  ;DOD (SET IF DISC ON)
01DF  2A 03                BPL    RPT1     ;GO IF PLUS
01E1  40                   NEGA
01E2  19 00                BCLR   4,FLAGA  ;DON CLEAR=REJ
01E4  BB 00          RPT1  ADD    VDISENS  ;vdi sens.: 1 (min) - 99 (max)
01E6  A1 64                CMP    #100
01E8  25 02                BLO    RPT2     ;GO IF <THRESHOLD
01EA  16 00                BSET   3,FLAGA  ;DOD: ENABLE DISCRIM.
01EC                 RPT2
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
                     ; ALWAYS UPDATE AUDIO AND DISPLAY.             ;
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
01EC                 WRITE
01EC  CD 00 00             JSR    AUDIO    ;DO AUDIO
01EF  81                   RTS             ;END OF REPORT
                     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
01F0                       END
```

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############ C R O S S R E F E R E N C E T A B L E ############

ACC	01C1	:	298										
ACGENS	EXTERN	:	252										
ADDEND	01DB	:	294										
ADDIT	01D1	:	313										
ADDUP	01A4	:											
ATEND	0198	:	274										
ATIME	EXTERN	:	270	271	275								
AUDIO	EXTERN	:	352										
AVCOUNT	EXTERN	:											
AVERG	013E	:	192										
BARIT	0060	:	92	95									
BARLOOP	0063	:	106										
BCREJ	EXTERN	:	303	316									
CLR	EXTERN	:	237										
CLRDATA	EXTERN	:	147										
CLRVDI	EXTERN	:	154										
COMP18	0132	:	203										
COMP2	0151	:	220										
COMP40	012A	:	199										
COMP5F	0149	:	216										
COMP64	0122	:	196										
DCPTST	006D	:	103										
DECEND	01A1	:	283	285									
DECIT	0194	:	272										
DISBAR	011A	:	189										
DISFLT	EXTERN	:	129										
DISLEV	EXTERN	:	284	286	296	330							
DISPTR	EXTERN	:	47	178									
DISTABL	EXTERN	:	88	93	97	104	161	164	168	171	173	176	214
DIVIDE	EXTERN	:	166										
DOVNUM	00E1	:	162										
FADE	EXTERN	:	128	226									
FADECOUNT	EXTERN	:	116	125									
FADERATE	EXTERN	:	111	123									
FLAG4	EXTERN	:	145	146	179	273							
FLAGA	EXTERN	:	132	265	338	339	342	346					
FLAGB	EXTERN	:	264	276	283	294							
FLAGP	EXTERN	:	300	313									
GCOUNT	EXTERN	:											
GDC	EXTERN	:											
GFAMP	EXTERN	:	195										
GFLEV	EXTERN	:	250										
GFOK	01BB	:	306										
GFOK2	01D0	:	319										
GHOT	EXTERN	:	69										
IDTONE	EXTERN	:	151										
INDXOK	0043	:	84										
JNP	00AA	:	137										
JWR	0072	:	49										
KEY	EXTERN	:											
LABEL	EXTERN	:	134										
LEARN	0162	:											
LRN1	016A	:	233										
LRNEND	0170	:	235	236									

```
                REPORT   07 FEB 89/modified 7/23/89  MDR

MRKRLOOP     004B  :     99
NEXTSEG      015E  :    224
NOATH        01BC  :    265
NOCLEAR      00B8  :    144    145
NOCLIP       01D7  :    310
NOFADE       0090  :    122    124    126
NOFS         01D7  :    324
NOTPK        009B  :    131    132
NOTPK2       0170  :    140
OPTST      EXTERN  :
PEAK         00A0  :    133
PHASE      EXTERN  :    107    149    183    301
PHRAC      EXTERN  :    174
POSVDI       00DC  :    158
RECOV      EXTERN  :    268
REPORT       0000  :      7
RPT1         01E4  :    340
RPT2         01EC  :    345
SCALE2       0019  :     58     64
SCALE3       001F  :     61
SCALE4       0025  :     65
SCALEIT      002A  :     70
SCALIT2      0032  :     73
SCLOOP       0037  :     82
SEARCH       0080  :     42
SET        EXTERN  :    234
SETFADE      0075  :    127    148
SHORT        013A  :    207
SHOWIT       003D  :     75
SIGBAL     EXTERN  :     50
SIGN?        00D2  :    108    152    153
