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United States Patent [19]

Sommer, Jr. et al.

[11] E **Patent Number: Re. 36,537**

[45] **Reissued Date of Patent: Feb. 1, 2000**

[54] **METHOD AND APPARATUS FOR SORTING MATERIALS USING ELECTROMAGNETIC SENSING**

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[73] Assignee: **National Recovery Technologies, Inc.**, Nashville, Tenn.

[21] Appl. No.: **08/802,716**

[22] Filed: **Feb. 18, 1997**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **5,339,962**
Issued: **Aug. 23, 1994**
Appl. No.: **07/777,718**
Filed: **Oct. 21, 1991**

U.S. Applications:

[63] Continuation-in-part of application No. 07/605,993, Oct. 29, 1990, Pat. No. 5,260,576.

[51] **Int. Cl.**[7] **B07C 5/00**; G01N 21/00

[52] **U.S. Cl.** **209/576**; 209/577; 209/589; 209/639; 209/930; 250/341.1; 250/349; 250/359.1; 356/432; 378/51

[58] **Field of Search** .... 209/522, 524, 209/576, 577, 578, 579, 585, 587, 588, 589, 639, 930; 250/223 R, 225, 341.1, 349, 358.1, 359.1; 356/432; 378/51

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Assistant Examiner—Tuan N Nguyen
Attorney, Agent, or Firm—Foley & Lardner

[57] **ABSTRACT**

An automated interrupt driven system which employs a circular buffer is used to sort materials based on differing electromagnetic radiation absorption and penetration characteristics. The system has a conveyor and a source of electromagnetic radiation which radiates materials travelling along the conveyor. A controller samples detector outputs at various times to evaluate the absorption and penetration characteristics of the materials to be sorted, based on a plurality of samples. Portions of the materials are ignored to obtain accurate readings from the detectors. Based on the detected penetration and absorption characteristics, the controller activates ejection mechanisms causing materials of different compositions to be deposited into different bins. The controller executes interrupts to cause detection, ejection, testing, and system history maintenance at required times. The circular buffer contains indices which point to various locations which are programmed in memory to trigger and perform specific events. The location of the indices in the circular buffer is used to control event timing, such as activating and deactivating the ejection mechanisms. This configuration, allows several events to be executed simultaneously by moving to the next location in the circular buffer while the event indicated by the index in the previous location continues in progress.

