US005596277A

United States Patent [19]

Rowan

[11] Patent Number: 5,596,277

[45] Date of Patent: * Jan. 21, 1997

[54] **METHOD AND APPARATUS FOR DISPLAYING SIGNAL INFORMATION FROM A METAL DETECTOR**

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[73] Assignee: **White's Electronics, Inc.**

[*] Notice: The term of this patent shall not extend beyond the expiration date of Pat. No. 5,523,690.

[21] Appl. No.: **485,810**

[22] Filed: **Jun. 7, 1995**

Related U.S. Application Data

[62] Division of Ser. No. 918,075, Jul. 24, 1992, Pat. No. 5,523,690.

[51] **Int. Cl.**[6] **G01N 27/72**; G01V 3/11; G01V 3/165; G01R 27/26

[52] **U.S. Cl.** **324/329**; 324/262

[58] **Field of Search** 324/326, 327, 324/328, 329, 233, 228, 226, 262

[56] **References Cited**

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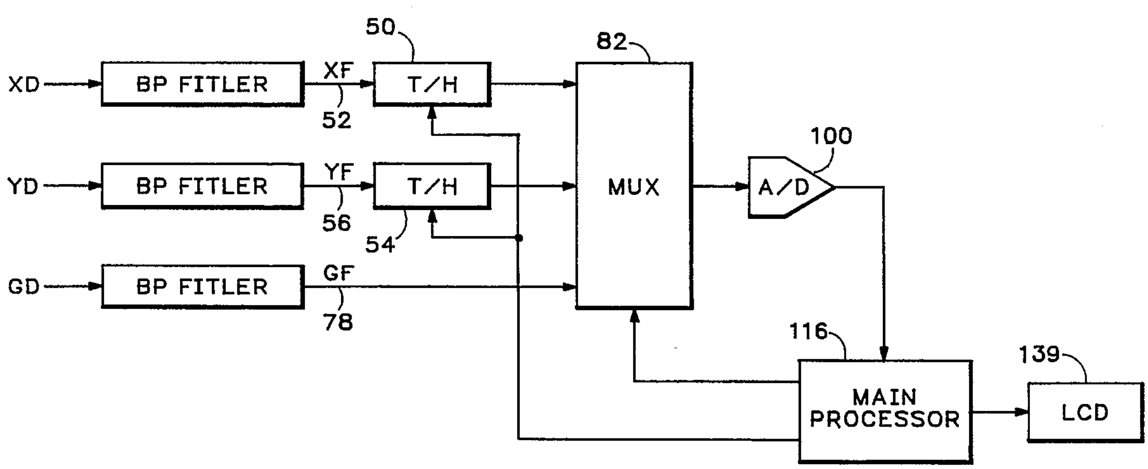
3228447	2/1984	Germany .

Primary Examiner—Walter E. Snow
Attorney, Agent, or Firm—Chernoff, Vilhauer, McClung & Stenzel

[57] **ABSTRACT**

A metal detector having a receive signal responsive to detected metal objects and having a display panel that can simultaneously display a plurality of phase angles associated with the receive signal. Additionally, the display panel can simultaneously display 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 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.