SPECTM       0109  :    157    180
STASH        015F  :    201    205    209    211    218    222
STAT       EXTERN  :     42    131    153    180    298
STATE      EXTERN  :    122
STATTABL   EXTERN  :     65    108    144    152    192    233    236
SUBIT        01BC  :    300    301
TEMA       EXTERN  :     77     79     89    102    185    188    225    227    258    305    307
318
                        320    322
TFREQ      EXTERN  :     56
VDI        EXTERN  :    135    139    150    156
VDIAV      EXTERN  :
VDISENS    EXTERN  :    343
VLOOP        0111  :    191
WGFEND       017E  :    251    254    256
WRITE        01EC  :    109    181


        LINES ASSEMBLED :   355            ASSEMBLY ERRORS :    0
```

Claims

1. A metal detector having induction balanced transmit and receive coils wherein an electronic signal supplied to said transmit coil generates a receive signal in said receive coil when said coils are subjected to local magnetic field pertubations, characterised by:
   (a) first variable calculation means (116) for determining phase angle values associated with said receive signal;
   (b) second variable calculation means (116) for determining second variable values associated with said receive signal; and
   (c) a visual display (139) having a plurality of display unit addresses wherein each address corresponds to a range of phase angle values for displaying said phase angle values and respective said second variable values.

2. The metal detector of Claim 1 wherein said second variable value is representative of a count of a number of times that the receive signal at a particular phase angle exceeds a predetermined amplitude threshold.

3. The metal detector of Claim 1 or 2 wherein said second variable value is representative of a signal amplitude associated with said receive signal.

4. The metal detector of Claim 1, 2 or 3 wherein said visual display (139) is a liquid crystal display.

5. The metal detector of Claims 1, 2, 3 or 4 wherein said first and second variable calculation means are software routines performed by a microprocessor (116).

6. A method of displaying signal information on a display unit (139) associated with a metal detector having a receive signal, characterised by the steps of:
   (a) establishing a plurality of display unit addresses wherein each said address can have display characters;
   (b) detecting a local maxima of an amplitude associated with said receive signal;
   (c) determining and quantifying a phase angle associated with said receive signal when said local maxima is detected;
   (d) converting said phase angle into a write address associated with one of said display unit addresses;
   (e) determining a second variable associated with said receive signal;
   (f) reading a display character at said write address; and
   (g) altering the display character at said write address to reflect said second variable.

7. The method Claim 6 wherein step (b) comprises detecting only local maxima that exceed a predetermined threshold.

8. The method of Claim 6 or 7 wherein said second variable is a count of the number of times the receive signal at a particular phase angle exceeds an amplitude threshold.

9. The method of Claim 6, 7 or 8 wherein said second variable is a signal amplitude associated with said receive signal.

10. The method of Claim 6, 7, 8 or 9 further comprising the step of determining that said display character at said write address cannot be altered to reflect said second variable and then altering display characters at all addresses having displaying characters except said write address.