36 Claims, 26 Drawing Sheets

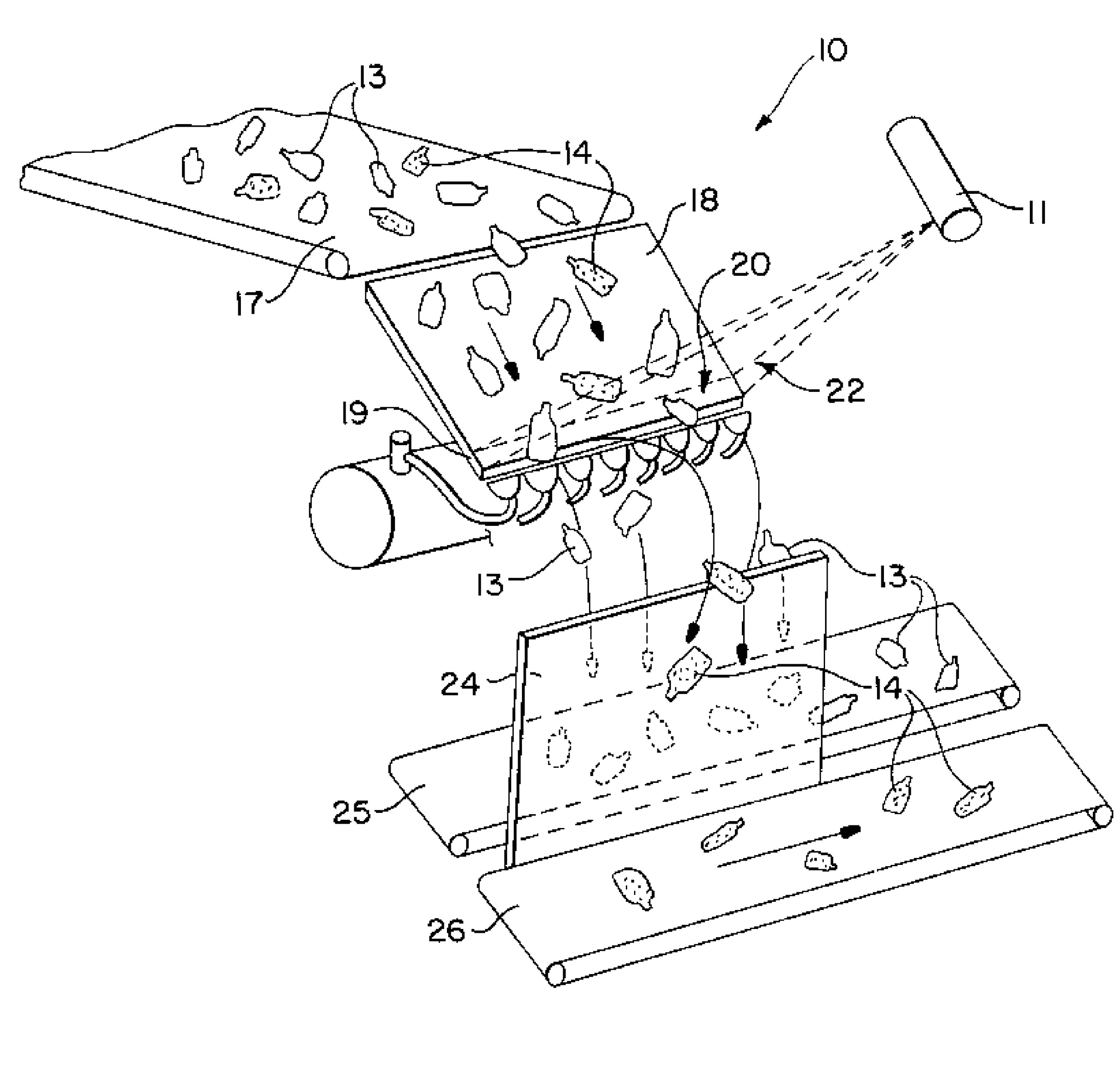

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FIG. 1

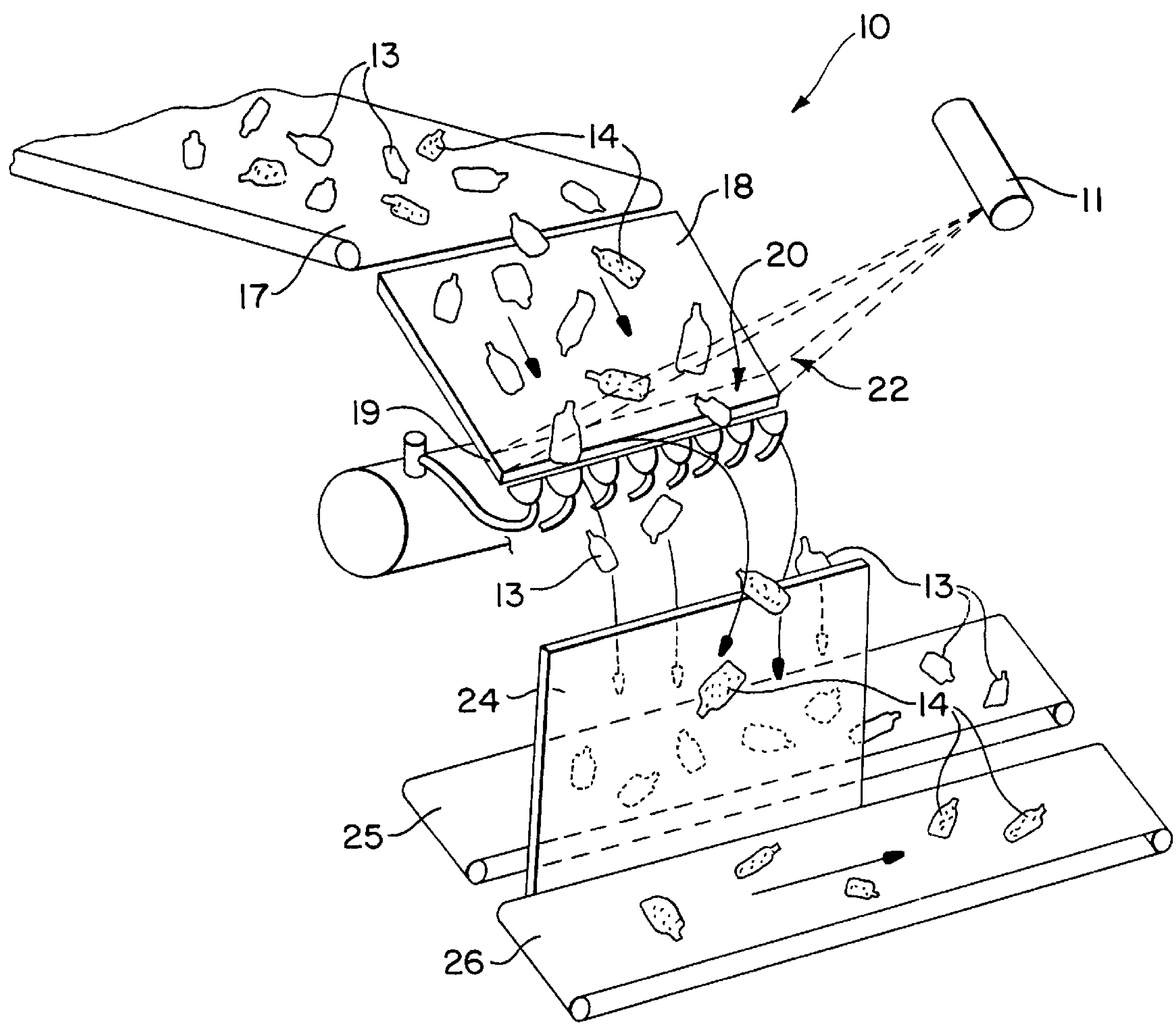


FIG. 2

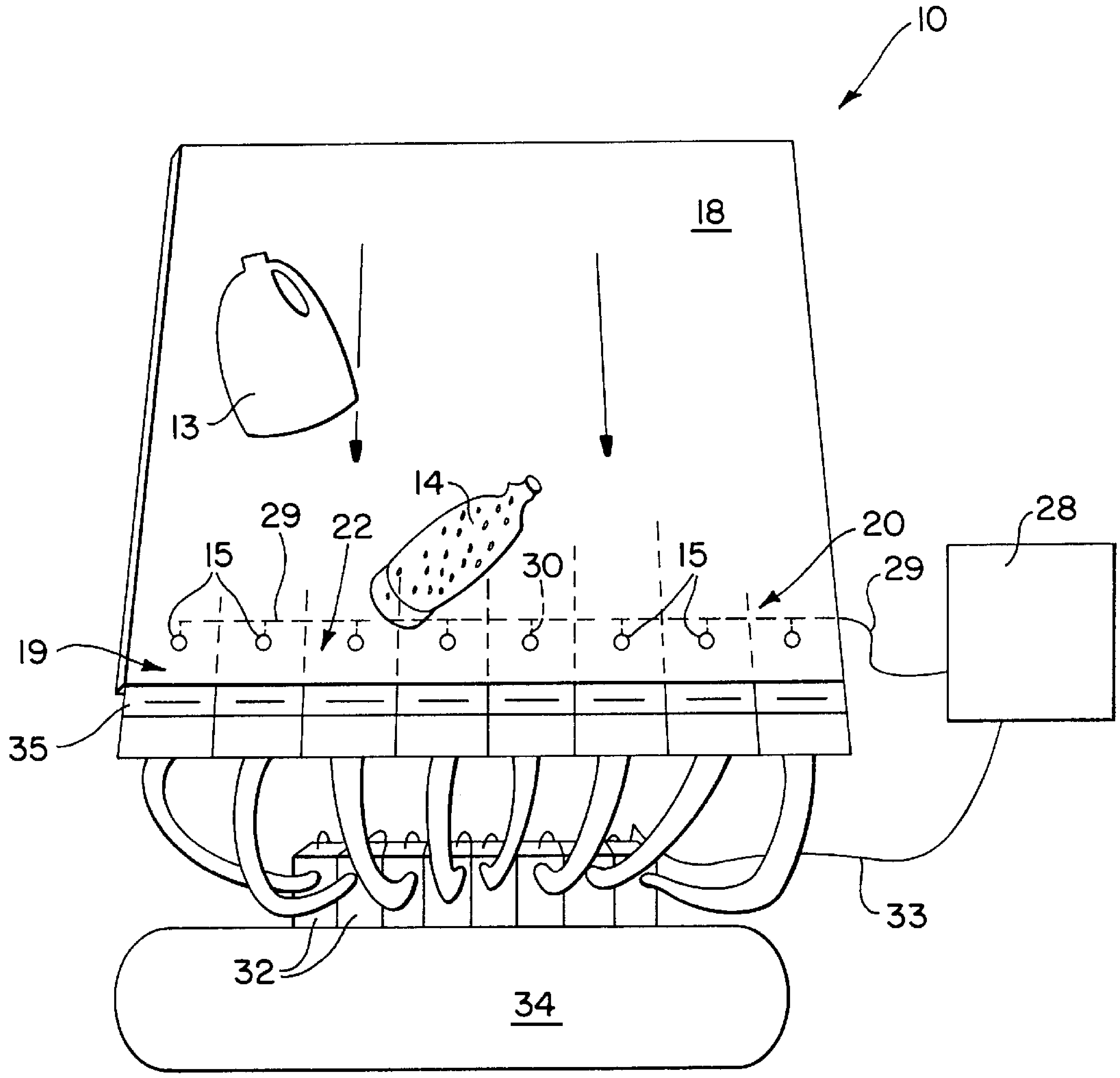


FIG. 3

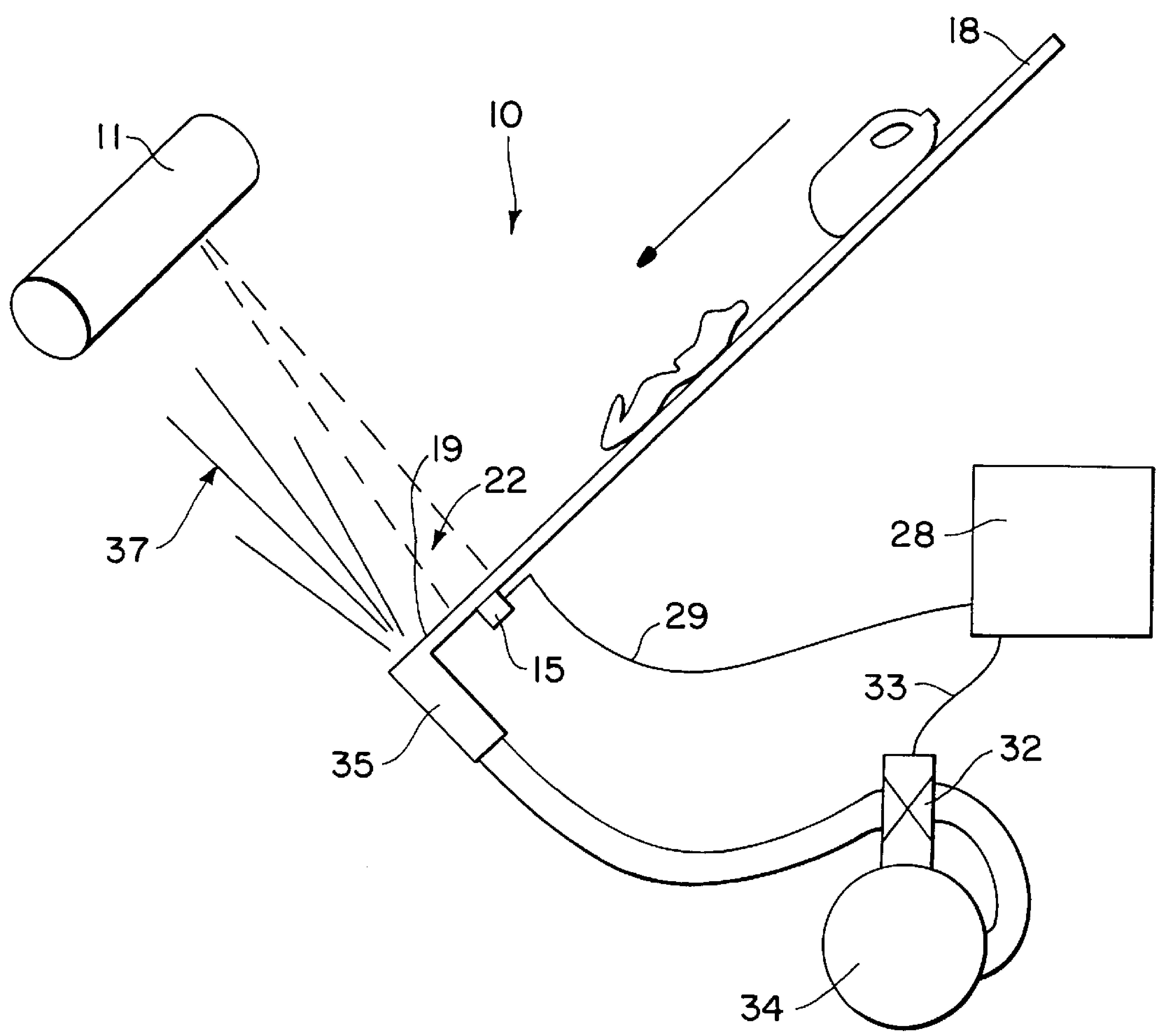


FIG.4a

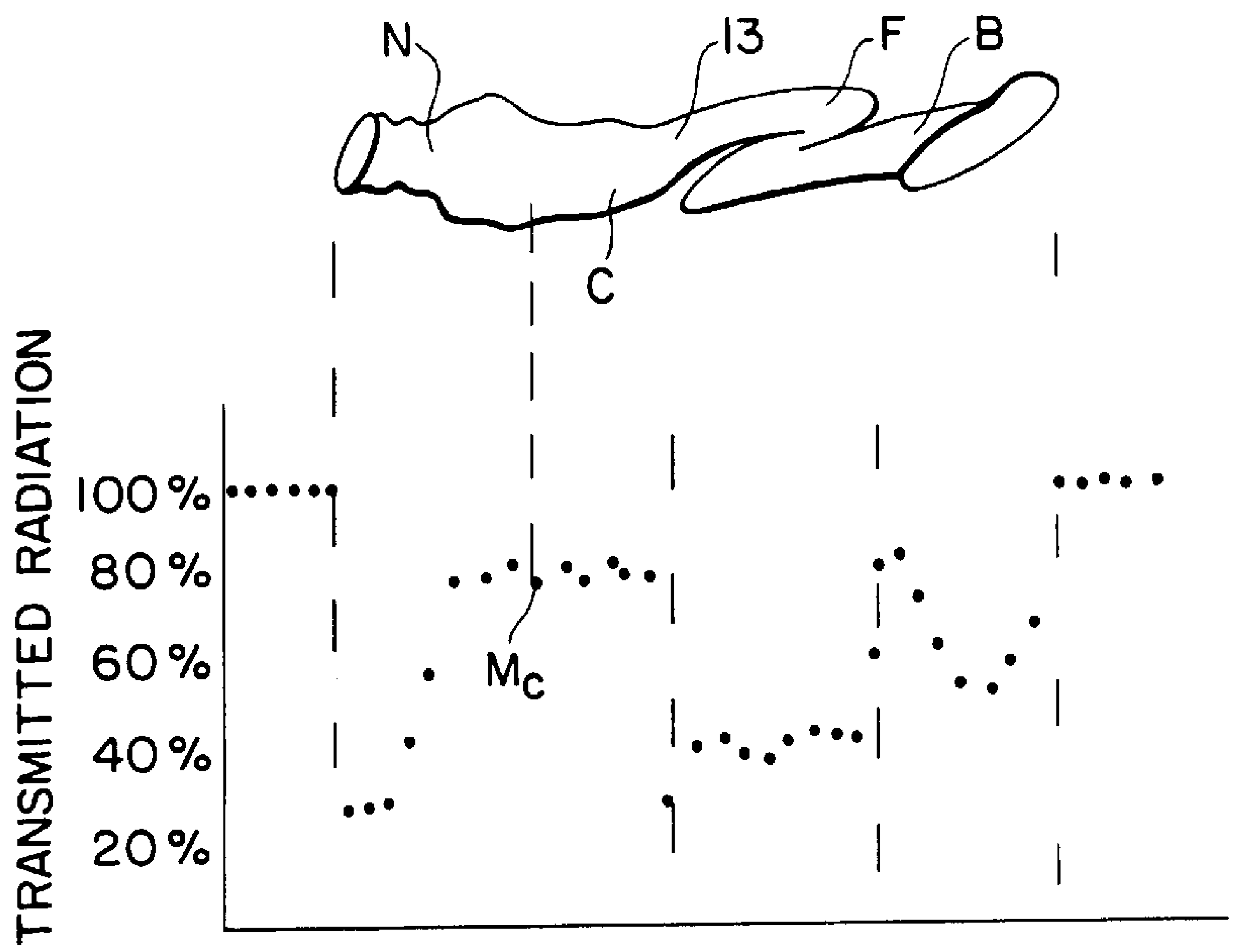

N
13
F
B
C
TRANSMITTED RADIATION
100%
80%
60%
40%
20%
M_C

FIG.4b

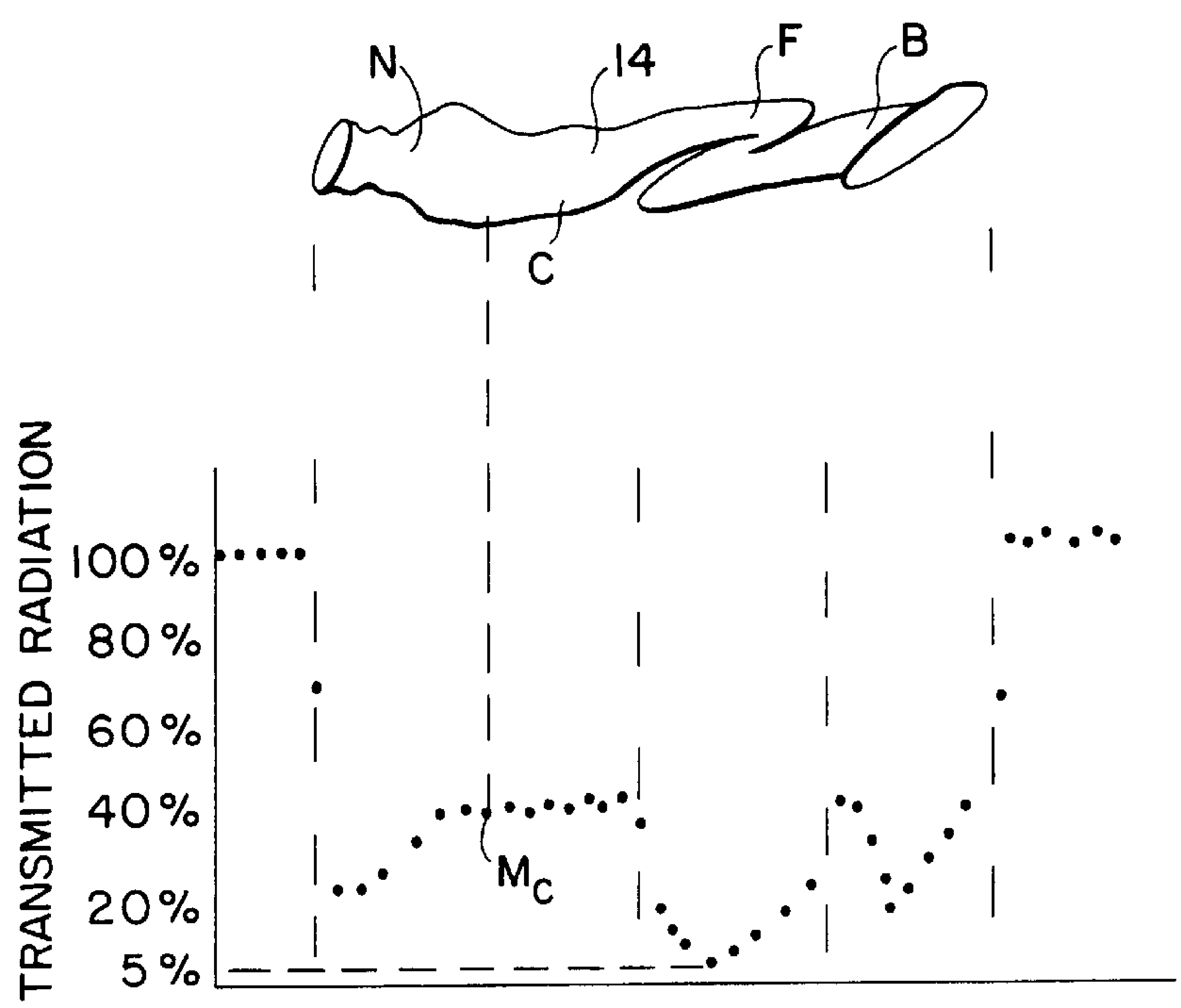
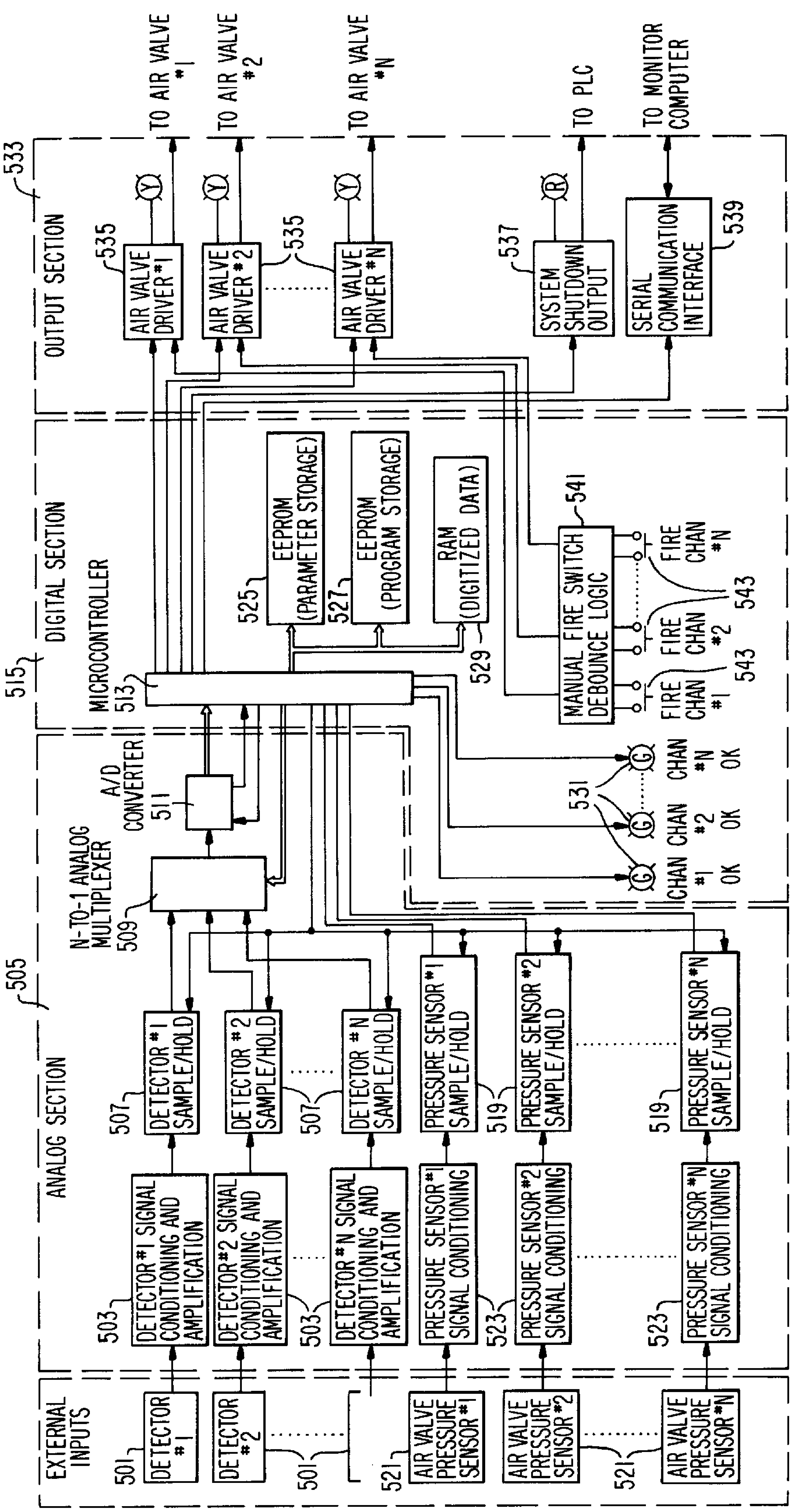

N
14
F
B
C
TRANSMITTED RADIATION
100%
80%
60%
40%
20%
5%
M_C

FIG. 5



EXTERNAL INPUTS
DETECTOR #1
DETECTOR #2
AIR VALVE PRESSURE SENSOR #1
AIR VALVE PRESSURE SENSOR #2
AIR VALVE PRESSURE SENSOR #N
501
521
ANALOG SECTION
505
DETECTOR #1 SIGNAL CONDITIONING AND AMPLIFICATION
DETECTOR #2 SIGNAL CONDITIONING AND AMPLIFICATION
DETECTOR #N SIGNAL CONDITIONING AND AMPLIFICATION
503
PRESSURE SENSOR #1 SIGNAL CONDITIONING
PRESSURE SENSOR #2 SIGNAL CONDITIONING
PRESSURE SENSOR #N SIGNAL CONDITIONING
523
DETECTOR #1 SAMPLE/HOLD
DETECTOR #2 SAMPLE/HOLD
DETECTOR #N SAMPLE/HOLD
507
PRESSURE SENSOR #1 SAMPLE/HOLD
PRESSURE SENSOR #2 SAMPLE/HOLD
PRESSURE SENSOR #N SAMPLE/HOLD
519
N-TO-1 ANALOG MULTIPLEXER
509
A/D CONVERTER
511
CHAN #1 OK
CHAN #2 OK
CHAN #N OK
531
DIGITAL SECTION
515
MICROCONTROLLER
513
EEPROM (PARAMETER STORAGE)
525
EEPROM (PROGRAM STORAGE)
527
RAM (DIGITIZED DATA)
529
MANUAL FIRE SWITCH DEBOUNCE LOGIC
541
FIRE CHAN #1
FIRE CHAN #2
FIRE CHAN #N
543
OUTPUT SECTION
533
AIR VALVE DRIVER #1
AIR VALVE DRIVER #2
AIR VALVE DRIVER #N
535
SYSTEM SHUTDOWN OUTPUT
537
SERIAL COMMUNICATION INTERFACE
539
TO AIR VALVE #1
TO AIR VALVE #2
TO AIR VALVE #N
TO PLC
TO MONITOR COMPUTER

FIG.6a

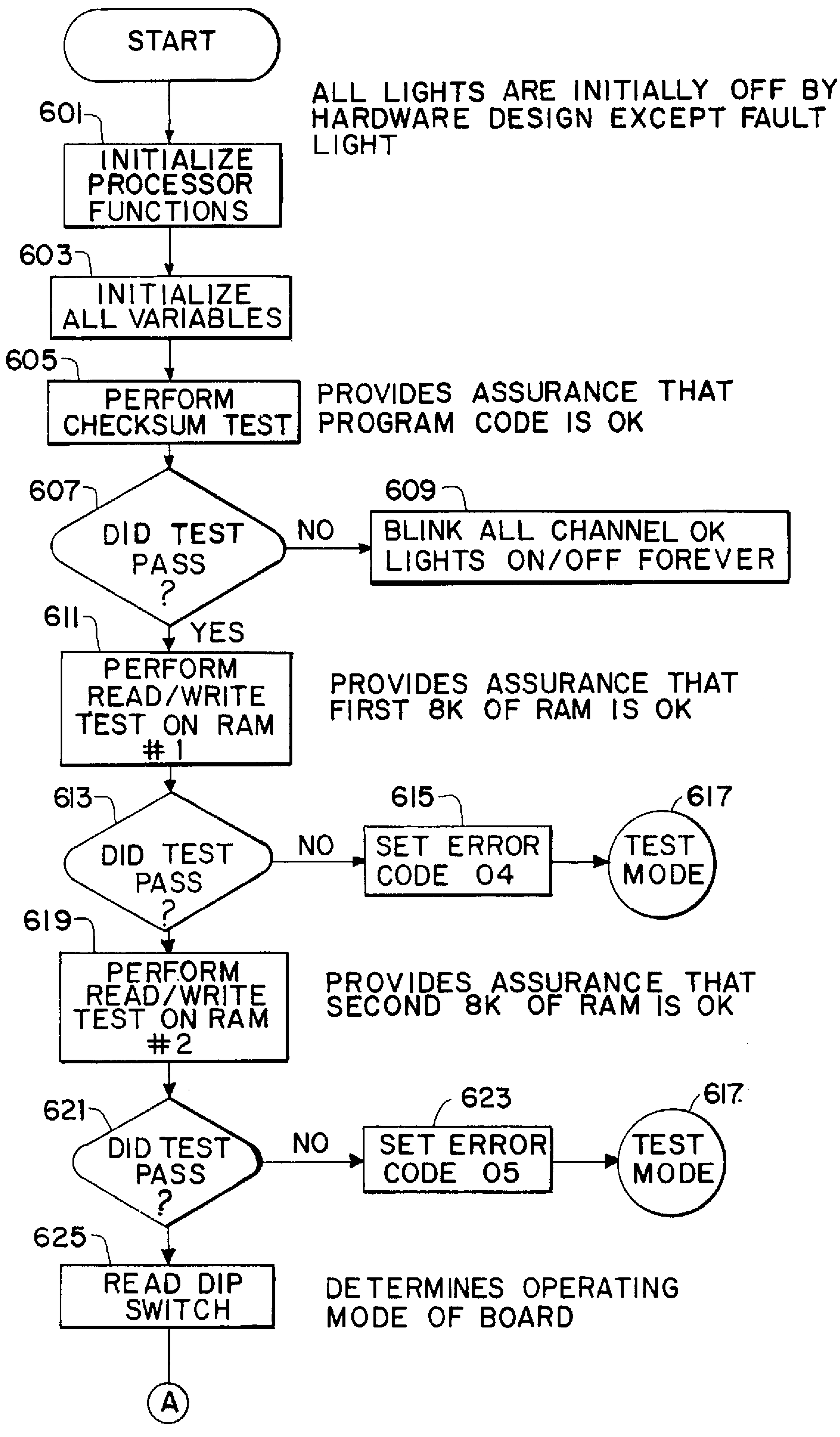

START
601
INITIALIZE PROCESSOR FUNCTIONS
ALL LIGHTS ARE INITIALLY OFF BY HARDWARE DESIGN EXCEPT FAULT LIGHT
603
INITIALIZE ALL VARIABLES
605
PERFORM CHECKSUM TEST
PROVIDES ASSURANCE THAT PROGRAM CODE IS OK
607
DID TEST PASS ?
NO
609
BLINK ALL CHANNEL OK LIGHTS ON/OFF FOREVER
YES
611
PERFORM READ/WRITE TEST ON RAM #1
PROVIDES ASSURANCE THAT FIRST 8K OF RAM IS OK
613
DID TEST PASS ?
NO
615
SET ERROR CODE 04
617
TEST MODE
619
PERFORM READ/WRITE TEST ON RAM #2
PROVIDES ASSURANCE THAT SECOND 8K OF RAM IS OK
621
DID TEST PASS ?
NO
623
SET ERROR CODE 05
617
TEST MODE
625
READ DIP SWITCH
DETERMINES OPERATING MODE OF BOARD
A