10 Claims, 6 Drawing Sheets



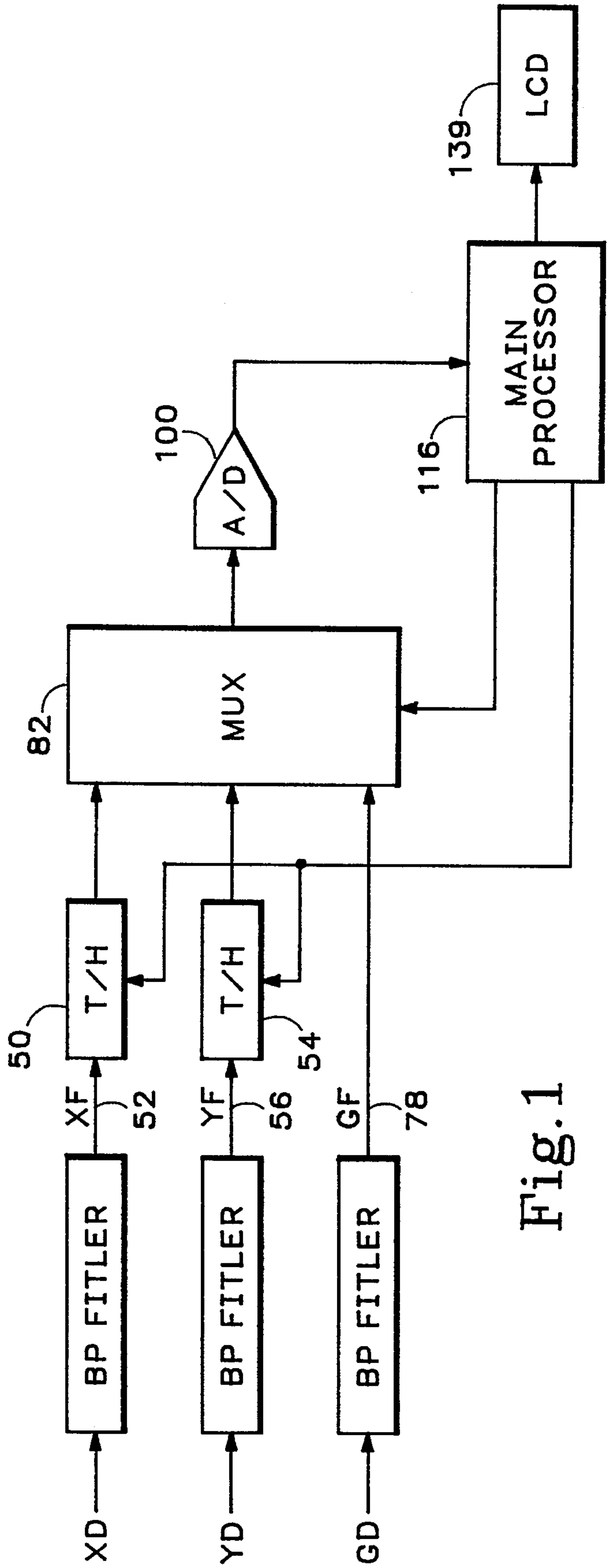

XD
YD
GD
BP FITLER
BP FITLER
BP FITLER
XF
52
YF
56
GF
78
50
T/H
T/H
54
82
MUX
100
A/D
116
MAIN PROCESSOR
139
LCD

Fig. 1

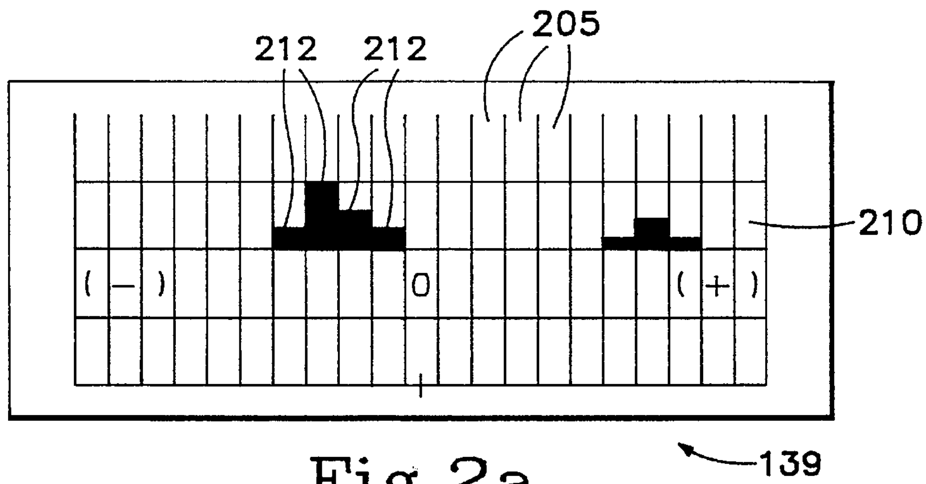


Fig. 2a

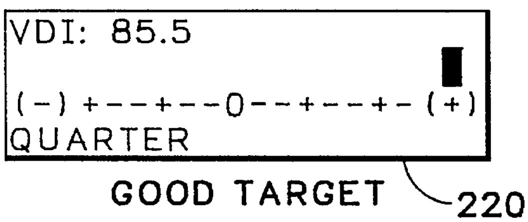


Fig. 2b

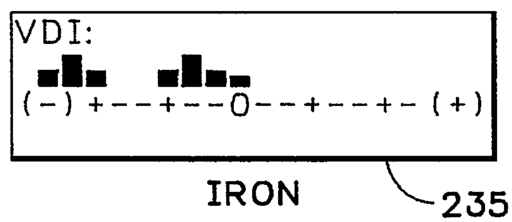


Fig. 2e