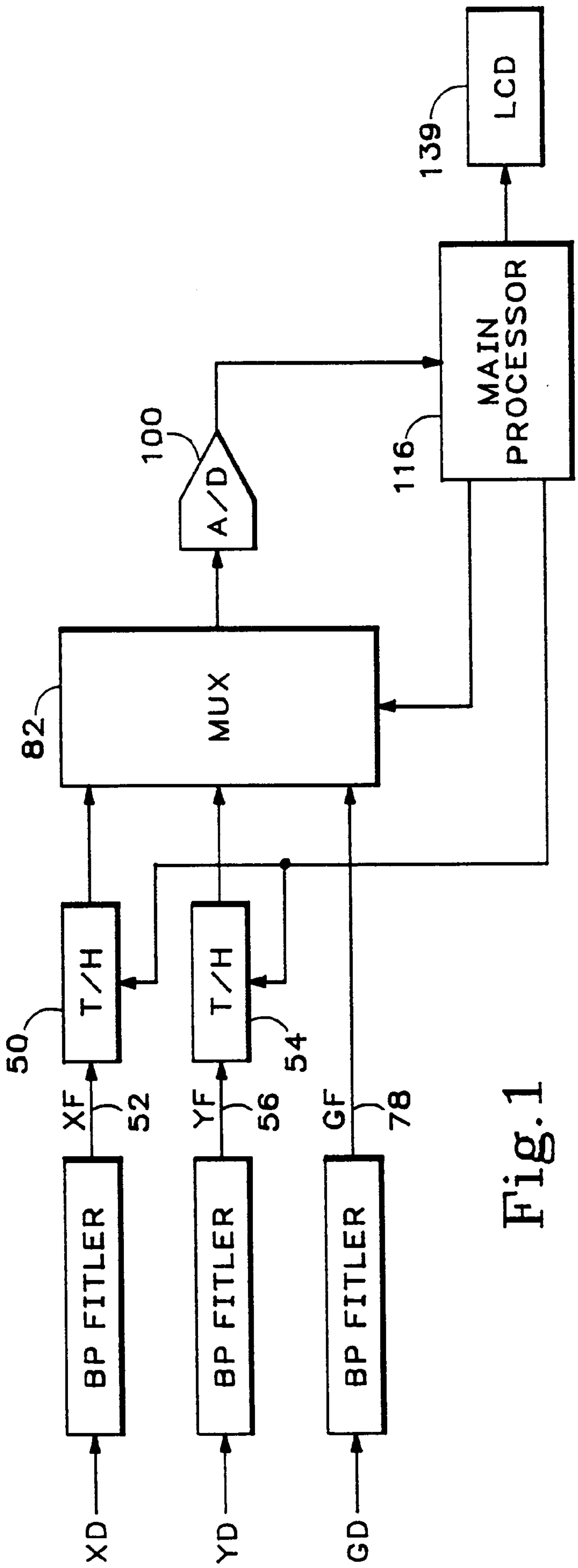
XD
YD
GD
BP FITLER
BP FITLER
BP FITLER
XF
52
YF
56
GF
78
50
T/H
T/H
54
82
MUX
100
A/D
116
MAIN PROCESSOR
139
LCD

Fig. 1

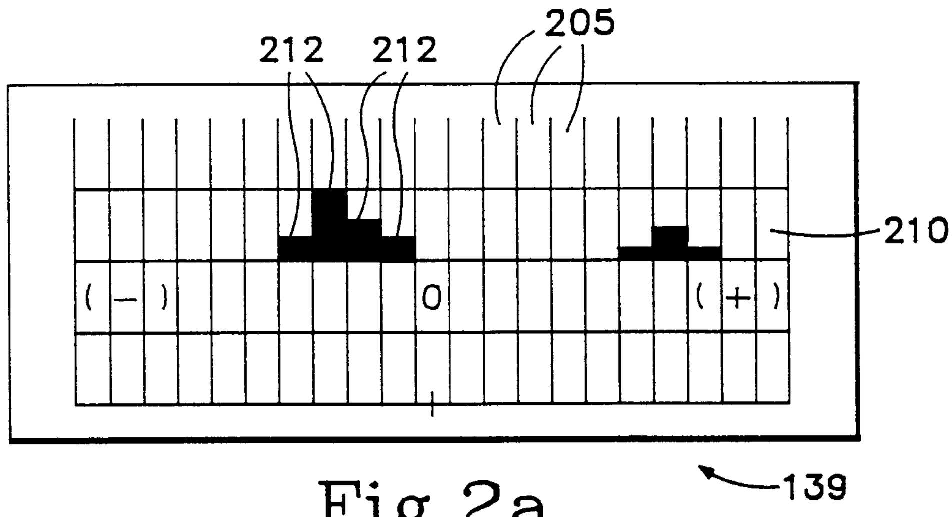

Fig. 2a

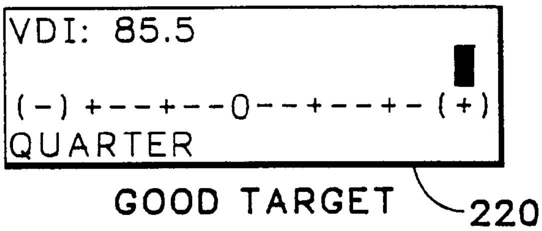

Fig. 2b