FIG. 6b

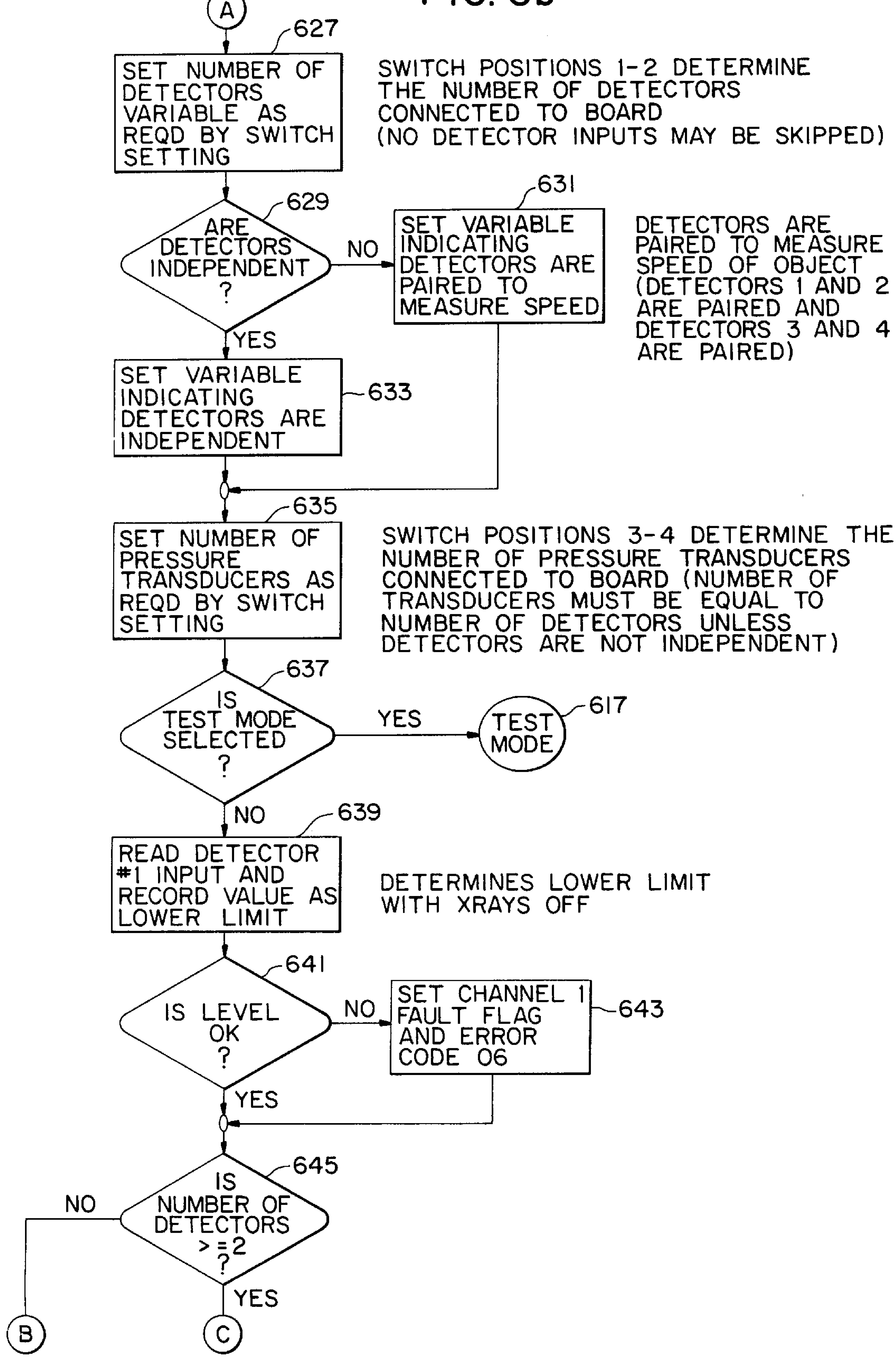

A
627
SET NUMBER OF DETECTORS VARIABLE AS REQD BY SWITCH SETTING
SWITCH POSITIONS 1-2 DETERMINE THE NUMBER OF DETECTORS CONNECTED TO BOARD (NO DETECTOR INPUTS MAY BE SKIPPED)
629
ARE DETECTORS INDEPENDENT ?
NO
631
SET VARIABLE INDICATING DETECTORS ARE PAIRED TO MEASURE SPEED
DETECTORS ARE PAIRED TO MEASURE SPEED OF OBJECT (DETECTORS 1 AND 2 ARE PAIRED AND DETECTORS 3 AND 4 ARE PAIRED)
YES
SET VARIABLE INDICATING DETECTORS ARE INDEPENDENT
633
635
SET NUMBER OF PRESSURE TRANSDUCERS AS REQD BY SWITCH SETTING
SWITCH POSITIONS 3-4 DETERMINE THE NUMBER OF PRESSURE TRANSDUCERS CONNECTED TO BOARD (NUMBER OF TRANSDUCERS MUST BE EQUAL TO NUMBER OF DETECTORS UNLESS DETECTORS ARE NOT INDEPENDENT)
637
IS TEST MODE SELECTED ?
YES
TEST MODE
617
NO
639
READ DETECTOR #1 INPUT AND RECORD VALUE AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH XRAYS OFF
641
IS LEVEL OK ?
NO
SET CHANNEL 1 FAULT FLAG AND ERROR CODE 06
643
YES
645
IS NUMBER OF DETECTORS > = 2 ?
NO
YES
B
C

FIG. 6c

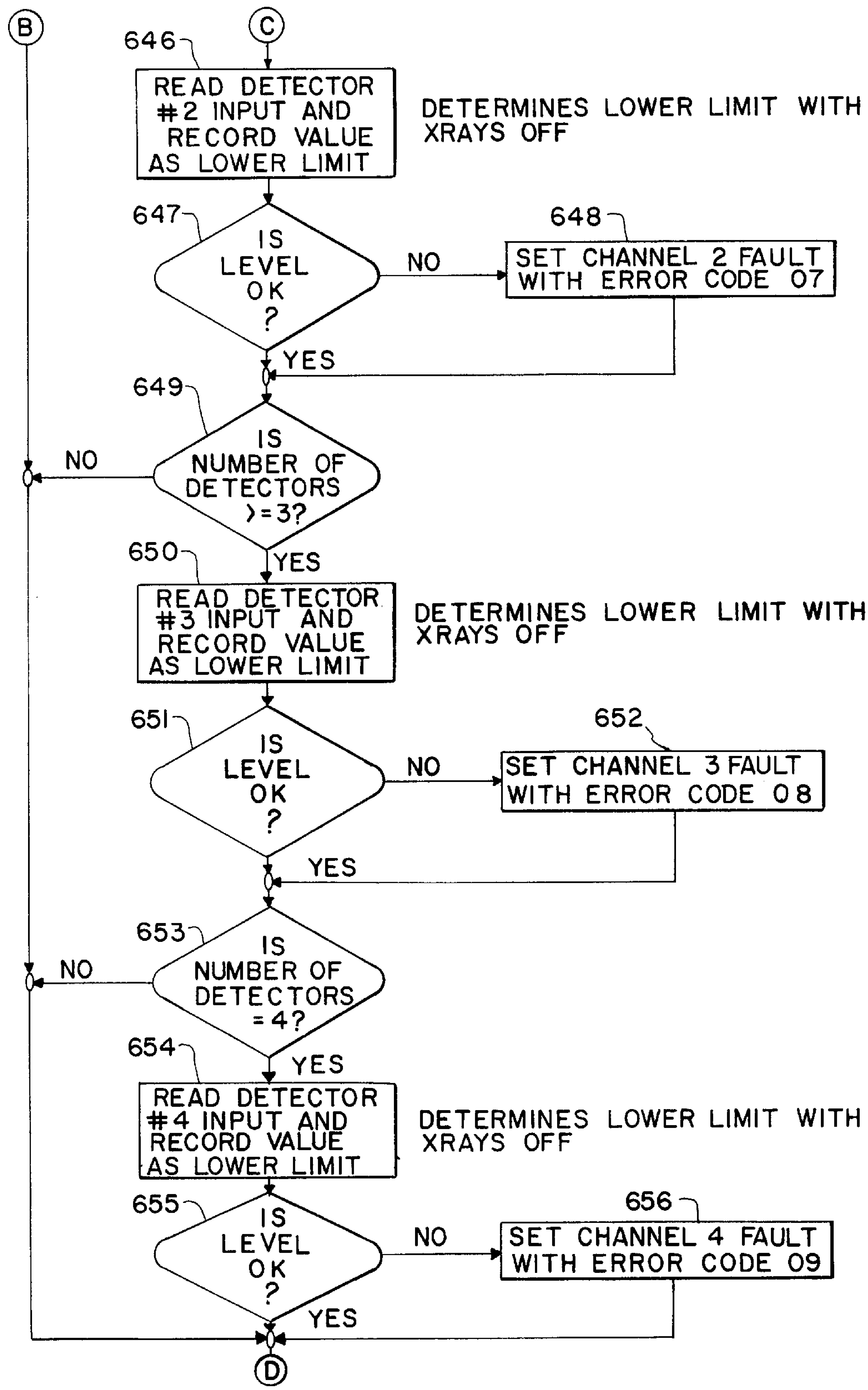

B
C
646
READ DETECTOR #2 INPUT AND RECORD VALUE AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH XRAYS OFF
647
IS LEVEL OK ?
NO
648
SET CHANNEL 2 FAULT WITH ERROR CODE 07
YES
649
IS NUMBER OF DETECTORS >=3?
NO
YES
650
READ DETECTOR #3 INPUT AND RECORD VALUE AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH XRAYS OFF
651
IS LEVEL OK ?
NO
652
SET CHANNEL 3 FAULT WITH ERROR CODE 08
YES
653
IS NUMBER OF DETECTORS =4?
NO
YES
654
READ DETECTOR #4 INPUT AND RECORD VALUE AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH XRAYS OFF
655
IS LEVEL OK ?
NO
656
SET CHANNEL 4 FAULT WITH ERROR CODE 09
YES
D

FIG.6d

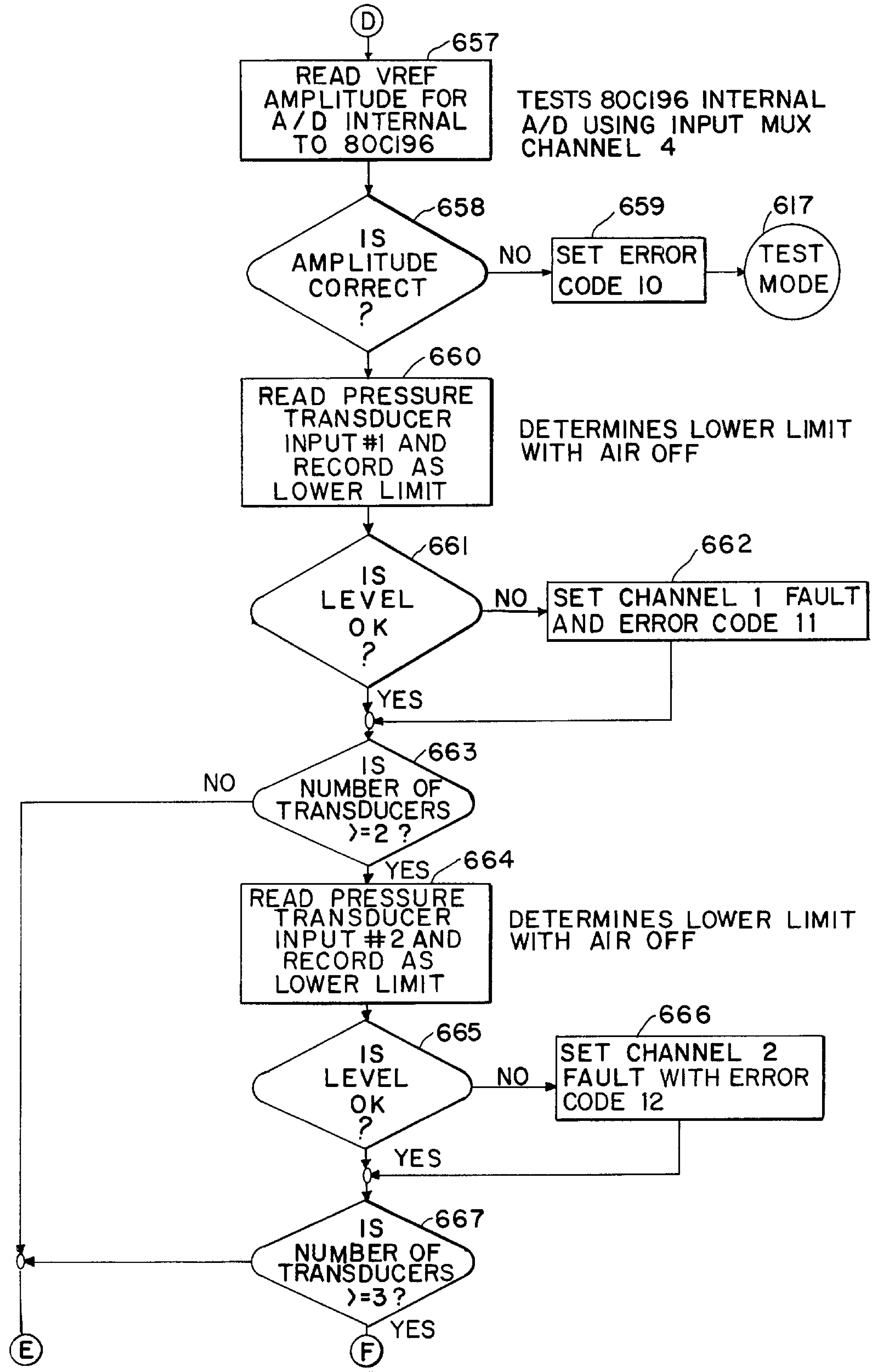

D
657
READ VREF AMPLITUDE FOR A/D INTERNAL TO 80C196
TESTS 80C196 INTERNAL A/D USING INPUT MUX CHANNEL 4
658
IS AMPLITUDE CORRECT ?
NO
659
SET ERROR CODE 10
617
TEST MODE
660
READ PRESSURE TRANSDUCER INPUT #1 AND RECORD AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH AIR OFF
661
IS LEVEL OK ?
NO
662
SET CHANNEL 1 FAULT AND ERROR CODE 11
YES
663
IS NUMBER OF TRANSDUCERS >=2 ?
NO
YES
664
READ PRESSURE TRANSDUCER INPUT #2 AND RECORD AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH AIR OFF
665
IS LEVEL OK ?
NO
666
SET CHANNEL 2 FAULT WITH ERROR CODE 12
YES
667
IS NUMBER OF TRANSDUCERS >=3 ?
YES
E
F

FIG. 6e

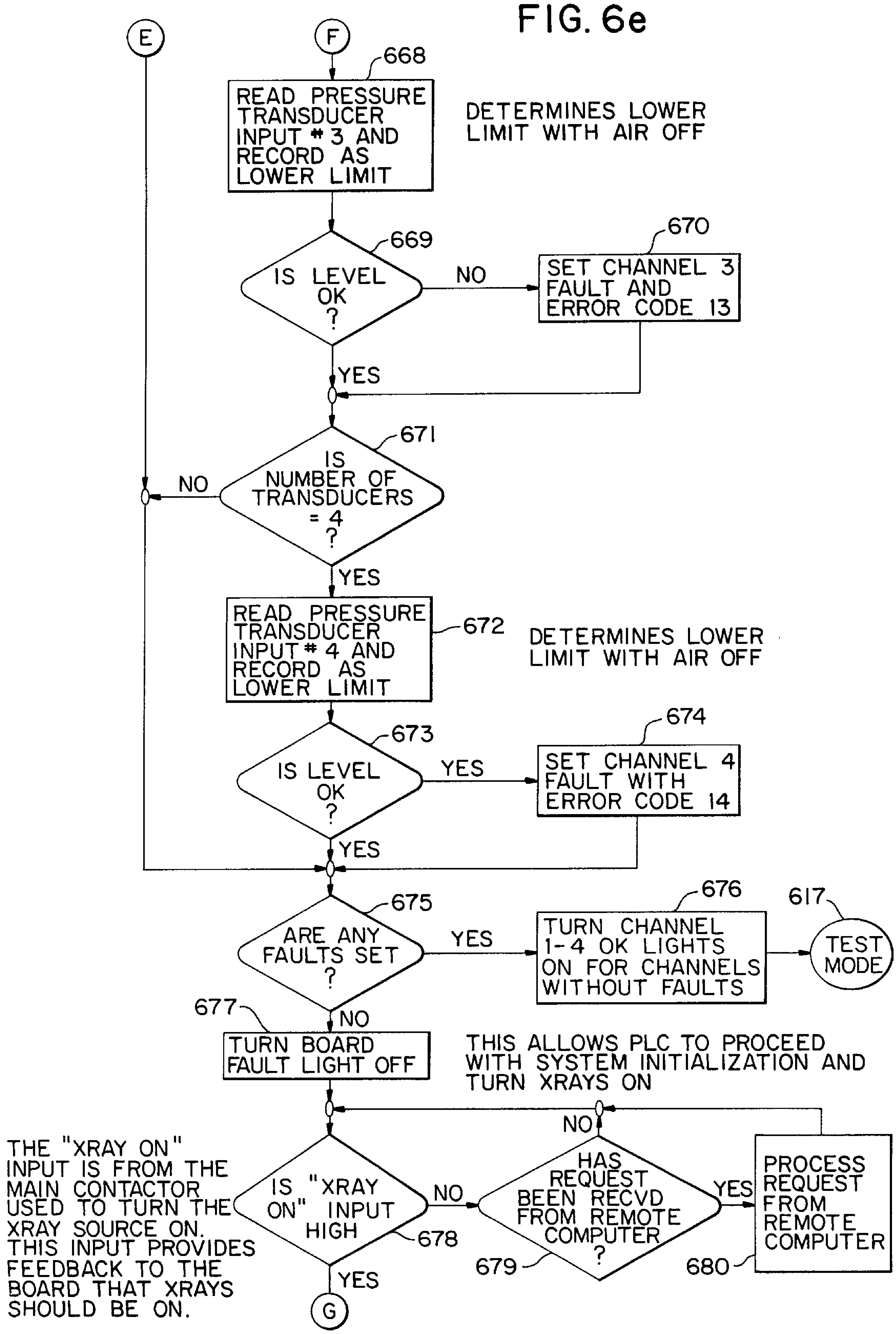

E
F
668
READ PRESSURE TRANSDUCER INPUT # 3 AND RECORD AS LOWER LIMIT
DETERMINES LOWER LIMIT WITH AIR OFF
669
IS LEVEL OK ?
NO
670
SET CHANNEL 3 FAULT AND ERROR CODE 13
YES
671
IS NUMBER OF TRANSDUCERS = 4 ?
NO
YES
READ PRESSURE TRANSDUCER INPUT # 4 AND RECORD AS LOWER LIMIT
672
DETERMINES LOWER LIMIT WITH AIR OFF
673
IS LEVEL OK ?
YES
674
SET CHANNEL 4 FAULT WITH ERROR CODE 14
YES
675
ARE ANY FAULTS SET ?
YES
676
TURN CHANNEL 1-4 OK LIGHTS ON FOR CHANNELS WITHOUT FAULTS
617
TEST MODE
677
NO
TURN BOARD FAULT LIGHT OFF
THIS ALLOWS PLC TO PROCEED WITH SYSTEM INITIALIZATION AND TURN XRAYS ON
NO
THE "XRAY ON" INPUT IS FROM THE MAIN CONTACTOR USED TO TURN THE XRAY SOURCE ON. THIS INPUT PROVIDES FEEDBACK TO THE BOARD THAT XRAYS SHOULD BE ON.
IS "XRAY ON" INPUT HIGH
678
NO
HAS REQUEST BEEN RECVD FROM REMOTE COMPUTER ?
679
YES
PROCESS REQUEST FROM REMOTE COMPUTER
680
YES
G