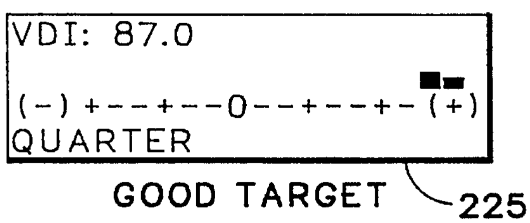


Fig. 2c

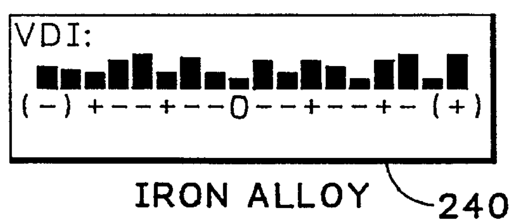


Fig. 2f

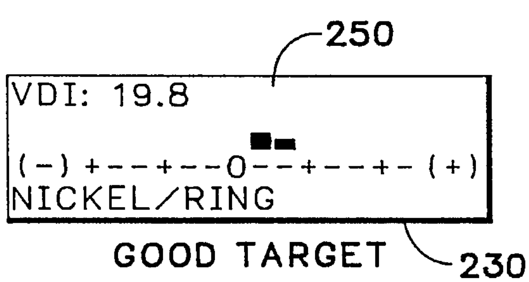


Fig. 2d

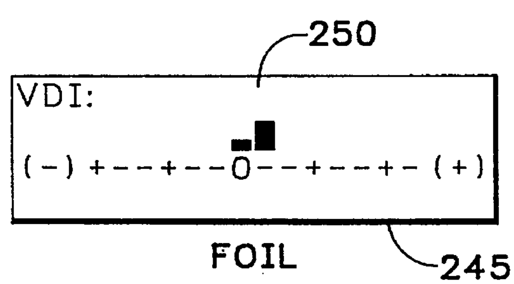


Fig. 2g

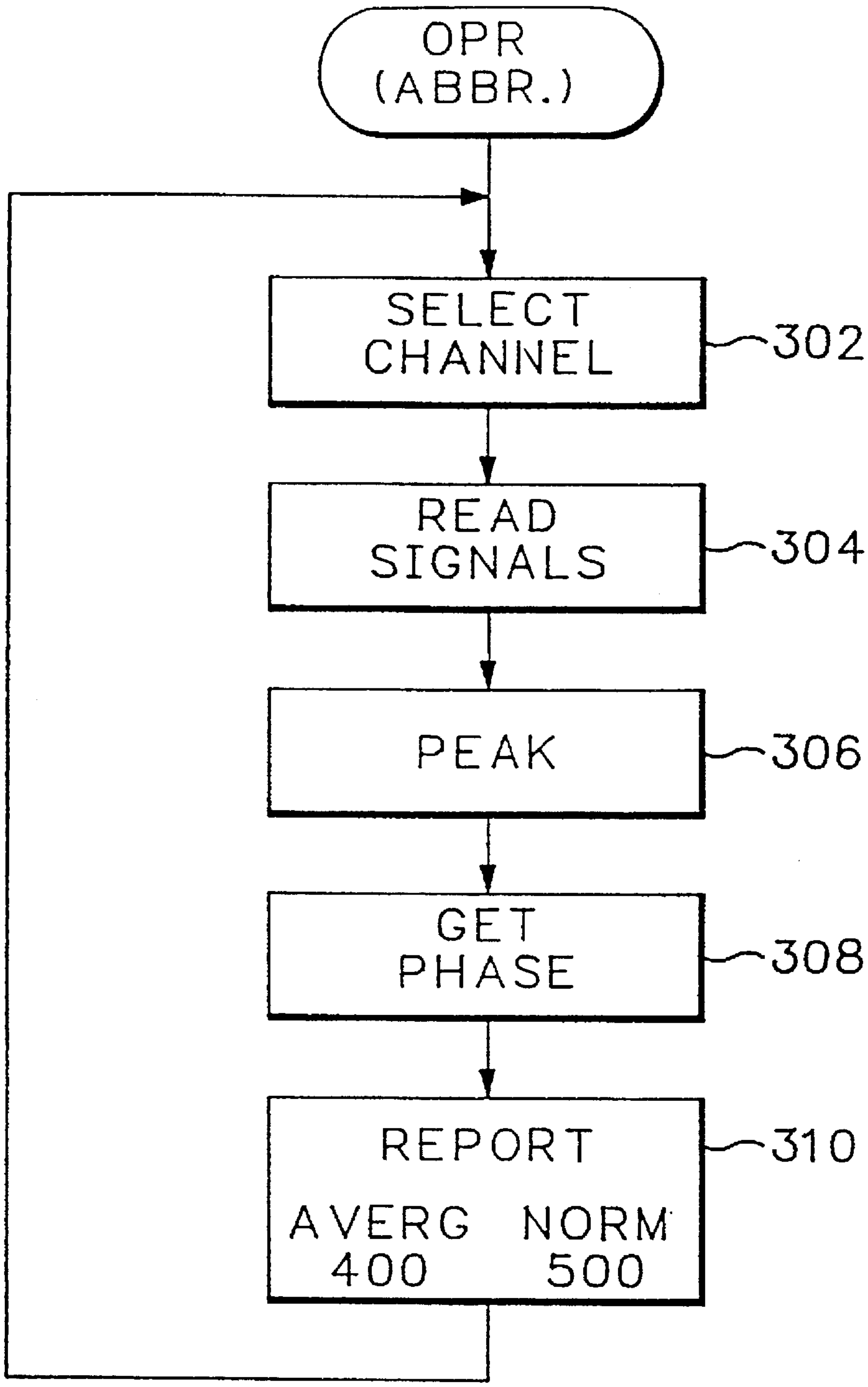

OPR
(ABBR.)
SELECT
CHANNEL
302
READ
SIGNALS
304
PEAK
306
GET
PHASE
308
REPORT
AVERG
400
NORM
500
310

Fig. 3

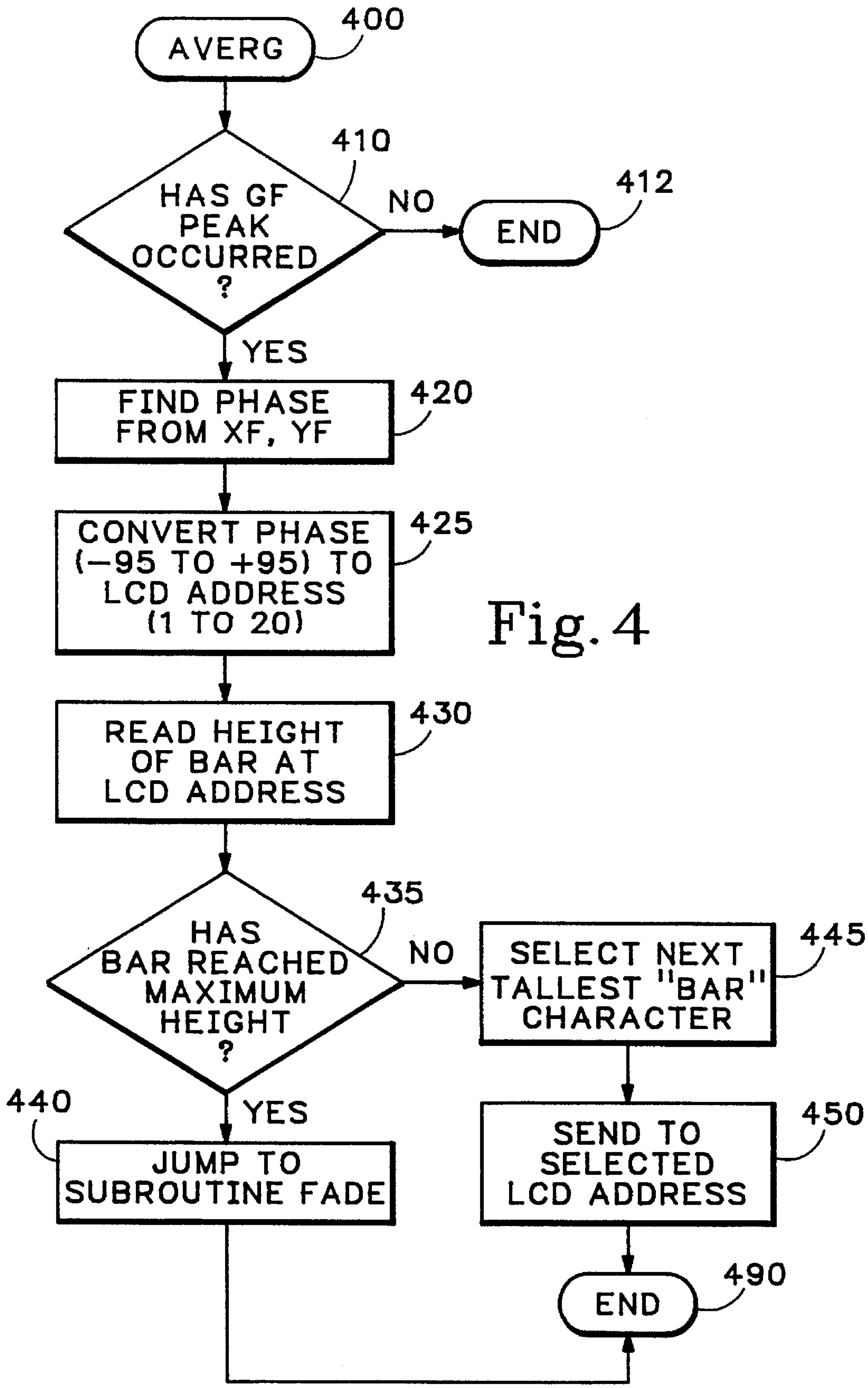

AVERG
400
HAS GF PEAK OCCURRED ?
410
NO
END
412
YES
FIND PHASE FROM XF, YF
420
CONVERT PHASE (−95 TO +95) TO LCD ADDRESS (1 TO 20)
425
READ HEIGHT OF BAR AT LCD ADDRESS
430
HAS BAR REACHED MAXIMUM HEIGHT ?
435
NO
SELECT NEXT TALLEST "BAR" CHARACTER
445
YES
440
JUMP TO SUBROUTINE FADE
SEND TO SELECTED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