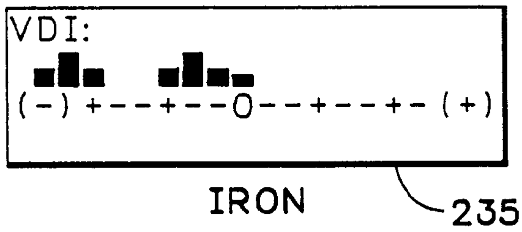

Fig. 2e

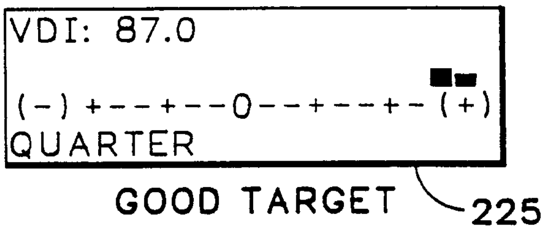

Fig. 2c

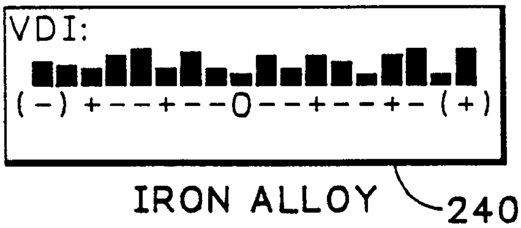

Fig. 2f

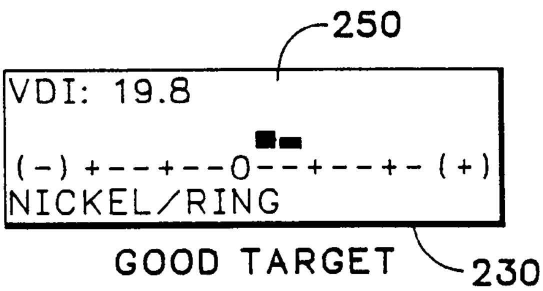

Fig. 2d

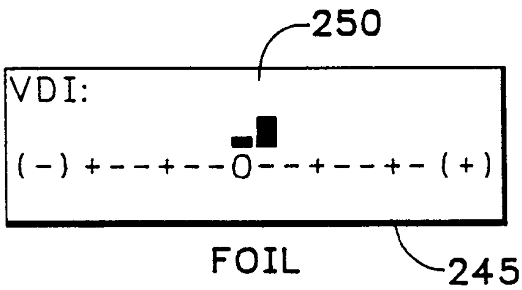

Fig. 2g

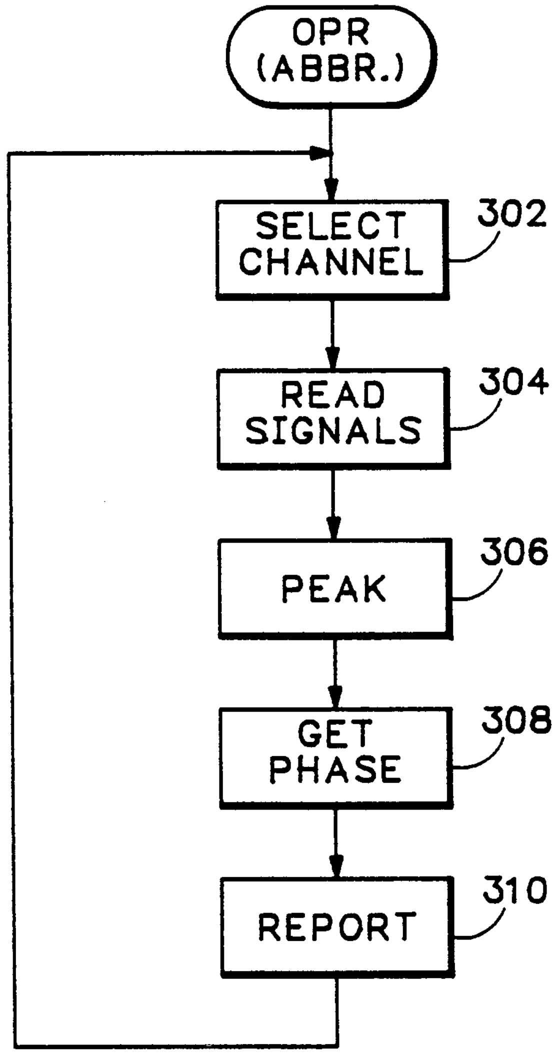
OPR
(ABBR.)