FIG.6f

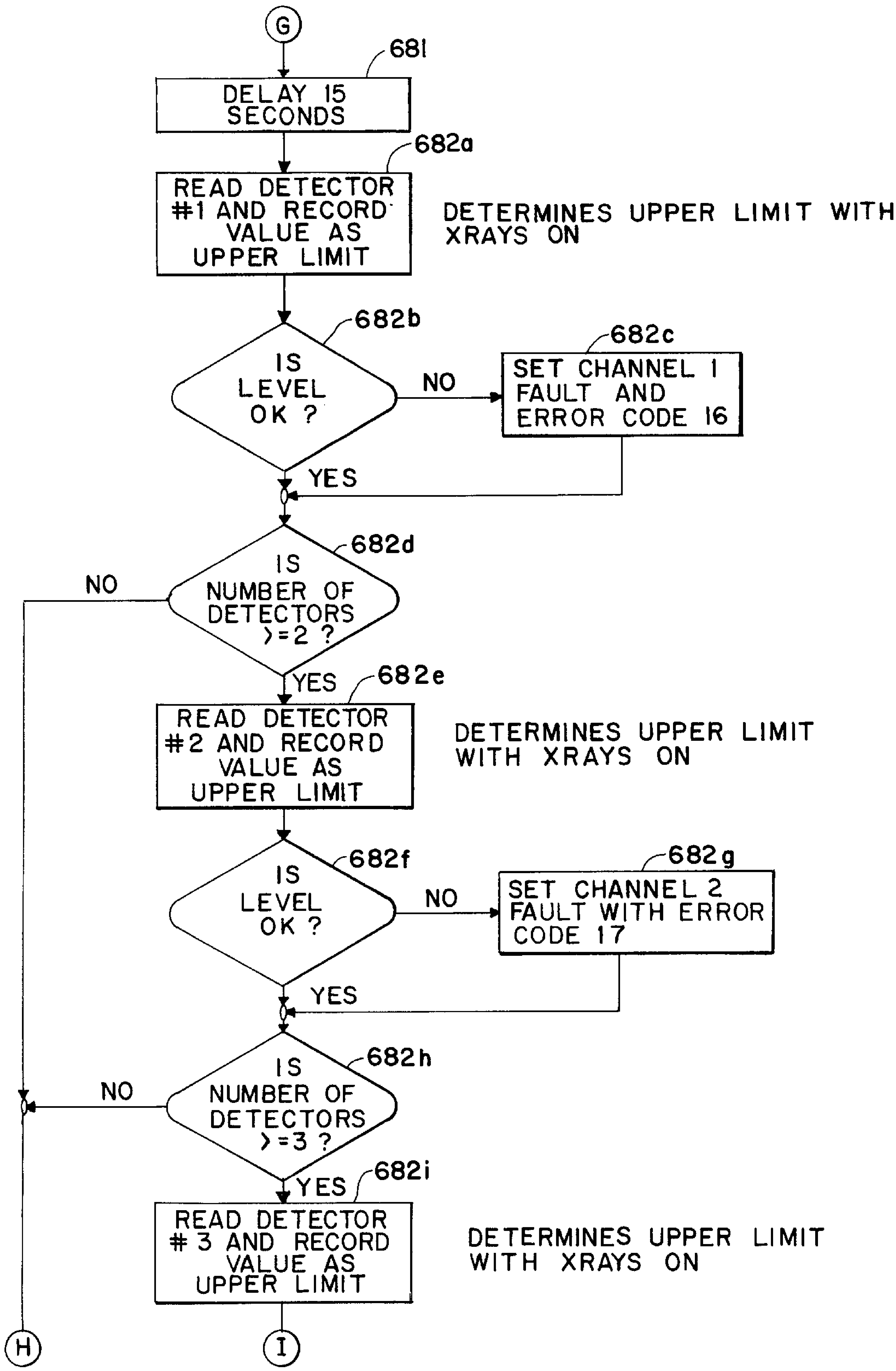

G
681
DELAY 15 SECONDS
682a
READ DETECTOR #1 AND RECORD VALUE AS UPPER LIMIT
DETERMINES UPPER LIMIT WITH XRAYS ON
682b
IS LEVEL OK ?
NO
682c
SET CHANNEL 1 FAULT AND ERROR CODE 16
YES
682d
IS NUMBER OF DETECTORS >=2 ?
NO
YES
682e
READ DETECTOR #2 AND RECORD VALUE AS UPPER LIMIT
DETERMINES UPPER LIMIT WITH XRAYS ON
682f
IS LEVEL OK ?
NO
682g
SET CHANNEL 2 FAULT WITH ERROR CODE 17
YES
682h
IS NUMBER OF DETECTORS >=3 ?
NO
YES
682i
READ DETECTOR # 3 AND RECORD VALUE AS UPPER LIMIT
DETERMINES UPPER LIMIT WITH XRAYS ON
H
I

FIG.6g

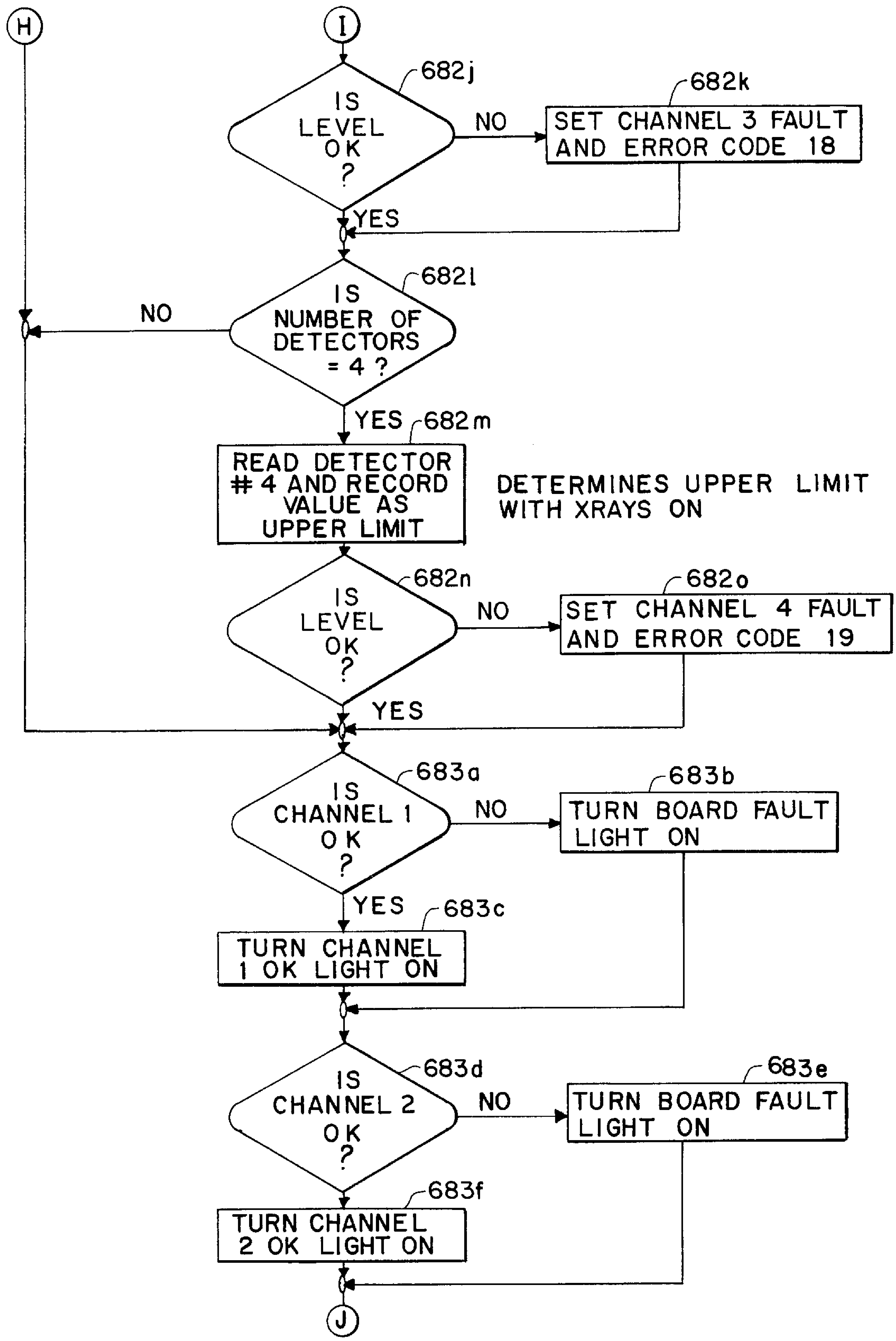

H
I
682j
IS LEVEL OK ?
NO
682k
SET CHANNEL 3 FAULT AND ERROR CODE 18
YES
682l
IS NUMBER OF DETECTORS = 4 ?
NO
YES
682m
READ DETECTOR # 4 AND RECORD VALUE AS UPPER LIMIT
DETERMINES UPPER LIMIT WITH XRAYS ON
682n
IS LEVEL OK ?
NO
682o
SET CHANNEL 4 FAULT AND ERROR CODE 19
YES
683a
IS CHANNEL 1 OK ?
NO
683b
TURN BOARD FAULT LIGHT ON
YES
683c
TURN CHANNEL 1 OK LIGHT ON
683d
IS CHANNEL 2 OK ?
NO
683e
TURN BOARD FAULT LIGHT ON
683f
TURN CHANNEL 2 OK LIGHT ON
J

FIG.6h

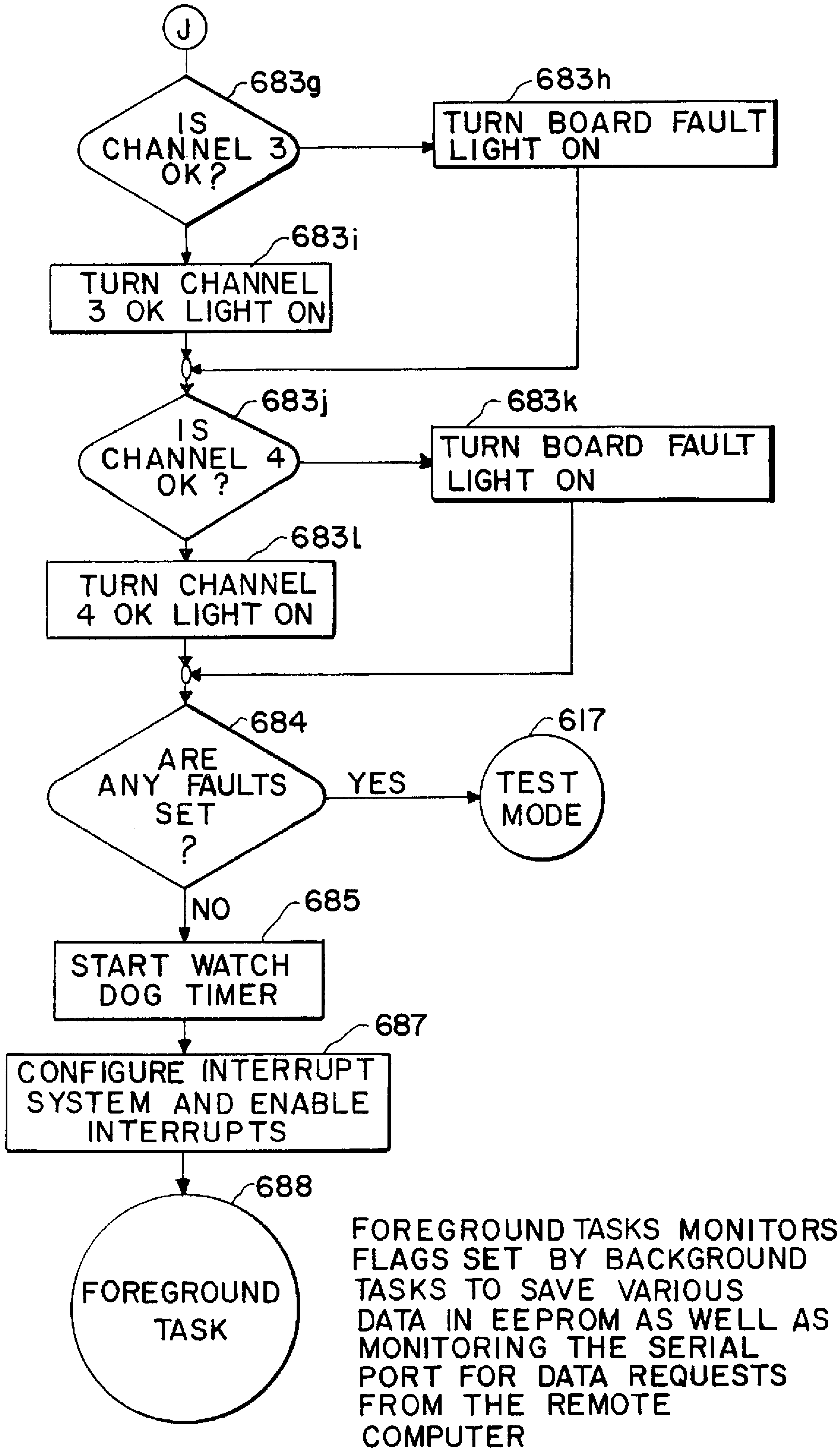

J
683g
IS CHANNEL 3 OK?
683h
TURN BOARD FAULT LIGHT ON
683i
TURN CHANNEL 3 OK LIGHT ON
683j
IS CHANNEL 4 OK ?
683k
TURN BOARD FAULT LIGHT ON
683L
TURN CHANNEL 4 OK LIGHT ON
684
ARE ANY FAULTS SET ?
YES
617
TEST MODE
NO
685
START WATCH DOG TIMER
687
CONFIGURE INTERRUPT SYSTEM AND ENABLE INTERRUPTS
688
FOREGROUND TASK
FOREGROUND TASKS MONITORS FLAGS SET BY BACKGROUND TASKS TO SAVE VARIOUS DATA IN EEPROM AS WELL AS MONITORING THE SERIAL PORT FOR DATA REQUESTS FROM THE REMOTE COMPUTER

FIG. 7a

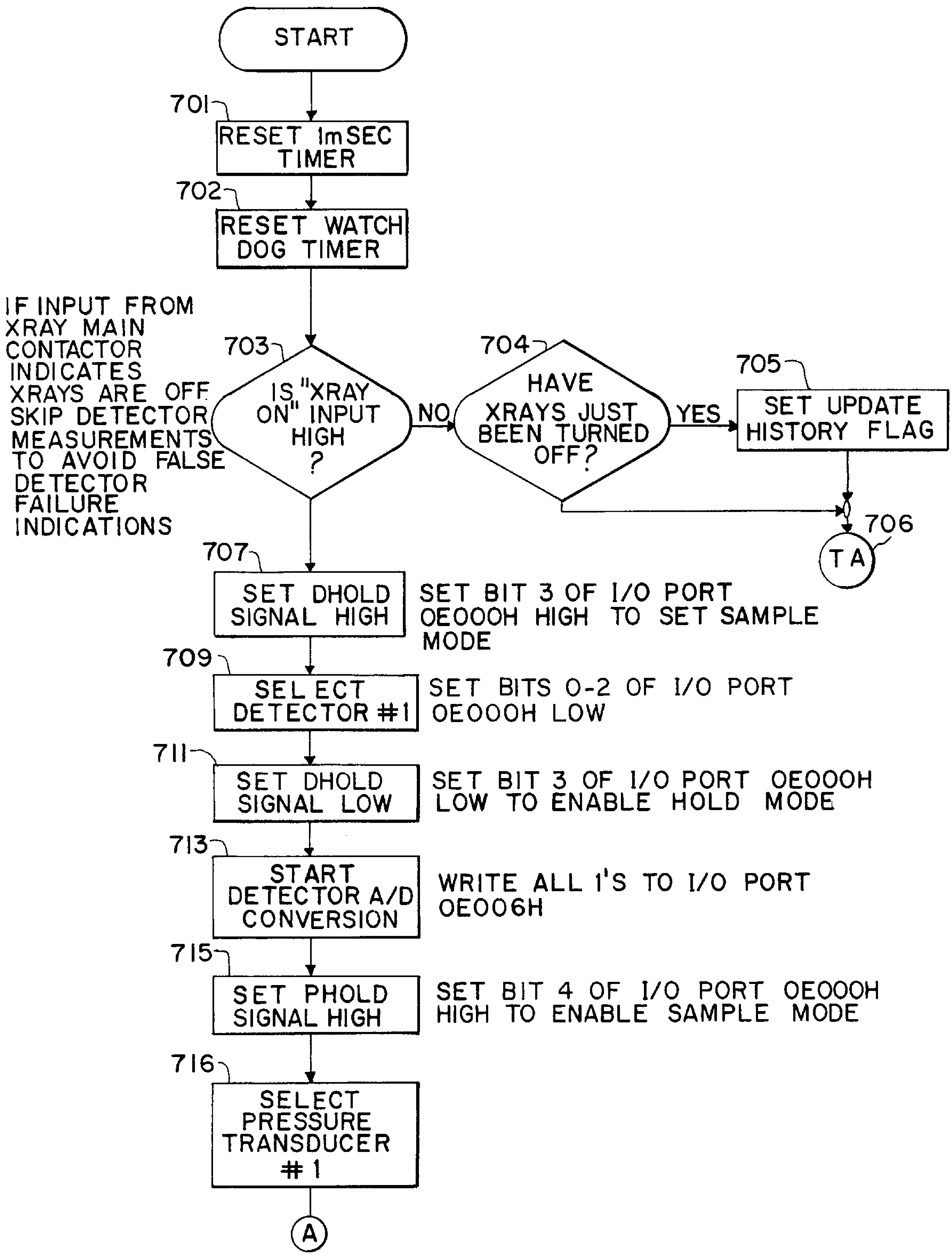

START
701
RESET 1mSEC TIMER
702
RESET WATCH DOG TIMER
IF INPUT FROM XRAY MAIN CONTACTOR INDICATES XRAYS ARE OFF SKIP DETECTOR MEASUREMENTS TO AVOID FALSE DETECTOR FAILURE INDICATIONS
703
IS "XRAY ON" INPUT HIGH ?
NO
704
HAVE XRAYS JUST BEEN TURNED OFF?
YES
705
SET UPDATE HISTORY FLAG
706
TA
707
SET DHOLD SIGNAL HIGH
SET BIT 3 OF I/O PORT OE000H HIGH TO SET SAMPLE MODE
709
SELECT DETECTOR #1
SET BITS 0-2 OF I/O PORT OE000H LOW
711
SET DHOLD SIGNAL LOW
SET BIT 3 OF I/O PORT OE000H LOW TO ENABLE HOLD MODE
713
START DETECTOR A/D CONVERSION
WRITE ALL 1'S TO I/O PORT OE006H
715
SET PHOLD SIGNAL HIGH
SET BIT 4 OF I/O PORT OE000H HIGH TO ENABLE SAMPLE MODE
716
SELECT PRESSURE TRANSDUCER #1
A