Fig. 4

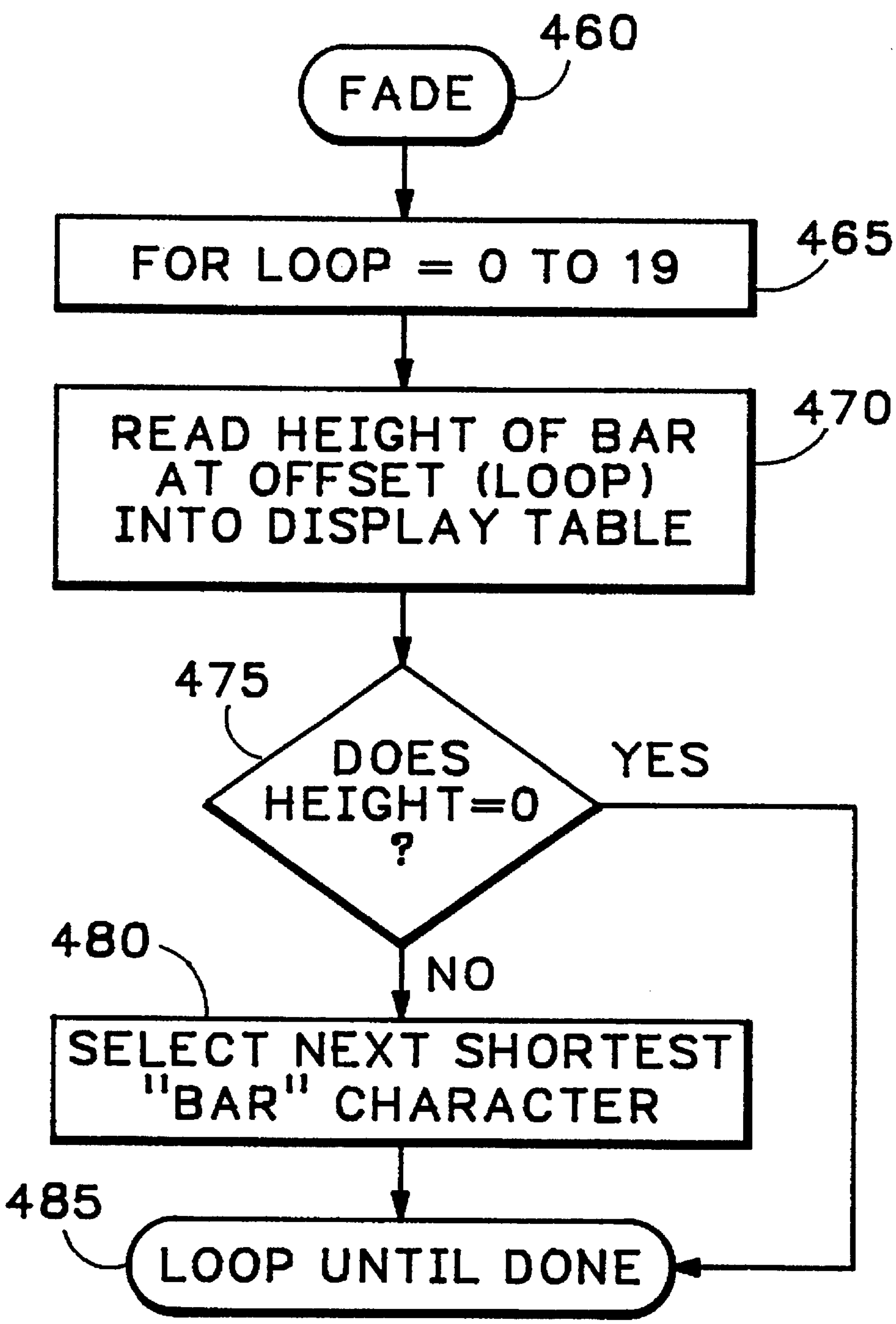