SELECT CHANNEL
302
READ SIGNALS
304
PEAK
306
GET PHASE
308
REPORT
310

Fig. 3

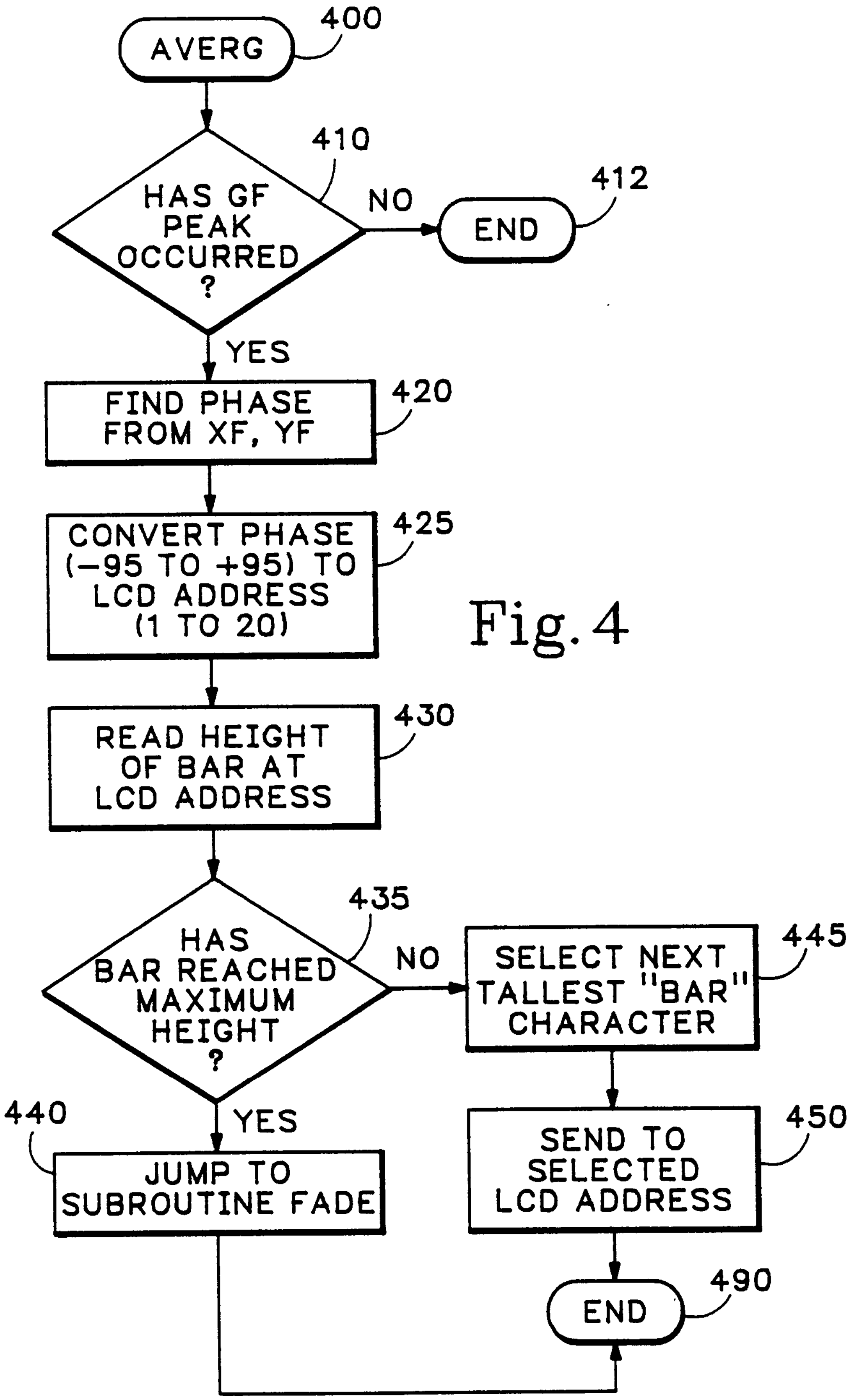
AVERG
400
HAS GF PEAK OCCURRED ?