FIG. 7b

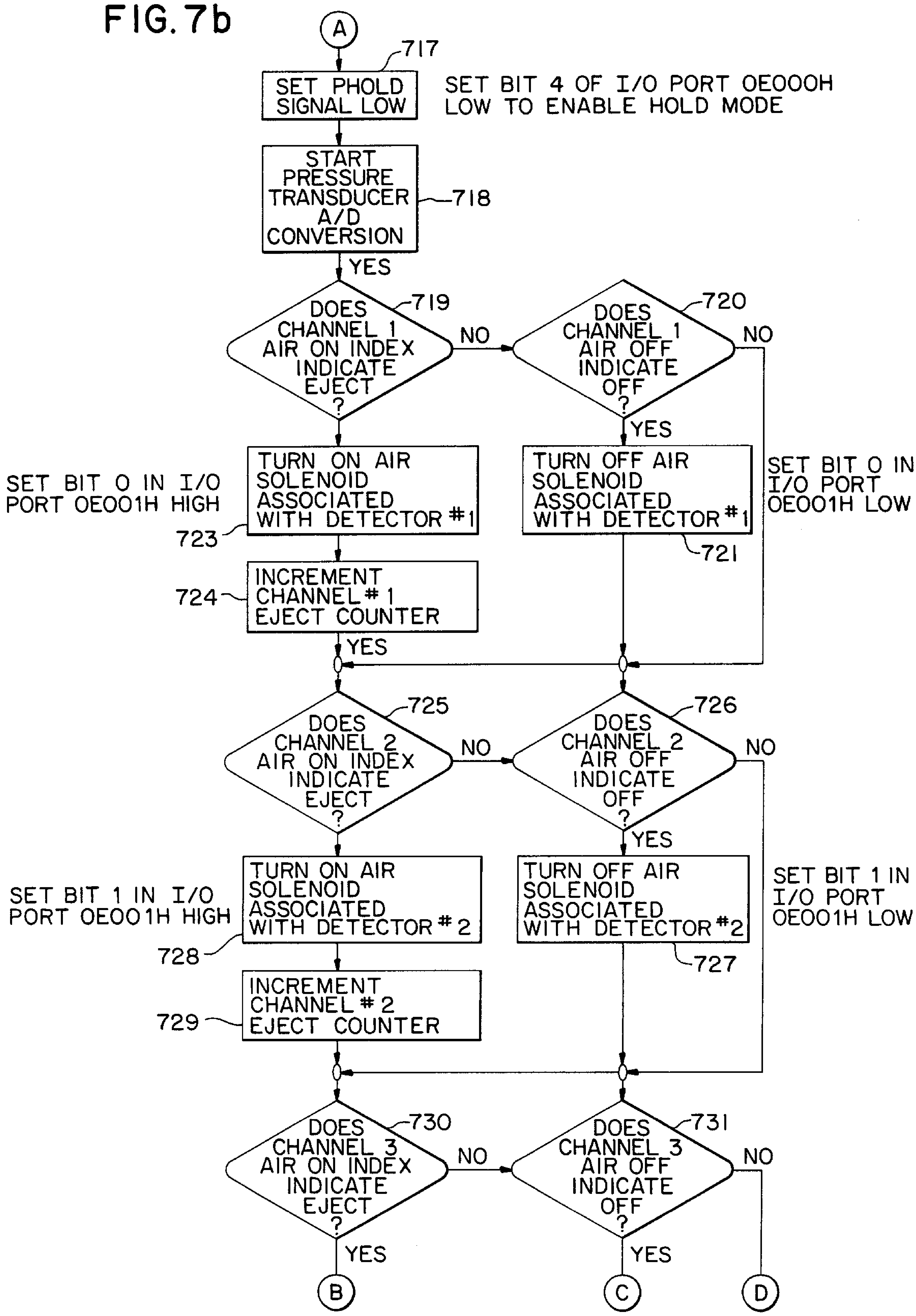

A
717
SET PHOLD SIGNAL LOW
SET BIT 4 OF I/O PORT OE000H LOW TO ENABLE HOLD MODE
START PRESSURE TRANSDUCER A/D CONVERSION
718
YES
DOES CHANNEL 1 AIR ON INDEX INDICATE EJECT ?
719
NO
DOES CHANNEL 1 AIR OFF INDICATE OFF ?
720
NO
YES
TURN ON AIR SOLENOID ASSOCIATED WITH DETECTOR #1
SET BIT 0 IN I/O PORT OE001H HIGH
723
TURN OFF AIR SOLENOID ASSOCIATED WITH DETECTOR #1
SET BIT 0 IN I/O PORT OE001H LOW
721
INCREMENT CHANNEL #1 EJECT COUNTER
724
YES
DOES CHANNEL 2 AIR ON INDEX INDICATE EJECT ?
725
NO
DOES CHANNEL 2 AIR OFF INDICATE OFF ?
726
NO
YES
TURN ON AIR SOLENOID ASSOCIATED WITH DETECTOR #2
SET BIT 1 IN I/O PORT OE001H HIGH
728
TURN OFF AIR SOLENOID ASSOCIATED WITH DETECTOR #2
SET BIT 1 IN I/O PORT OE001H LOW
727
INCREMENT CHANNEL #2 EJECT COUNTER
729
DOES CHANNEL 3 AIR ON INDEX INDICATE EJECT ?
730
NO
DOES CHANNEL 3 AIR OFF INDICATE OFF ?
731
NO
YES
YES
B
C
D

FIG. 7c

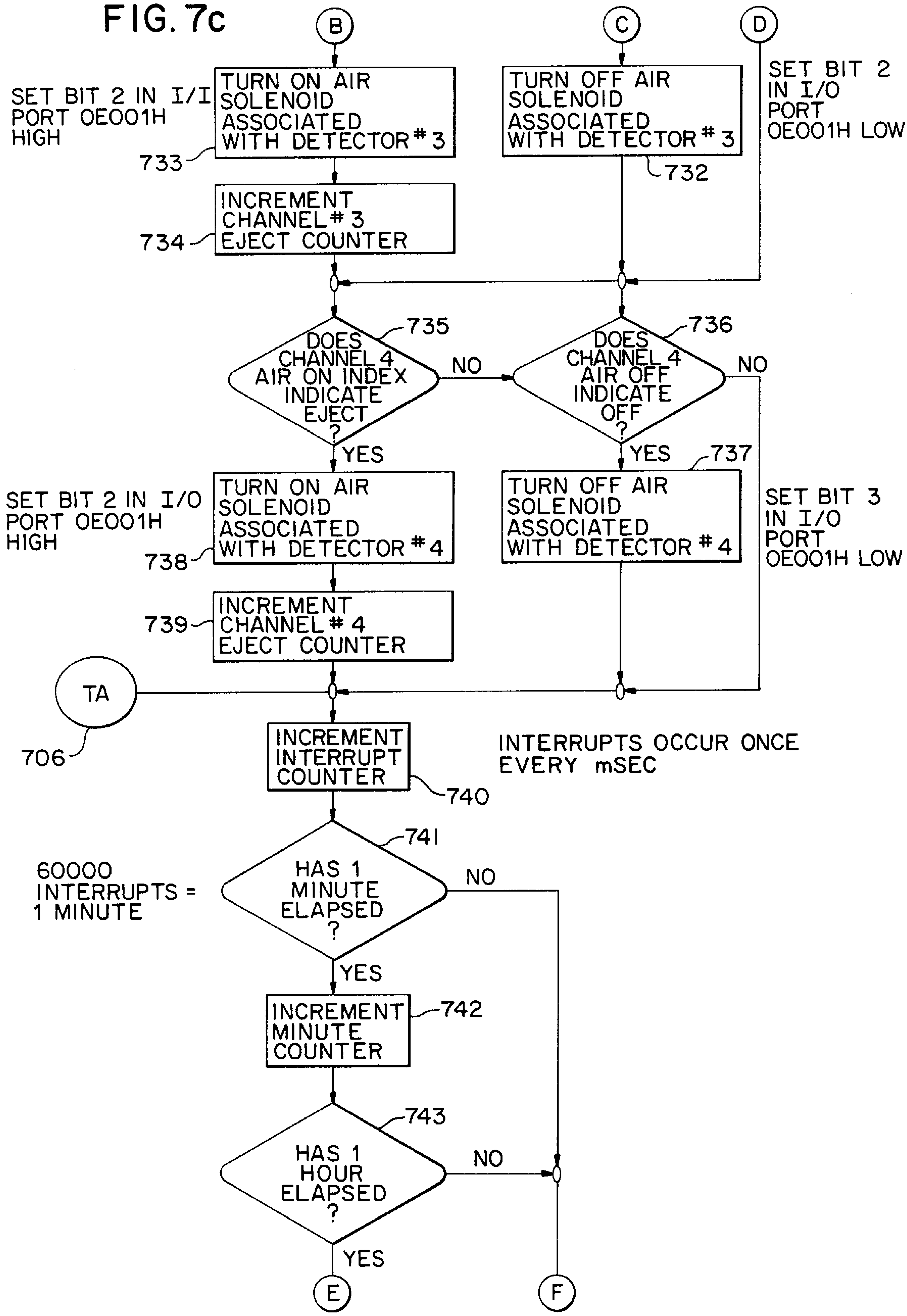

B
C
D
SET BIT 2 IN I/I PORT OE001H HIGH
TURN ON AIR SOLENOID ASSOCIATED WITH DETECTOR # 3
733
TURN OFF AIR SOLENOID ASSOCIATED WITH DETECTOR # 3
732
SET BIT 2 IN I/O PORT OE001H LOW
INCREMENT CHANNEL # 3 EJECT COUNTER
734
DOES CHANNEL 4 AIR ON INDEX INDICATE EJECT ?
735
NO
DOES CHANNEL 4 AIR OFF INDICATE OFF ?
736
NO
YES
YES
737
SET BIT 2 IN I/O PORT OE001H HIGH
TURN ON AIR SOLENOID ASSOCIATED WITH DETECTOR # 4
738
TURN OFF AIR SOLENOID ASSOCIATED WITH DETECTOR # 4
SET BIT 3 IN I/O PORT OE001H LOW
INCREMENT CHANNEL # 4 EJECT COUNTER
739
TA
706
INCREMENT INTERRUPT COUNTER
740
INTERRUPTS OCCUR ONCE EVERY mSEC
60000 INTERRUPTS = 1 MINUTE
HAS 1 MINUTE ELAPSED ?
741
NO
YES
INCREMENT MINUTE COUNTER
742
HAS 1 HOUR ELAPSED ?
743
NO
YES
E
F

FIG. 7d

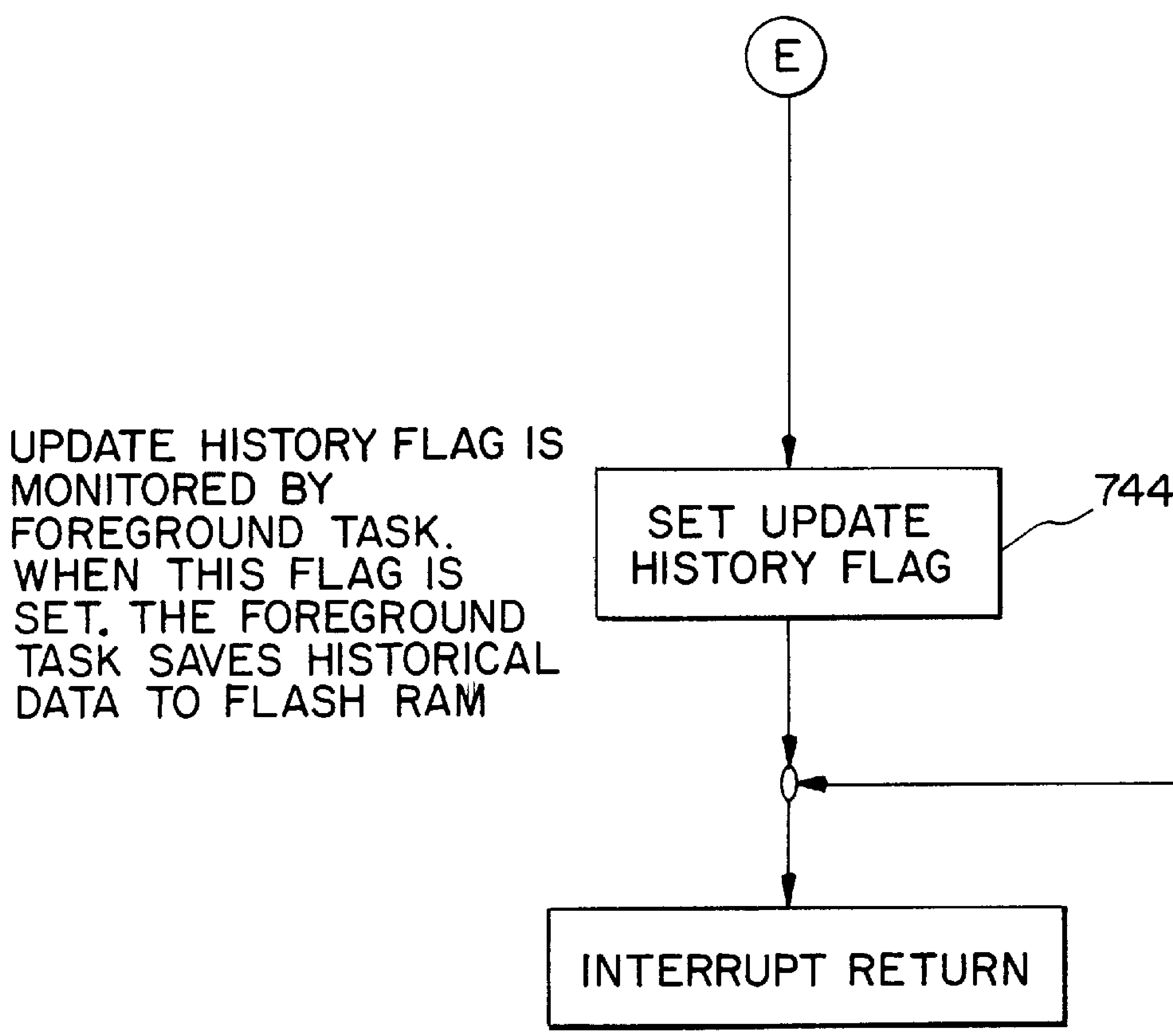

E
F
UPDATE HISTORY FLAG IS MONITORED BY FOREGROUND TASK. WHEN THIS FLAG IS SET, THE FOREGROUND TASK SAVES HISTORICAL DATA TO FLASH RAM
SET UPDATE HISTORY FLAG
744
INTERRUPT RETURN

FIG. 8a

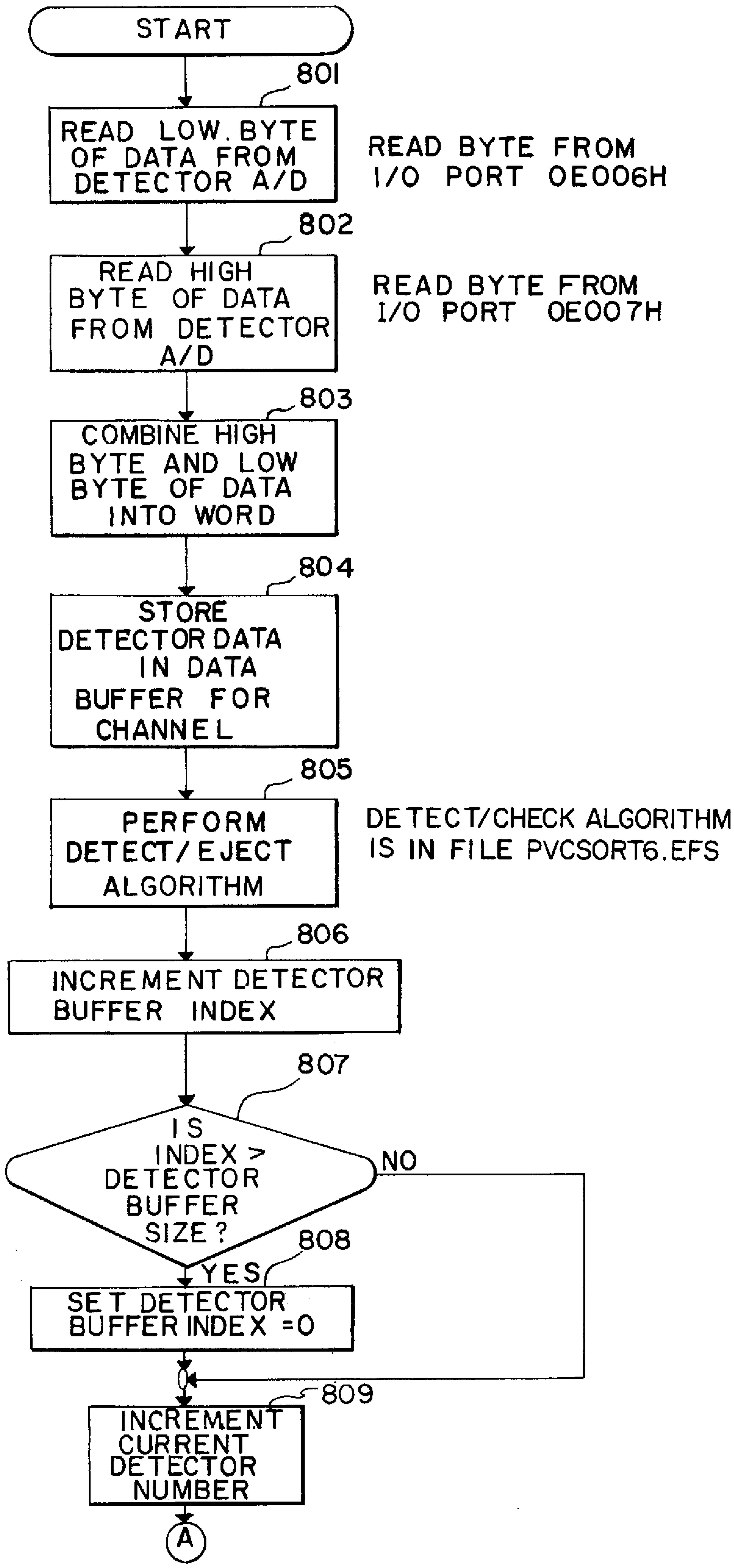

START
801
READ LOW. BYTE OF DATA FROM DETECTOR A/D
READ BYTE FROM I/O PORT 0E006H
802
READ HIGH BYTE OF DATA FROM DETECTOR A/D
READ BYTE FROM I/O PORT 0E007H
803
COMBINE HIGH BYTE AND LOW BYTE OF DATA INTO WORD
804
STORE DETECTOR DATA IN DATA BUFFER FOR CHANNEL
805
PERFORM DETECT/EJECT ALGORITHM
DETECT/CHECK ALGORITHM IS IN FILE PVCSORT6.EFS
806
INCREMENT DETECTOR BUFFER INDEX
807
IS INDEX > DETECTOR BUFFER SIZE?
NO
YES
808
SET DETECTOR BUFFER INDEX =0
809
INCREMENT CURRENT DETECTOR NUMBER
A