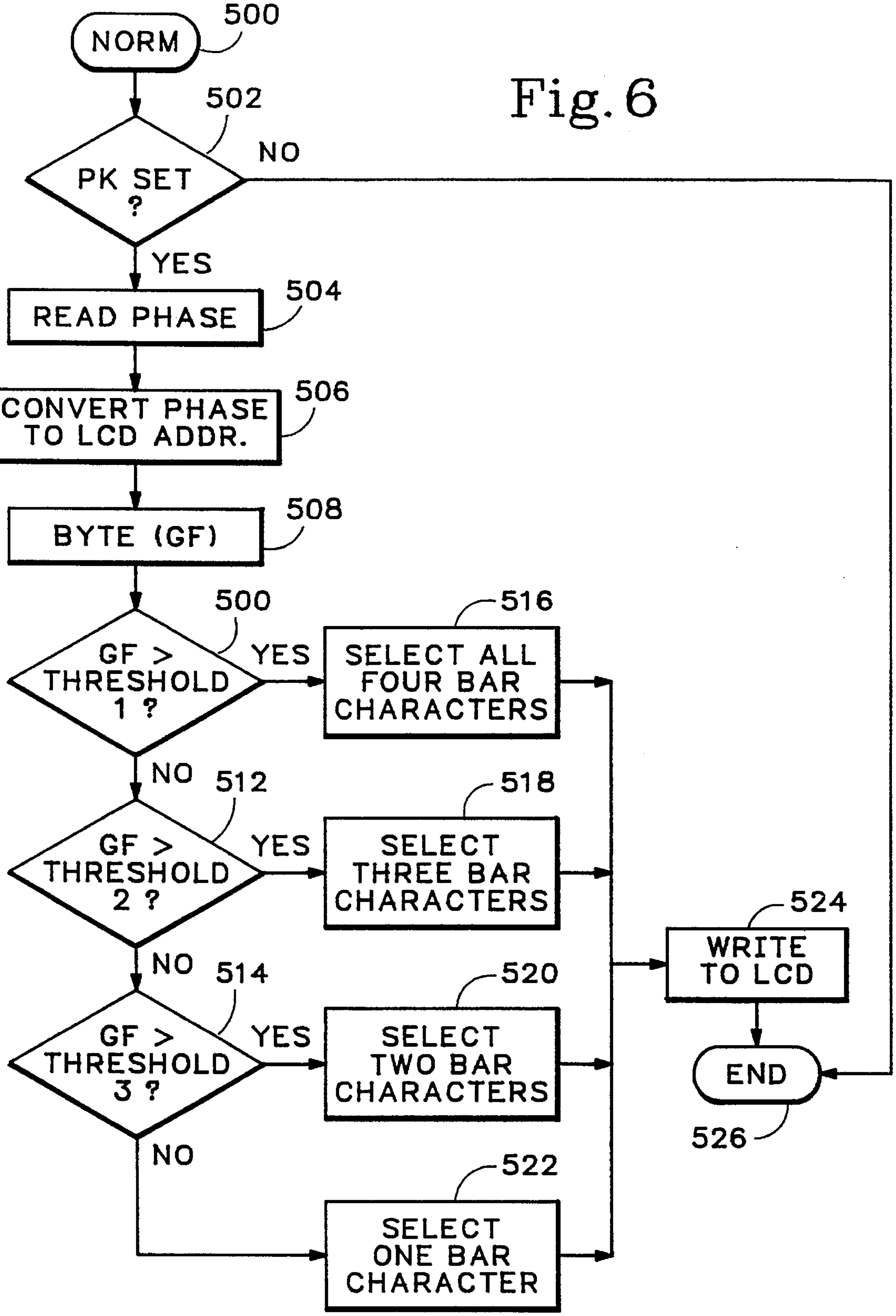