410
NO
END
412
YES
FIND PHASE FROM XF, YF
420
CONVERT PHASE (−95 TO +95) TO LCD ADDRESS (1 TO 20)
425
READ HEIGHT OF BAR AT LCD ADDRESS
430
HAS BAR REACHED MAXIMUM HEIGHT ?
435
NO
SELECT NEXT TALLEST "BAR" CHARACTER
445
YES
440
JUMP TO SUBROUTINE FADE
SEND TO SELECTED LCD ADDRESS
450
END
490

Fig. 4

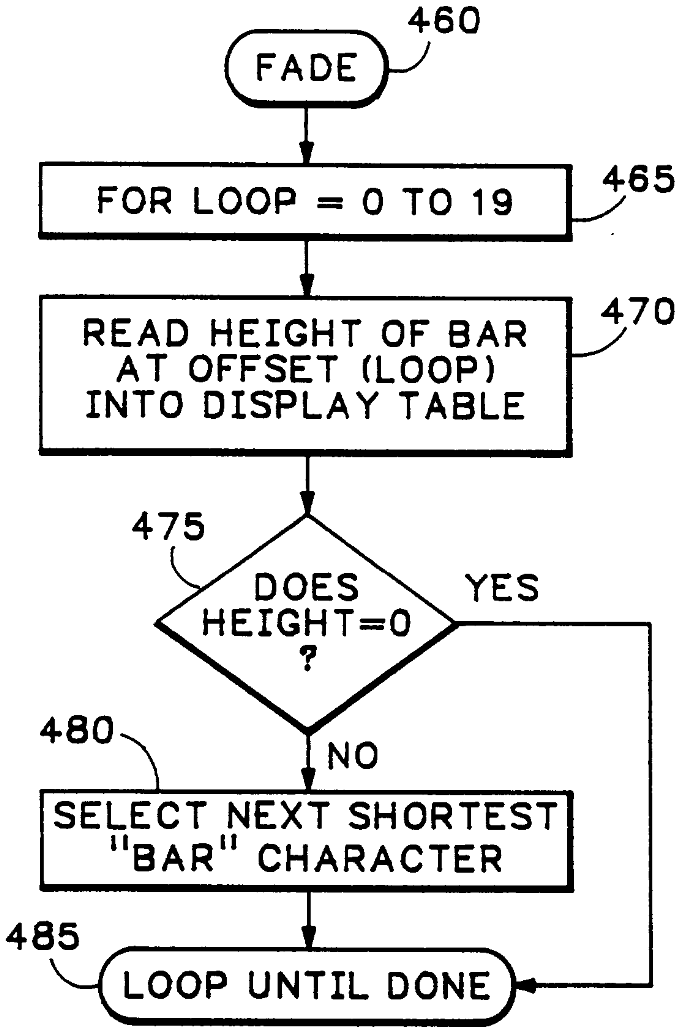
460
FADE
465
FOR LOOP = 0 TO 19
470
READ HEIGHT OF BAR AT OFFSET (LOOP) INTO DISPLAY TABLE
475
DOES HEIGHT=0 ?