FIG. 8b

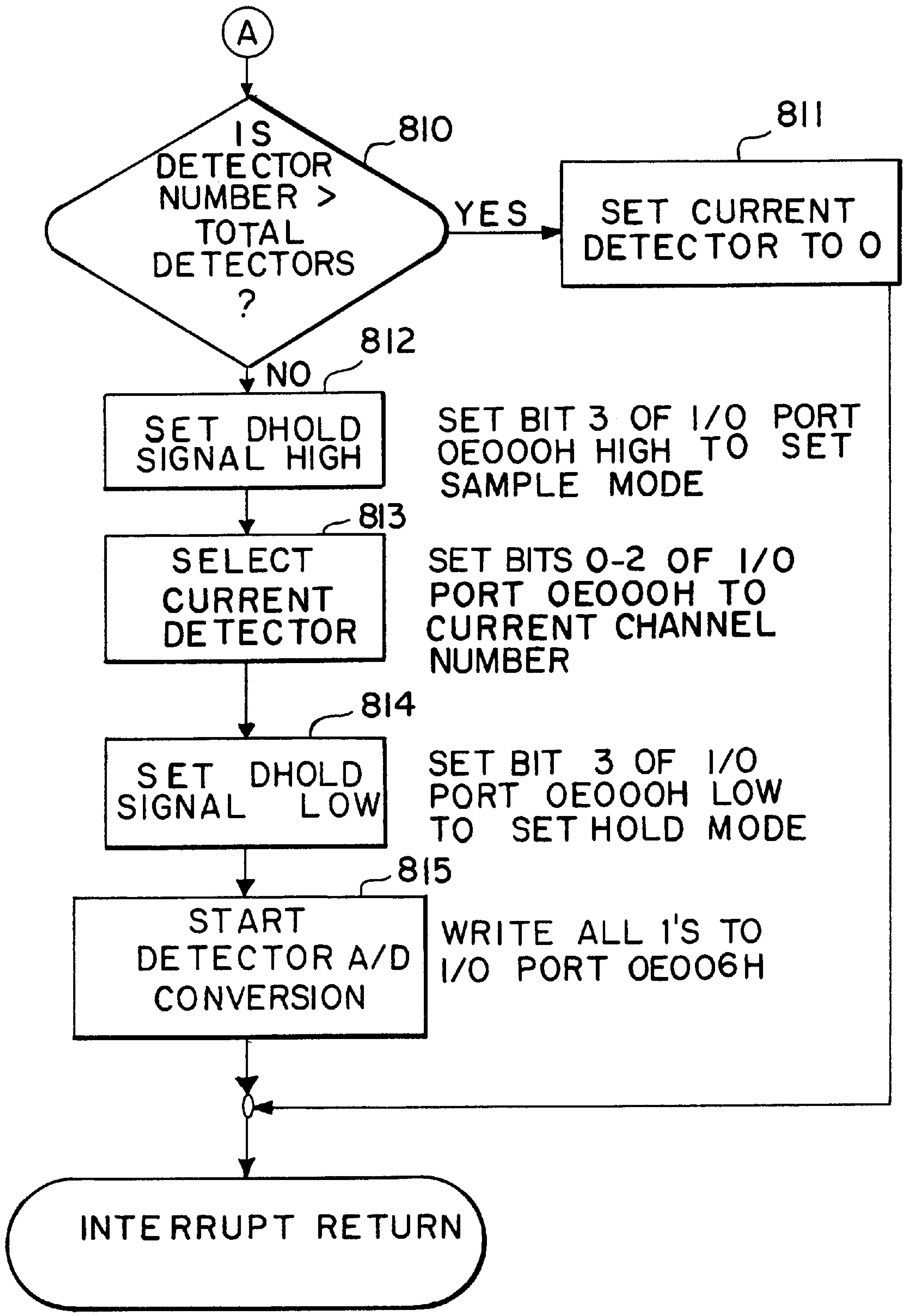

A
IS DETECTOR NUMBER > TOTAL DETECTORS ?
810
YES
811
SET CURRENT DETECTOR TO 0
NO
812
SET DHOLD SIGNAL HIGH
SET BIT 3 OF I/O PORT OEOOOH HIGH TO SET SAMPLE MODE
813
SELECT CURRENT DETECTOR
SET BITS 0-2 OF I/O PORT OEOOOH TO CURRENT CHANNEL NUMBER
814
SET DHOLD SIGNAL LOW
SET BIT 3 OF I/O PORT OEOOOH LOW TO SET HOLD MODE
815
START DETECTOR A/D CONVERSION
WRITE ALL 1'S TO I/O PORT OEOO6H
INTERRUPT RETURN

FIG. 9a

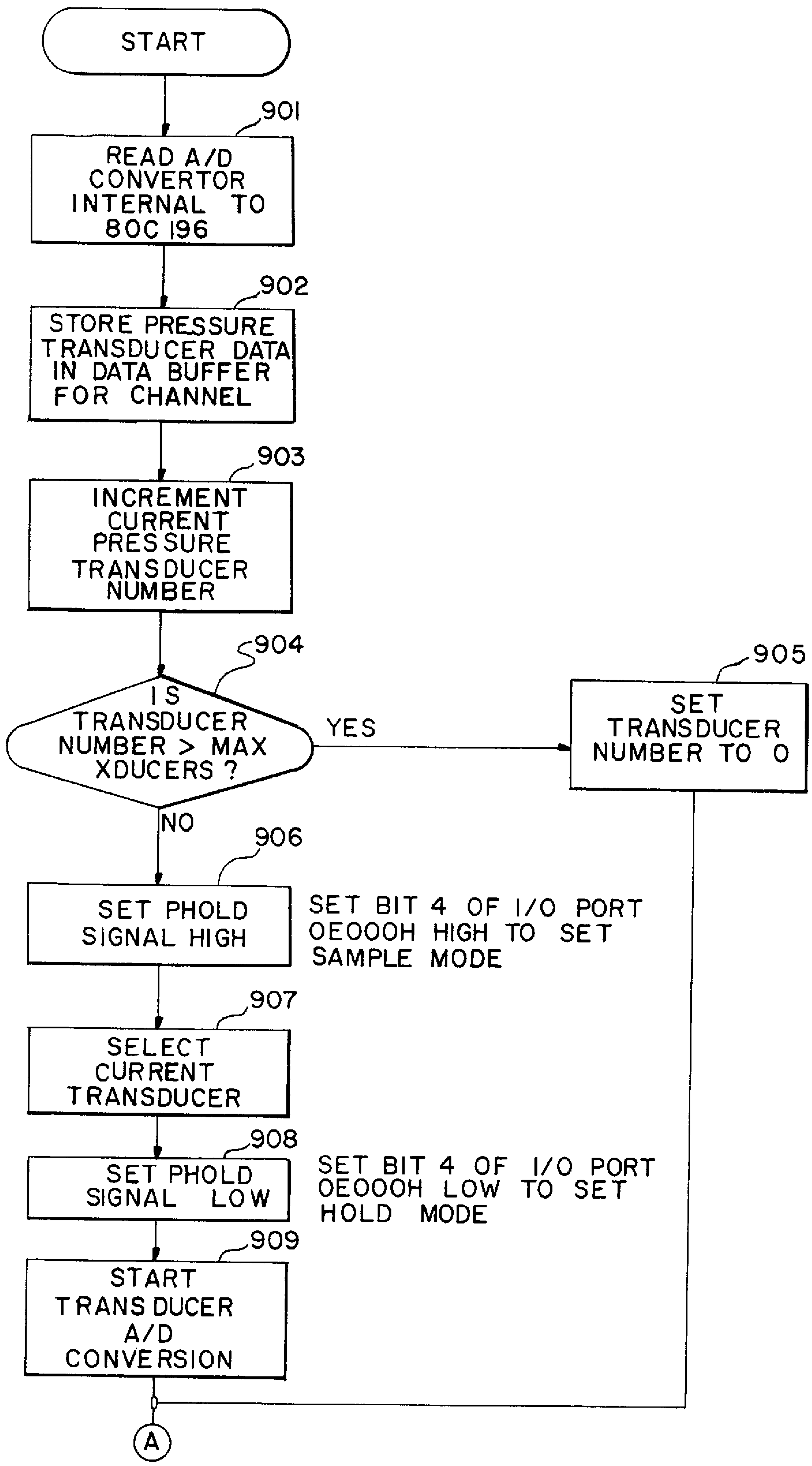

START
901
READ A/D CONVERTOR INTERNAL TO 80C 196
902
STORE PRESSURE TRANSDUCER DATA IN DATA BUFFER FOR CHANNEL
903
INCREMENT CURRENT PRESSURE TRANSDUCER NUMBER
904
IS TRANSDUCER NUMBER > MAX XDUCERS ?
YES
905
SET TRANSDUCER NUMBER TO 0
NO
906
SET PHOLD SIGNAL HIGH
SET BIT 4 OF I/O PORT OEOOOH HIGH TO SET SAMPLE MODE
907
SELECT CURRENT TRANSDUCER
908
SET PHOLD SIGNAL LOW
SET BIT 4 OF I/O PORT OEOOOH LOW TO SET HOLD MODE
909
START TRANSDUCER A/D CONVERSION
A

FIG. 9b

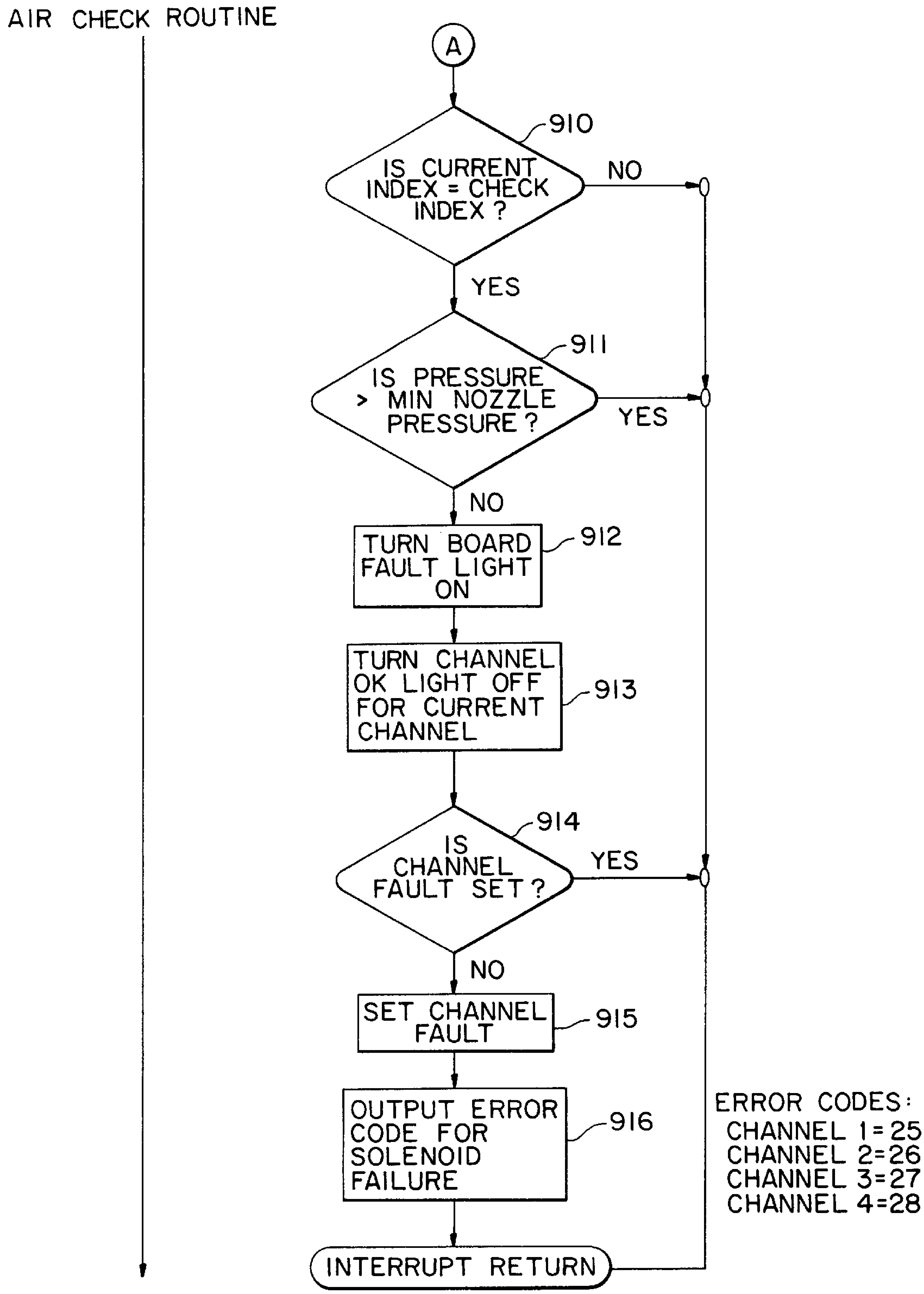

AIR CHECK ROUTINE
A
IS CURRENT INDEX = CHECK INDEX ?
910
NO
YES
IS PRESSURE > MIN NOZZLE PRESSURE ?
911
YES
NO
TURN BOARD FAULT LIGHT ON
912
TURN CHANNEL OK LIGHT OFF FOR CURRENT CHANNEL
913
IS CHANNEL FAULT SET ?
914
YES
NO
SET CHANNEL FAULT
915
OUTPUT ERROR CODE FOR SOLENOID FAILURE
916
ERROR CODES:
CHANNEL 1=25
CHANNEL 2=26
CHANNEL 3=27
CHANNEL 4=28
INTERRUPT RETURN

FIG. 10

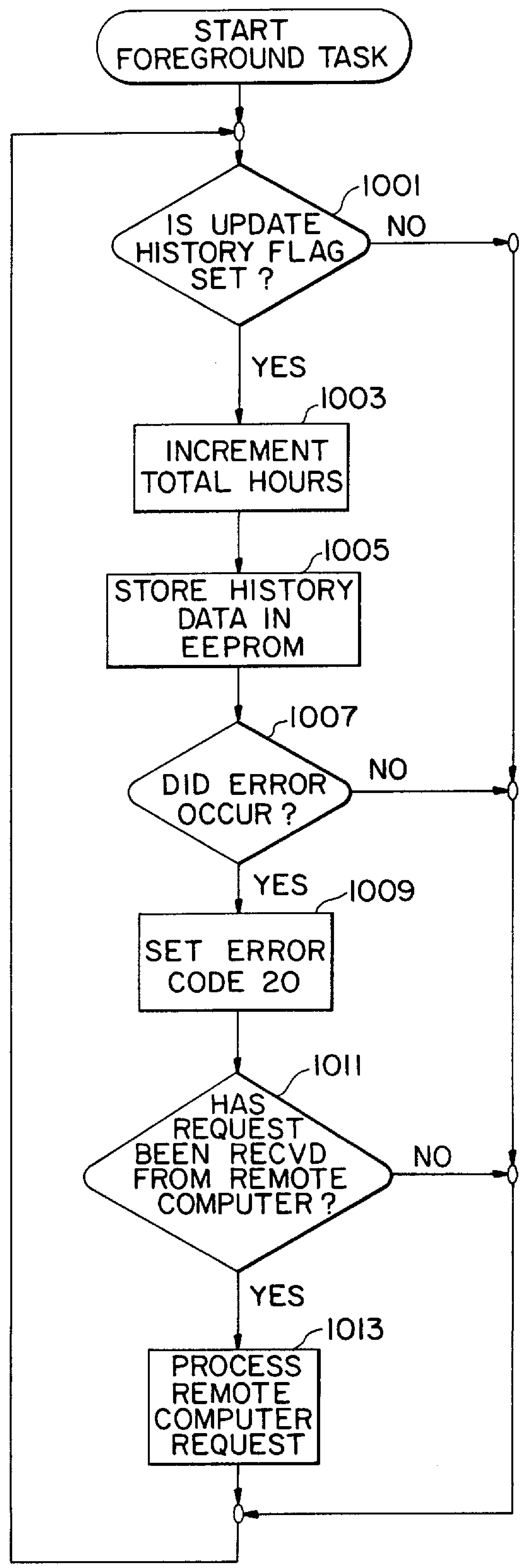
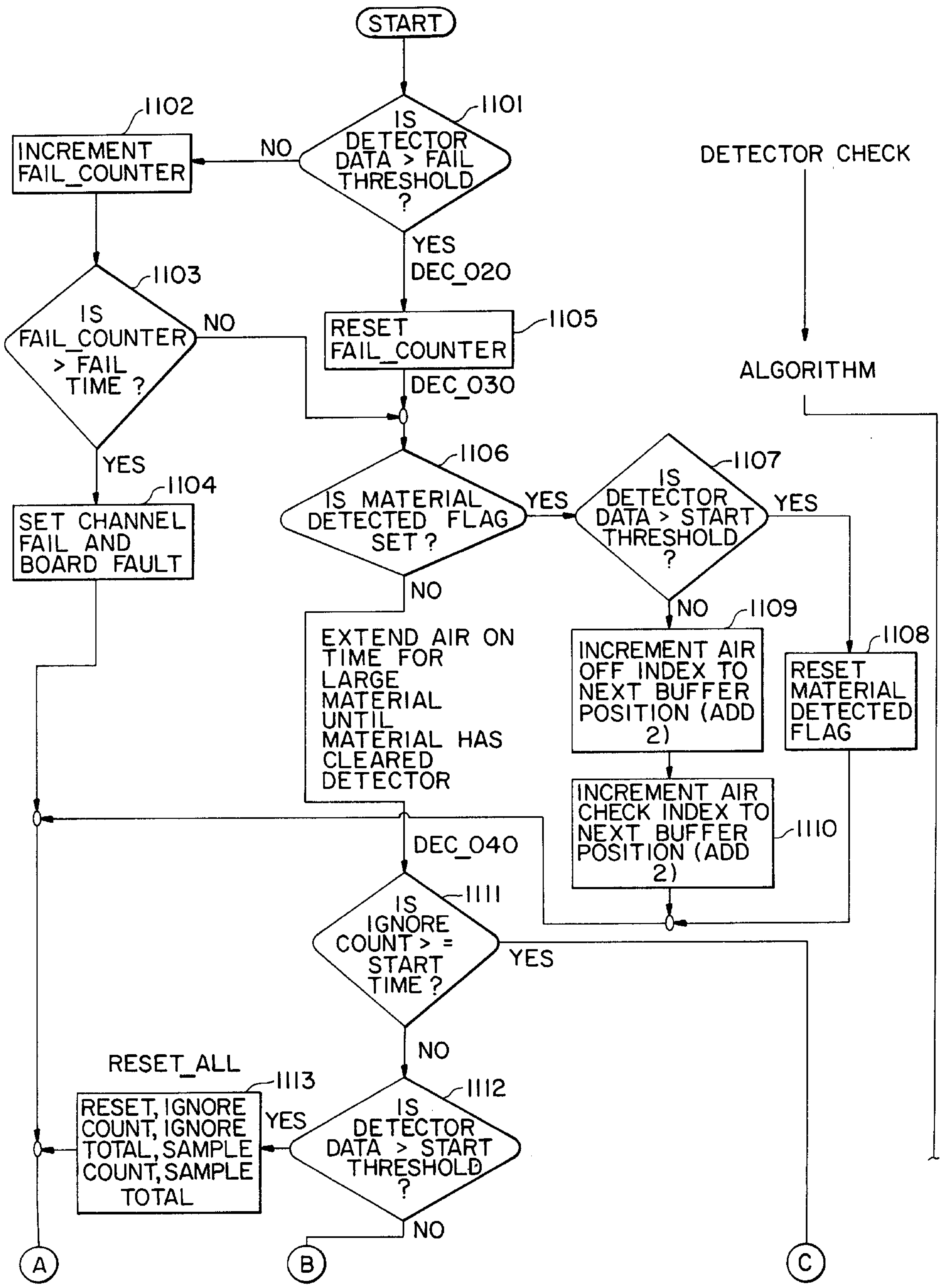