460
FADE
FOR LOOP = 0 TO 19
465
READ HEIGHT OF BAR AT OFFSET (LOOP) INTO DISPLAY TABLE
470
475
DOES HEIGHT=0 ?
YES
NO
480
SELECT NEXT SHORTEST "BAR" CHARACTER
485
LOOP UNTIL DONE

Fig. 5

Fig. 6


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

METHOD AND APPARATUS FOR DISPLAYING SIGNAL INFORMATION FROM A METAL DETECTOR

This is divisional of application Ser. No. 07/918,075 filed on Jul. 24, 1992, now U.S. Pat. No. 5,523,690.

FIELD OF INVENTION

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

BACKGROUND OF THE INVENTION

An 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 perturbations 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 target.

However, in actual practice the phase angle information is materially affected by ground mineralization 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. Pat. 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: (1) the receive signal's phase angle (with respect to the transmit signal) and (2) the choice of 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 bivariate information is displayed on a suitable graphic device such as an LCD. This method permits 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 perturbations.

The principal objective of the present invention is to provide a metal detector having a bivariate visual display of two signal characteristics that are representative of a target object.

It is a further objective of the present invention to provide 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 displaying both the phase angle and signal count on a visual display device.

It is a still further objective of the present invention to provide a metal detector that measures the phase angle between the transmit signal and receive signal when the signal strength exceeds a predetermined level by displaying the phase angle and received signal strength simultaneously on a visual display device.

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

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

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

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

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

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

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

DESCRIPTION OF THE 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. Pat. 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, FIG. 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 mineralization effects. (See Maulding, FIG. 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, FIGS. 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 mineralization.

FIG. **1** of this application shows the components of Maulding's circuit which are also in the present invention. (The reference numbers in FIG. **1** correspond to Maulding reference numbers for identical component blocks.) All the reference elements in FIG. **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 FIG. **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 system is different from Maulding in that the main processor then writes the information to LCD **139** in a suitable format using onboard software programming described hereinafter.

FIG. **2***a* 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 4×20 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 FIGS. **2***a*–**2***g*, 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 4×20 LCD would represent a 9° range of phase angles. The vertical scale **210** represents a second variable which is either (1) 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).

FIGS. **2***b*–**2***g* are examples of the LCD display when the search head encounters various buried metals. FIGS. **2***b*–**2***d* 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 characterized by a tight grouping of bars within a narrow range of phase angles, or optimally at a single phase angle range as shown in FIG. **2***b*. Additionally, good targets are characterized by groupings in the positive portion of the graph; i.e., the area between the "0" and "(+)" symbols. The exemplary embodiments of FIGS. **2***b*–**2***d* 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 FIG. **2***b*.

FIGS. **2***e*–**2***g* 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 predominately 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 FIG. **2***f*. 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 FIG. **2***g* with FIG. **2***d*. 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 center 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 FIG. **2***d* has a bar to the positive side whereas the undesirable target FIG. **2***g* has a bar to the negative side of the largest bar. A user familiar with these displays will recognize the more positive phase angles as indicative of a good target.

FIG. **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 all steps necessary for operation of a metal detector is shown in Maulding, FIG. 11. Continuing with FIG. **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 exemplarily shown in Maulding FIG. 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 exemplarily shown in Maulding, FIG. 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 utilizes one of two routines AVERG (FIGS. **4** and **5**) or NORM (FIG. **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 (FIG. **4**). Alternatively, if the user selects the amplitude display, then REPORT will branch to the routine NORM (FIG. **6**). AVERG and NORM could be subroutines, but in the preferred embodiment they are code within the subroutine REPORT.

FIG. **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 4×20 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**, FIG. **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 sub-routine 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**.

FIG. **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, FIG. 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 recognized that the scope of the invention is defined and limited only by the claims which follow.

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 PAGEO STATE,PAGEO GHOT,PAGEO DISPTR,PAGEO KEY
                            EXTERN PAGEO STAT ;7=LRNREJ,6=LRNACC         IN
                                              ;2=PK,3=TRIG,5=DISC        IN
                                              ;0=DOK                     OUT
                            EXTERN PAGEO FLAGA ;3=DON:SET IF ACCEPT      OUT
                                               ;4=DOK:SET IF DISC ON     OUT
                                               ;2=ATH                    IN
                            EXTERN PAGEO FLAGB ;6=200N                   OUT
                                               ;4=SIGN BIT               INT
                                               ;5=ATIME RUNNING          INT
                            EXTERN PAGEO FLAGP ;0=ac overload
                            EXTERN PAGEO GFLEV ;DATA FROM PEAK           IN
                            EXTERN PAGEO GFAMP ; abs(compressed(GF))
                            EXTERN PAGEO DISLEV ;DISC. DATA TO AUDIO     OUT
                            EXTERN PAGEO ACSENS ;USED FOR SHIFTS         IN
                            EXTERN PAGEO PHASE ;SB                       IN
                            EXTERN PAGEO PHRAC
                            EXTERN PAGEO TEMA  ;STASH                    INT
                            EXTERN PAGEO OPTST ;RAM TEST ADDRESS         IN
                            EXTERN PAGEO ATIME ;RECOVERY HOLD OFF        INT
                            EXTERN PAGEO RECOV ;user adj. hold off
                            EXTERN PAGEO VDISENS,PAGEO FADERATE,PAGEO FADECOUNT
                            EXTERN PAGEO BCREJ
                            EXTERN PAGEO SIGBAL
                            EXTERN PAGEO STATTABL
                            EXTERN PAGEO TFREQ
                            EXTERN PAGEO 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
```

PAGE 2

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    GHOT
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
```