YES
NO
480
SELECT NEXT SHORTEST "BAR" CHARACTER
485
LOOP UNTIL DONE

Fig. 5

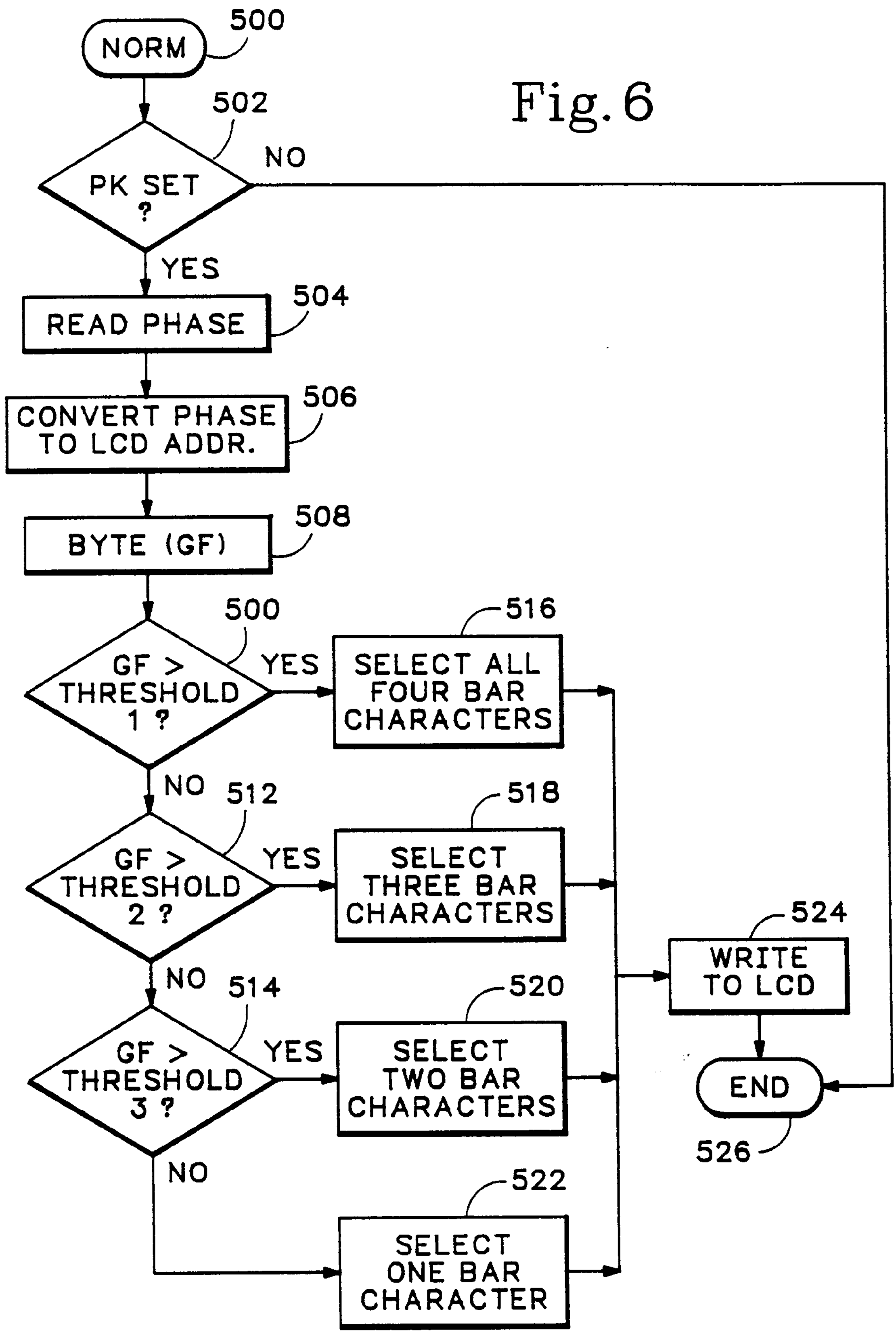
NORM
500
502
PK SET ?
NO
YES
READ PHASE
504
CONVERT PHASE TO LCD ADDR.
506
BYTE (GF)
508
500
GF > THRESHOLD 1 ?
YES
516
SELECT ALL FOUR BAR CHARACTERS
NO
512
GF > THRESHOLD 2 ?
YES
518
SELECT THREE BAR CHARACTERS
NO
514
GF > THRESHOLD 3 ?
YES
520
SELECT TWO BAR CHARACTERS
NO
522
SELECT ONE BAR CHARACTER
524
WRITE TO LCD
END
526

Fig. 6