START
FOREGROUND TASK
1001
IS UPDATE HISTORY FLAG SET ?
NO
YES
1003
INCREMENT TOTAL HOURS
1005
STORE HISTORY DATA IN EEPROM
1007
DID ERROR OCCUR ?
NO
YES
1009
SET ERROR CODE 20
1011
HAS REQUEST BEEN RECVD FROM REMOTE COMPUTER ?
NO
YES
1013
PROCESS REMOTE COMPUTER REQUEST

FIG. 11a


START
1101
IS DETECTOR DATA > FAIL THRESHOLD ?
NO
1102
INCREMENT FAIL_COUNTER
1103
IS FAIL_COUNTER > FAIL TIME ?
NO
YES
1104
SET CHANNEL FAIL AND BOARD FAULT
YES
DEC_020
1105
RESET FAIL_COUNTER
DEC_030
1106
IS MATERIAL DETECTED FLAG SET ?
YES
1107
IS DETECTOR DATA > START THRESHOLD ?
YES
NO
1109
INCREMENT AIR OFF INDEX TO NEXT BUFFER POSITION (ADD 2)
1108
RESET MATERIAL DETECTED FLAG
INCREMENT AIR CHECK INDEX TO NEXT BUFFER POSITION (ADD 2)
1110
NO
EXTEND AIR ON TIME FOR LARGE MATERIAL UNTIL MATERIAL HAS CLEARED DETECTOR
DEC_040
1111
IS IGNORE COUNT > = START TIME ?
YES
NO
1112
IS DETECTOR DATA > START THRESHOLD ?
YES
RESET_ALL
1113
RESET, IGNORE COUNT, IGNORE TOTAL, SAMPLE COUNT, SAMPLE TOTAL
NO
A
B
C
DETECTOR CHECK
ALGORITHM

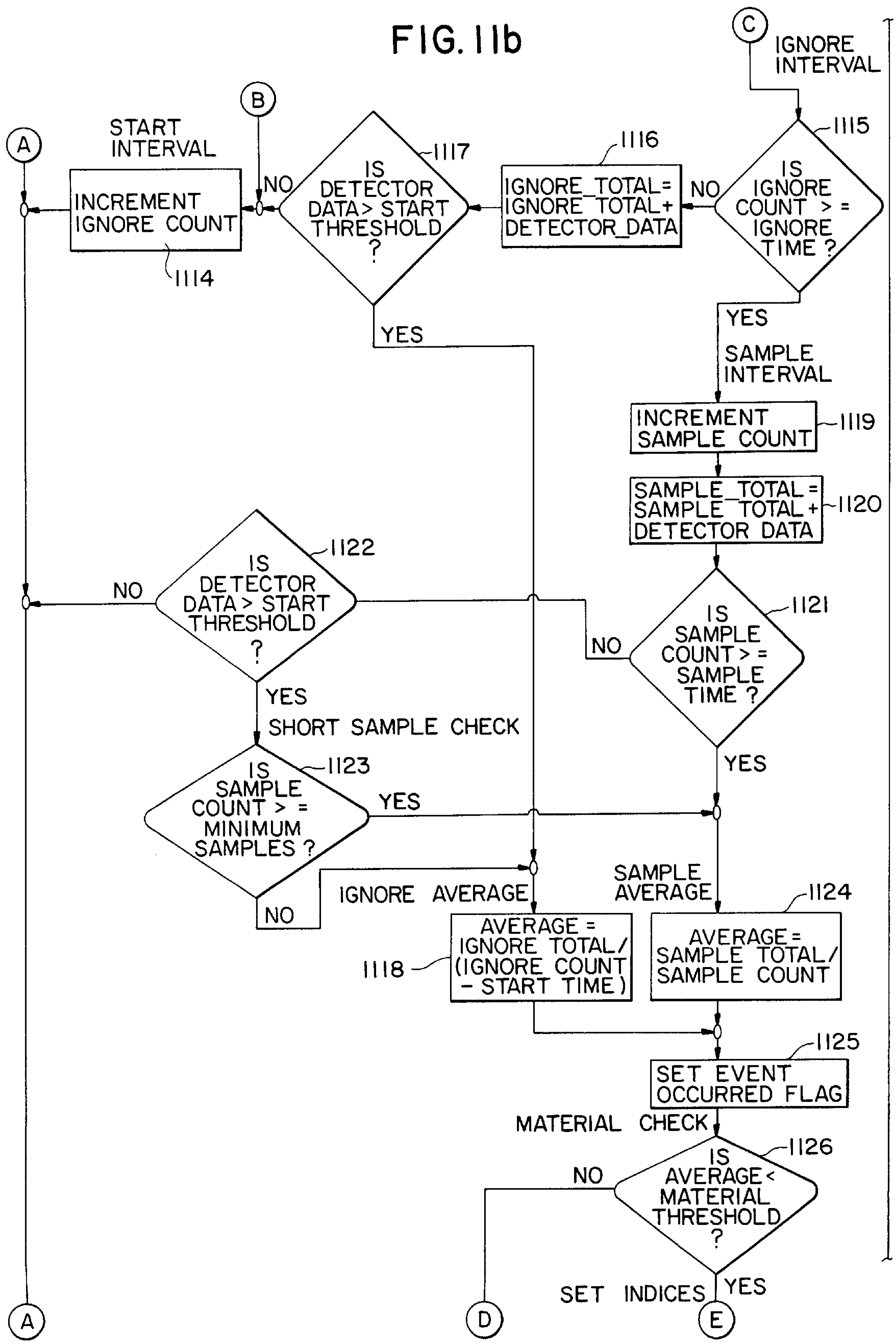
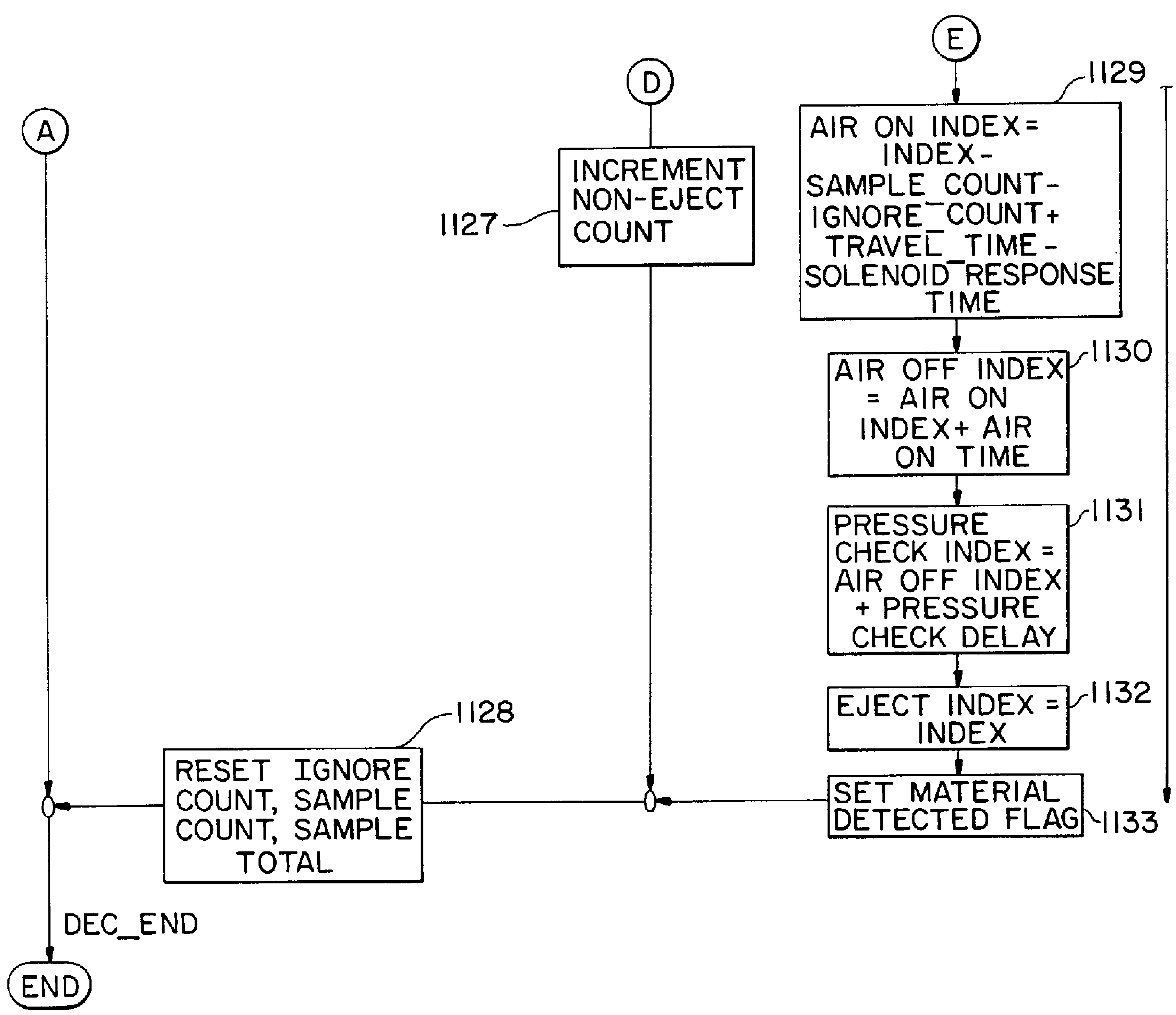


FIG. 11b
C
IGNORE INTERVAL
IS IGNORE COUNT > = IGNORE TIME ?
1115
NO
IGNORE_TOTAL= IGNORE_TOTAL+ DETECTOR_DATA
1116
IS DETECTOR DATA > START THRESHOLD ?
1117
B
NO
INCREMENT IGNORE COUNT
1114
START INTERVAL
A
YES
SAMPLE INTERVAL
INCREMENT SAMPLE COUNT
1119
SAMPLE_TOTAL = SAMPLE_TOTAL + DETECTOR DATA
1120
IS SAMPLE COUNT > = SAMPLE TIME ?
1121
NO
IS DETECTOR DATA > START THRESHOLD ?
1122
NO
YES
SHORT SAMPLE CHECK
IS SAMPLE COUNT > = MINIMUM SAMPLES ?
1123
YES
NO
IGNORE AVERAGE
SAMPLE AVERAGE
AVERAGE = IGNORE TOTAL/ (IGNORE COUNT - START TIME)
1118
AVERAGE = SAMPLE TOTAL/ SAMPLE COUNT
1124
SET EVENT OCCURRED FLAG
1125
MATERIAL CHECK
IS AVERAGE < MATERIAL THRESHOLD ?
1126
NO
YES
SET INDICES
D
E
A

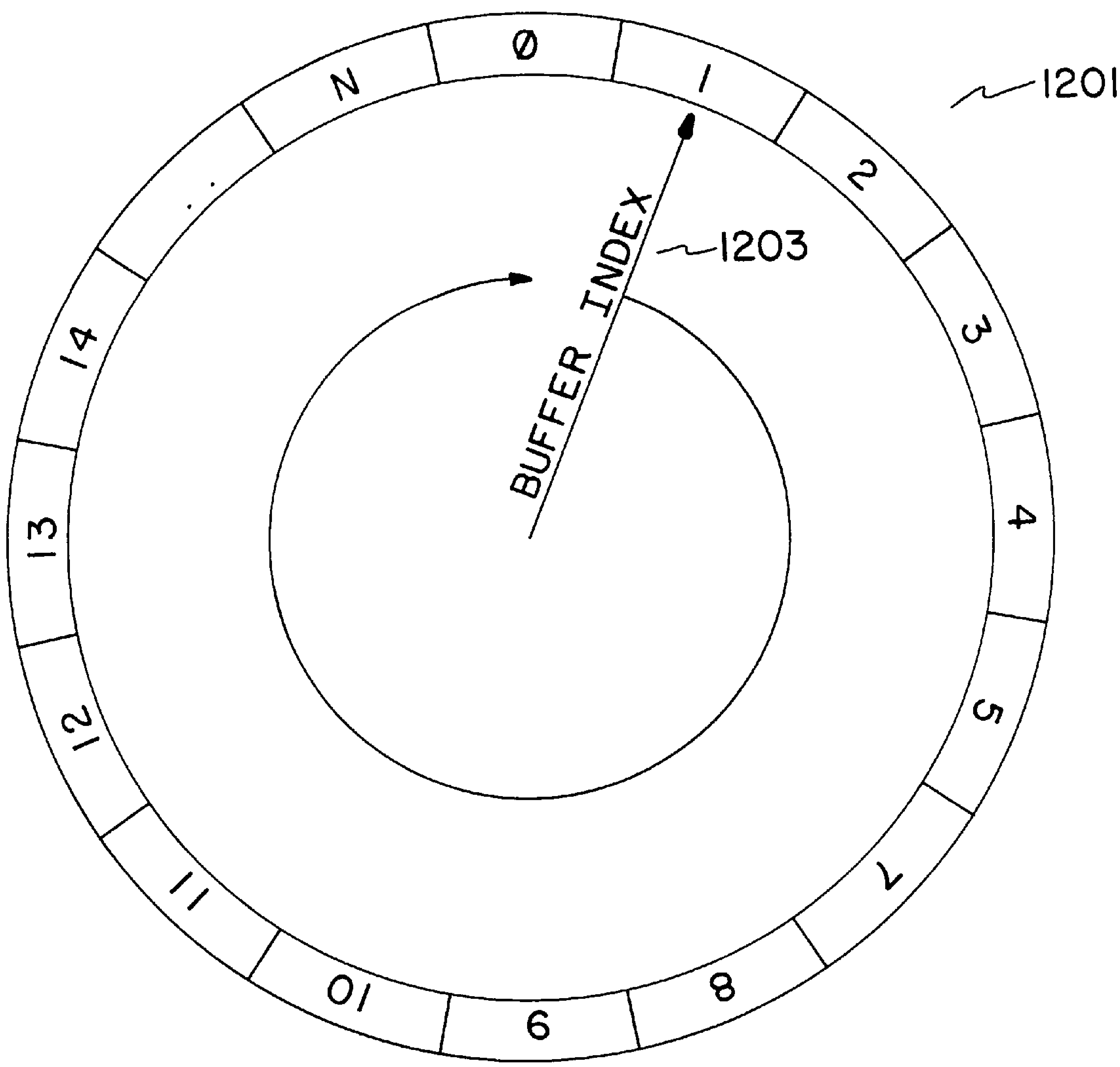
FIG. 11c



A
D
E
INCREMENT NON-EJECT COUNT
1127
1129
AIR ON INDEX= INDEX- SAMPLE_COUNT- IGNORE_COUNT+ TRAVEL_TIME- SOLENOID_RESPONSE TIME
1130
AIR OFF INDEX = AIR ON INDEX+ AIR ON TIME
1131
PRESSURE CHECK INDEX = AIR OFF INDEX + PRESSURE CHECK DELAY
1132
EJECT INDEX = INDEX
1128
RESET IGNORE COUNT, SAMPLE COUNT, SAMPLE TOTAL
SET MATERIAL DETECTED FLAG
1133
DEC_END
END

FIG. 12

DETECTOR AND TRANSDUCER CIRCULAR DATA BUFFERS



METHOD AND APPARATUS FOR SORTING MATERIALS USING ELECTROMAGNETIC SENSING

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

This is a continuation-in-part of U.S. patent application Ser. No. [07/605,933] *07/605,993* filed Oct. 29, 1990 now U.S. Pat. No. [5,269,576] *5,260,576.*

This invention was made with Government support under Contract No. 68D80025 having an effective date of Aug. 18, 1988, awarded by the Environmental Protection Agency. The Government has certain rights in this invention.

The disclosed invention classifies materials by utilizing the tendency of penetrating electromagnetic radiation to pass through differing materials with differing levels of attenuation within the materials according to their chemical properties. The invention provides for separation of the differing materials from each other according to the amount of radiation passing through them. More specifically, penetrating electromagnetic radiation is used to simultaneously scan multiple material items as they pass through a region of radiation. Analysis of the measured radiation passed through differing portions of the body of each item is used to classify each item and activate means for separating from each other items which have differing chemical properties.

It is well known that for materials having similar thicknesses, those materials comprised of elements having a lesser atomic number generally allow a greater degree of penetrating electromagnetic radiation to pass through them then do those materials comprised of elements having a greater atomic number. Additionally, it is also well known that for materials having similar chemical properties, those materials of lesser thickness generally allow a greater degree of penetrating electromagnetic radiation to pass through them than do those materials of greater thickness. Therefore materials of differing chemical properties can be selected according to the amount of penetrating electromagnetic radiation passing through them, if differences in thicknesses of the materials have relatively less effect on the transmission of penetrating electromagnetic radiation through them than do differences in chemistry.

In the recycling of waste or secondary materials it is very useful to be able to separate mixtures of materials into usable fractions, each having similar chemical properties. For instance it is useful to separate plastic materials from glass materials, to separate metals from nonmetals, to separate differing plastics from each other, and to separate dense materials from less dense materials. There are many other such useful separations practiced in industry using many different methods which are too numerous to enumerate herein.

It has been found that in separating mixtures of materials for recycling, the disclosed invention is very effective at distinguishing and separating items of differing chemical composition. Mixtures containing metals, plastics, textiles, paper, and/or other such waste materials can be separated, since penetrating electromagnetic radiation typically passes through the items of different materials to differing degrees. Such mixtures occur frequency in the municipal solid waste recycling industry and in the secondary materials recycling industries. An example is the separation of aluminum beverage cans from mixtures containing such cans and plastic containers. Such mixtures are commonplace in curbside recycling programs. Another example is the separation of chlorinated plastics (a source of corrosive gasses when burned) from a municipal solid waste mixture to provide a less polluting fuel for municipal waste incineration.

It has also been found that the invention is useful for separating chlorinated plastics from mixtures containing nonchlorinated plastics, since it has been found that chlorinated plastics typically allow less transmission of penetrating electromagnetic radiation than do nonchlorinated plastics. Such separation renders each of these plastics more valuable for recycling. Such mixtures of plastics are commonplace in municipal waste recycling programs. Until now such separations have been performed using methods which are cumbersome and slow, thereby limiting their usefulness. For instance in the United States, the manufacturers of plastic containers for consumables have recently begun molding a numerical identification code into the base of the containers. The code indicates chemical composition, such as polyolefins, polyesters, or vinyls (polychlorinated plastics). Using these codes, the plastics can be manually hand-sorted from each other. However, this method is slow, labor intensive, and expensive and has not found widespread use for these reasons.

There exist three known processes for automated separation of chlorinated plastics from mixtures of plastics according to their response to electromagnetic radiation. One of these processes is disclosed in European patent application No. 88107970.1 of Giovanni, filed May 18, 1988, and published on Nov. 23, 1988. Another process is disclosed in U.S. Pat. No. 4,884,386, issued to Gulmini Carlo on Dec. 5, 1989. The third process is known as the Rutgers process.

Each process requires that items in the mixture be placed singly into a radiation chamber, following which placement measurements are made to classify the plastic item according to its response to an electromagnetic radiation beam. Subsequently the plastic item is directed to a destination according to its chemical composition. After this sequence is completed, another plastic item is fed into the radiation region and the sequence is repeated. This requirement for operation with single items necessitates elaborate equipment for singly selecting items from the mixture and placing them one at a time into these separators. Furthermore, since the plastics are required to be single classified one after another, the methods are limited in throughput because of the finite time required to execute the sequence for each item.