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```
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 0D    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 08    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  E7 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    SPECTR
00D2  2A 05       SIGN?   BPL    POSVDI
00D4  40                  NEGA
00D5  AE 2D               LDX    #2DH
00D7  CF 00 01            STX    DISTABL+1
00DA  20 05               BRA    DOVNUM
```

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```
0ODC  AE 20         POSVDI  LDX    #32
00DE  CF 00 01              STX    DISTABL+1
00E1  AE 0A         DGVNUM  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    FHRAC
00F8  AB 30                 ADD    #30H
00FA  C7 00 05              STA    DISTABL+5
00FD  A6 1C                 LDA    #25
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          ;norm'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
```

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```
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    ACGENS
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,FLAGA
0192  20 04              BRA    ATEND
0194  3A 00        DECIT DEC    ATIME    ;SERVICE ATIME &
0196  1A 00              BSET   5,FLAGB  ; SET FLAG
```

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```
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 08          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
ACSENS      EXTERN :   252
ADDEND      01D8   :   294
ADBIT       01B1   :   313
ADDUP       01A4   :
ATEND       0196   :   274
ATINE       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      0062   :   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   230
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
INDXDX      0043   :    64
JNP         00AA   :   137
JNR         0072   :    49
KEY         EXTERN :
LABEL       EXTERN :   134
LEARN       0162   :
LRN1        0164   :   233
LRNEND      0170   :   235   236
```

```
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MRKRLOOP    004B  :    99
NEXTSEG     015E  :   224
NOATH       018C  :   265
NOCLEAR     0088  :   144    145
NOCLIP      01D7  :   310
NOFADE      0090  :   122    124    126
NOFS        01D7  :   324
NOTPK       009B  :   131    132
NOTPK2      0170  :   140
OPTST      EXTERN :
PEAK        00A9  :   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    309
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
```

What is claimed is:

1. A method of displaying signal information on a display associated with a metal detector having a receive signal, comprising the steps of:

(a) establishing a plurality of display unit addresses wherein each said address can display a plurality of display characters up to a maximum number;

(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) reading a number of display characters at said write address; and

(f) increasing the number of display characters at said write address if the number of display characters at said write address is less than said maximum number and, alternatively, when the number of display characters at said write address is equal to said maximum number, then decreasing the number of display characters at all addresses having display characters except the write address.

2. The method of claim **1** wherein step (b) comprises detecting only local maxima that exceed a predetermined threshold.

3. A display in a metal detector for graphically displaying information associated with a receive signal, comprising:

(a) means for receiving a phase angle value associated with said receive signal;

(b) means for receiving a signal amplitude value associated with said receive signal, said amplitude value being time-correlated with said phase angle value; and

(c) microprocessor means for grouping said phase angle value into a selected one of a plurality of respective ranges of phase angle values and causing said selected one of said phase angle ranges and said signal amplitude value to appear instantaneously and simultaneously on said display.

4. In a metal detector having a transmit coil and a receive coil, said transmit coil transmitting a transmit signal which is acted upon by perturbations and said receive coil receiving the acted-upon transmit signal as a receive signal, the improvement comprising:

(a) said receive signal having a phase angle value which is a measurement of a phase angle between said transmit signal and said receive signal, and further having a signal amplitude value associated with the strength of said receive signal, said amplitude value being time-correlated with said phase angle value; and

(b) a visual display having a plurality of display unit addresses wherein each address corresponds to a range of phase angle values for instantaneously displaying said signal amplitude value at one of said plurality of display unit addresses corresponding to said phase angle values.

5. The metal detector of claim **4** wherein said visual display is a liquid crystal display.

6. A display method for graphically displaying signal information associated with a metal detector, comprising the steps of:

(a) displaying a plurality of phase angles associated with said signal information simultaneously on a display, wherein said phase angles are the phase angles between transmit signals and receive signals produced by said metal detector; and

(b) instantaneously displaying a time-correlated signal amplitude representative of the strength of said signal information and associated with a particular phase angle, and simultaneously said time-correlated signal amplitude with said plurality of phase angles on said display when said signal amplitude exceeds a predetermined threshold value.

7. The method of claim **6**, further comprising the step of displaying said signal amplitude simultaneously with said plurality of phase angles as a bar graph.

8. A method of displaying signal information associated with a pass of a metal detector, comprising the steps of:

(a) establishing a receive signal amplitude threshold;

(b) detecting each occurrence that the receive signal exceeds said threshold in said pass;

(c) counting the number of said occurrences;

(d) displaying said number of occurrences on a display unit; and

(e) detecting phase angle associated with said receive signal when said receive signal exceeds said threshold and simultaneously displaying said phase angle and said number of occurrences.

9. The method of claim **8** wherein said number of occurrences and said phase angle are displayed, one as a function of the other, on a two-axes visual display device.

10. The method of claim **8** wherein said number of occurrences is resolved into a correlative number of predetermined ranges of numbers corresponding to a number of display characters on said display unit.

* * * * *