Typical plastic containers for consumables are manufactured with thicker walls at the neck and base than in their central portions. Such plastic containers, when flattened for storage or shipping reasons during recycling, typically contain folds incurred during the flattening process. Necks, caps, bases and fold give rise to significant variations in total material thickness presented to a penetrating electromagnetic radiation beam. It has been found by the inventors that utilizing measures of radiation transmission through the neck, cap, base, or a folded region of a plastic container can give inaccurate results in attempting to classify the chemical composition of the container due to these variations in total material thickness.

SUMMARY OF THE INVENTION

It has been found that the disclosed invention surmounts the above mentioned limitations and provides efficient high volume separations by allowing plastic materials to be fed multiply and in a continuous manner without regard to orientation into a common region of penetrating electromagnetic radiation. Simultaneous measurements are made on all items as they move through the region of radiation, in order to distinguish and classify each plastic item according to its chemical properties and thicknesses. The items are then simultaneously directed to different destinations, according to their chemical properties and thicknesses. As a result of this capability of operation with multiple items, the disclosed invention operates at a significantly greater throughput rate than the aforementioned processes and requires no specialized means for singly placing materials into the radiation region.

We have found that, in practice, taking a measurement through only a relatively thin cross section of an item required detailed knowledge of the geometry and orientation of the item (such as a container). Accordingly, placement of an item between a radiation source and a radiation detector, such that radiation passing through only a relatively thin cross section is measured, requires sophisticated and expensive materials handling means. However, our invention overcomes this limitation. We have found that use of high speed electronic signal processing circuitry to analyze a group of separate measurements taken through differing portions of the body of an item to be classified as its passes between the radiation source and radiation detector allows selection of only those measurements of greater transmission rate for use in classifying the item. Therefore specialized placement and orientation of the item between the source and detector is not required.

Accordingly it has been found that the method of the disclosed invention of acquiring multiple separate measurements of radiation transmitted through different portions of the body of an item to be classified and using high speed signal processing circuitry to identify and use only those measurements of highest transmission rate through the item to classify the item overcomes uncertainties in classification arising from variations in total thickness of the item. It is noted that with our invention other signal processing algorithms which correlate the separate measurements taken on an item could also be used such as, for example, averaging the measurements or averaging the selected measurements.

The disclosed invention employs an improved method for distinguishing, classifying and separating mixtures of material items which comprises:

(a) conveying the items multiply and in a continuous manner through a radiation region or zone of penetrating electromagnetic radiation,

(b) irradiating the multiple items simultaneously with penetrating electromagnetic radiation as the items pass through the radiation region,

(c) simultaneously acquiring for the multiple items a group of separate measurements for each item, each measurement within a group being a measurement of the amount of penetrating electromagnetic radiation passing through a different portion of the body of an item, and

(d) simultaneously directing the multiple items each to a destination determined by analysis of the group of measurements of the amount of transmission of penetrating electromagnetic radiation passing through each item.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention shall be described with particularity by reference to the appended drawings in which:

FIG. **1** is a front perspective view of the apparatus for the separation of materials using penetrating electromagnetic radiation, made in accordance with this invention, in which two sets of material items are being processed and separated;

FIG. **2** is an enlarged front elevation of the apparatus disclosed in FIG. **1**, illustrating a single item of the first set and a single item of the second set being moved over the slide conveyor;

FIG. **3** is a side elevation of the apparatus disclosed in FIG. **2**, illustrating one uncrushed item of one set and one crushed item of a second set of the material from moving over the slide conveyor;

FIG. **4**-A is a graphic illustration of a crushed polyester plastic container, typical of a first set of material items to be classified, and a graph illustrating the transmitted radiation measurements at various longitudinal portions of the container;

FIG. **4**-B is a graphic illustration similar to FIG. **4**-A illustrating a crushed PVC (polyvinyl chloride) container, and a graph illustrating corresponding measurements of transmitted radiation along the container; and

FIG. **5** is a block circuit diagram of the electronic signal processing circuitry.

FIGS. **6**a–**6**h illustrate the steps performed in an initialization sequence of a system according to the invention;

FIGS. **7**a–**7**d illustrate the steps performed in a timer interrupt routine for a system according to the invention;

FIGS. **8**a–**8**b illustrate steps performed in a detector analog to digital conversion interrupt routine in a system according to the invention;

FIGS. **9**a–**9**b illustrate steps performed in a pressure transducer interrupt routine in a system according to the invention;

FIG. **10** illustrates the steps performed in a foreground routine in a system according to the invention;

FIGS. **11**a–**11**c illustrate steps performed in a detect/eject algorithm routine of a system according to the invention;

FIG. **12** illustrates a circular buffer as used in the invention.

DESCRIPTION OF THE EMBODIMENTS

According to the invention, materials having different electromagnetic radiation absorption and penetration characteristics are separated. First, the materials are conveyed along a plurality of channels from at least one inlet toward a plurality of outlets through a source of electromagnetic radiation. Portions of the materials conveyed are radiated with the electromagnetic radiation. A predetermined sequence of detectors is periodically polled. Each detector corresponds to a channel. The polling includes sampling for a predetermined sample time with the detectors the electromagnetic absorption and penetration characteristics of the material portions radiated. In response to the electromagnetic radiation absorption and penetration characteristics measured by the detectors, material ejection mechanisms are activated at different times, so that materials having different electromagnetic radiation absorption and penetration characteristics are ejected at different times and locations on the conveyor into different sorting bins. In addition, the system allows simultaneous operation of different system mechanisms, so that operations of the material ejection mechanisms can be verified prior to polling the channel detector corresponding to the material ejection mechanism. Thus, it is not necessary to verify operation of all material ejection mechanisms before beginning polling. It is only necessary that the corresponding channel be verified prior to initiation of polling in that channel.

The ejection mechanisms are air pressure ejectors which produce air pressure data that can be measured by sensors and stored in a sequence identical to the sequence of the detectors polled. A fault can be indicated if the air pressure data measured and stored is less than a predetermined minimum.

It is also useful to ignore a portion of each item of material to be separated. Therefore, an ignore time is counted from a time when a detection is made, so that although sampling takes place during this ignore time, the data is set aside for consideration only in special cases. One such case is where the material sampled is of too small a size to permit entry into a sample interval following the ignore time. When sampling is initiated after the ignore time, the outputs of the detectors are sampled a plurality of times during the sample interval and a sample average is determined from the detector outputs and a count of the number of samples during the sample interval. The average is compared to a predetermined material threshold. This material threshold is a ratio equal to a predetermined amount of radiation transmitted through the material divided by the amount of radiation transmitted without the material present in the path between the radiation source and the detector. When the average is less than the predetermined material threshold, an air-on index is set to activate the air ejection mechanism at a time and for a duration based on the sample count, the ignore count, the amount of time it takes for the material to go from the detectors to the air pressure ejection mechanism and a response time of a solenoid which activates the individual air ejection mechanisms. By measuring and storing air pressure data from each ejection mechanism in a separation identical to the sequence of the detectors polled, a fault can be indicated if the air pressure data measured is less than a predetermined minimum.

The system also includes a processor which controls the system operation and performs an initialization sequence. In the initialization sequence, variables are initialized and the number of detectors is compared with the number of ejection mechanism for one to one correspondence. High and low limits of detection and ejection mechanisms can be tested and operation of fault indicators, verified In addition, the total operation time, a system history and a record of errors can be provided. This is accomplished by periodically interrupting detection processing to store such information.

To carry out these functions, the system has an acceleration slide, an electromagnetic radiation source arranged above the acceleration slide, a plurality of detectors, with each detector corresponding to a channel, for measuring electromagnetic absorption and penetration characteristics of material portions radiated, and a means for periodically polling a predetermined sequence of the detectors. Polling means includes a sampler which is arranged to sample the detectors a plurality of times for a sample time. Ejection mechanisms, e.g., air pressure ejectors, are activated by an activating means at different times as the materials are conveyed so that materials with different electromagnetic radiation absorption and penetration characteristics are ejected at different locations on the acceleration slide into different sorting bins. Control is achieved with a processor which maintains a current index. The current index represents a pointer in a circular buffer and identifies a location in memory where current information is stored.

In the disclosed apparatus **10** in FIGS. **1–3**, the source of penetrating electromagnetic radiation may be either an X-ray source, a microwave source, a radioactive substance which emits gamma rays, or any other source of electromagnetic radiation, such as the X-ray tube **11**, whose rays penetrate through a class of materials to be separated from a mixture of materials. The preferred wavelength of radiation to be used depends upon the physical and chemical properties of the items **13** and **14** to be separated, since the amount of transmission through the items is dependent upon these factors. It is preferred to use wavelengths which result in transmissions of 10% to 90% of incident radiation passing through the items **13** and **14** to be separated, although other wavelengths could be used. Radiation detectors **15** should be selected to be optimally sensitive to the radiation wavelengths used. The detectors should be of high speed response, preferably with a response time of one millisecond or less to allow for accurate measurement with high throughput rates of items to be separated.

FIG. **1** is an illustration of the apparatus **10** in operation. A mixture of two types of materials **13** and **14** to be separated are delivered to the apparatus **10** via a feed conveyor **17**. Conveyor **17** is selected so as to deliver the mixture of materials **13** and **14** in uniform fashion across the width of an acceleration slide **18**. The acceleration slide **18** is positioned at a declining angle to the horizontal such that the mixture of items **13** and **14** upon it will move down the slide **18** under the influence of gravitational force, preferably accelerating to increasing speeds as the items **13** and **14** progress down the slide **18**, causing the items to spread during their descent. As shown in FIG. **2**, at the lower end portion **19** of the slide **18** is an array **20** of radiation detectors **15** positioned so that they span the width of the slide **18**. The detectors **15** are spaced apart so that any item **13** or **14** in the mixture to be separated cannot pass over the array **20** without passing over at least one detector **15**.

Positioned above the detector array **20**, as illustrated in FIG. **1**, is a collimated source **11** of penetrating electromagnetic radiation. Source **11** delivers a sheet-like beam of radiation which falls incident upon the width of the acceleration slide **18** in an area strip or radiation zone **22** containing the radiation detector array **20**, such that as items **13** and **14** of the mixture pass through this beam. They pass between the radiation source **11** and the detector array **20**. Spaced downstream from the lower end **19** of the acceleration slide **18** is a splitter **24** for segregating separated materials **13** and **14**, which then fall onto conveyors **25** and **26** placed on the two opposite sides of the splitter **24** for conveyance away from the apparatus **10** to remote discharge areas, not shown. Of course additional splitters and sorting bins or other suitable discharge apparatus can be employed.

Each detector **15** in the array **20** is connected to an electronic signal processing circuitry **28** as depicted in FIGS. **2** and **3**, through leads **29** and branch leads **30**. The circuitry **28** is connected to an electromagnetic air valve **32** through lead **33**. The air valve **32** connects a reservoir **34** of compressed gas or air to an air nozzle **35** located directly downstream from each corresponding detector **15**. Each detector **15**, in combination with its associated circuitry, is capable of operating independently of any other detector **15**, together with its corresponding circuitry. Each air valve **32** and air nozzle **35** combination is capable of operating independently of any other air valve **32** and its corresponding air nozzle **35**. In the apparatus **10** shown in FIG. **3**, each detector **15** and its associated circuitry is connected to a single air valve **32** and combination air nozzle **35**, although in practice one or more adjacent detectors **15** and its associated circuitry may be connected to one or more air valves **35**, in order to feed one or more air nozzles **35** which span the width of the corresponding adjacent detector **15**.

In operation, signals are picked up by the detectors **15** and transmitted to signal acquisition, analog, and digital conversion circuitry **505**. These signals are then transmitted to a microprocessor analyzer, such as controller **513**, to identify the region of least thickness in the materials treated. The analyzer then determines if that signal meets the criteria for the material to be selected and energizes ejection mechanisms, such as air valve circuitry to either activate the air valve **32** or not.

As a material item **13** or **14** to be separated passes over the detector array **20** it passes between the radiation source **11** and one or more detectors **15**. Each detector **15** takes multiple measurements of the intensity of radiation passing through differing portions of the body of the item **13** or **14** as it passes over the detectors **15**. These measurements are analyzed by the electronic signal processing circuitry **28** connected to each detector **15**, applying selection algorithm to identify the item as being of Type A or Type B, such as **13** or **14**. If, in the case depicted, the item **13** is identified as Type A, no action is taken and the item **13** falls off the end of the slide **18** and onto the Type A item conveyor **25**. If the item identified as **14** is Type B, then the corresponding air valve or air valves **32** are activated at the appropriate time to cause an air blast **37** (FIG. **3**) to be emitted from the appropriate air nozzles **35**, so as to eject the item **14** away from the end of the slide **18** and over the splitter **24** so that the item **14** falls onto the Type B item conveyor **26**.

As many items **13** or **14** as there are air nozzles **35** can be separated simultaneously in this manner. In the apparatus **10** depicted, up to eight items can be separated simultaneously, since eight nozzles **35** are illustrated in the drawings. We have found that each detector **15**, circuitry **28**, air valve **32**, and air nozzle **35** combination currently used can operate upon as many as ten items per second. Thus, the illustrated embodiment of the apparatus **10** is ultimately capable of classifying up to eighty containers per second.

FIG. **4**-A depicts a typical flattened polyester plastic container **13** (Type A) which has a neck N, central portion C, and base B, and which contains a fold F caused by the flattening process. A typical graph of measurements of incident penetrating electromagnetic radiation transmitted through corresponding portions of the container is shown below the container **13** and positioned such that a measurement of transmitted radiation shown at a point along the graph corresponds to the portion of the container directly above the graph. (For example, measurement Mc is vertically below a point on central portion C.) It can be seen from the graph that in this example, radiation transmission rates of from 20% to 80% can be measured depending upon which portion of the container the transmission being measured through. Similarly from the graph of FIG. **4**-B PVC plastic container of similar geometry it can be seen that measurements of transmission rate from 5% to 40% can be obtained.

A problem arises if only a threshold comparator (such as disclosed in Giovanni) is used in an attempt to distinguish between the polyester and PVC containers. In order to reliably distinguish the PVC container **14** in the example of FIG. **4**-B, a classification threshold set at less than 40% transmission would risk failing to recognize the container as PVC if the measurement used was taken through a relatively thin cross section such as through an unfolded central portion of the container (which can easily occur if the container passes the radiation detector in an orientation such that the detector does not see a neck, cap, base, or fold). However, using a threshold comparator with the above mentioned 40% classification threshold or greater for PVC when examining a polyester container **13** as in FIG. **4**-A may cause the polyester container **13** to be misclassified as PVC if the container passes the detector in an orientation such that the detector sees a neck, cap, base, or fold, since some of these measurements show a transmission rate of less than 40%, which would trip the threshold comparator by its nature of operation.

Because of possible misclassifications arising from these types of signal overlap, we have determined that in general the most reliable measurements for making a classification are those measurements taken through those portions of the body of an item to be classified which exhibit the greatest rates of transmission of radiation through the item (such as those taken through a relatively thin cross section such as through an unfolded central portion of the container).

A processor, such as either a central or distributed master computer, can implement system operation in accordance with the flow diagrams shown in FIGS. **6–11**. Detection and ejection circuitry may also be located on one or more remote boards, which may include remote processors or computers. FIGS. **6–11** illustrate a system with four channels and a corresponding number of detectors and material ejectors. However, this is by way of illustration and not limitation, as it will be clear to those of ordinary skill that any number of channels and corresponding detectors and material ejectors can be employed.

The block diagram in FIG. **5** illustrates that external inputs are provided by detectors **501** to detector signal conditioning and amplification circuits **503** in analog section **505**. Detector sample and hold circuits **507** sample and hold the outputs of the detector signal conditioning and amplification circuits **503**. Sample and hold circuits **507** provide the conditioned signals to the analog multiplexer **509**. As FIG. **5** illustrates, each channel has its own detector and sample and hold circuit. Multiplexer **509** operates under the control of microcontroller **513**, which resides in digital section **515**. In response to microcontroller **513**, analog multiplexer **509** delivers one of the channel detector outputs to the A to D converter **511**. The digitized output from the A to D converter **511** is provided to microcontroller **513**. It should be noted that microcontroller **513** also controls the sampling performed by sample and hold detectors, as shown by signal line **517**. Signal line **517** also transmits information from microcontroller **513** to the pressure sensor sample and hold devices **519**. These pressure sensor sample and hold circuits are used to sample the operation of the air valve pressure sensors **521** as buffered by signal conditioning circuits **523**. The outputs of sample and hold circuits **519** are transmitted to microcontroller **513**, as illustrated in FIG. **5**. Microcontroller **513** also communicates in a bi-directional manner with three memory devices. EEPROM **525** stores system parameters. EPROM **527** stores a program which operates microcontroller **513**. RAM **529** stores digitized data. It should be noted that the microcontroller operates channel OK indicators **531**. Output section **533** contains air valve drivers **535** which are operated by outputs by the microcontroller **513**. The air valve drivers are used to control the air ejection mechanism to provide air pressure that is used to eject material into the correct bin after material has been irradiated and scanned by the detectors. FIG. **15** also illustrates several auxiliary functions. One is system shut down output **537** and another is serial communications interface **539**, which can be routed to a monitor computer. In addition, manual fire switch debounce logic **541** can also be used to manually active the air valve drivers **535** by activation of the corresponding fire channel switch **543**.

The detector software such as that resident on a remote detector board, utilizes circular buffers to store data. Each channel uses two circular buffers. One is used to store the data for detectors while the other is used to store data for the pressure transducers. A circular buffer **1201** having N positions is shown in FIG. **12**.

At initialization the buffer index **1203** is set to point to buffer position **0**. When the first data point is read, it is stored in position **0**. The buffer index **1203** is then incremented to the next buffer position. Widen the next data point is read, the data is stored in the circuit buffer at the position indicated by the buffer index. Again the buffer index is incremented to the next buffer position. This process continues until the buffer index reaches the end of the buffer (position N). At this time the buffer index is set to position **0**. This is effect creates a first-in-first-out circular buffer that maintains a history of the most recent N data points which are used by the detect/eject algorithm to determine plastic types, as described herein.

The circular buffer **1201** is also used to indicate relative points in time. This is critical to the proper timing of eject and pressure measurement events. When used as a relative time clock, the buffer index **1203** is analogous to the minute hand on a clock. Events are scheduled to occur at specific points in the buffer, just as one might schedule an event, for example, at 15 minutes after the hour. When the buffer index **1203** points to the scheduled position, the event is performed. This is how the air-on and air-off indices are handled. Once it has been determined that material is to be ejected, the specific point in time to cause the ejection is calculated using the methods shown in the flowcharts of FIGS. **6–11**. This point is marked on the circular buffer (relative time clock) as the air-on index. Once the air-on index is determined, the air-off index is calculated and likewise marked in the circular buffer. When the buffer index points to the buffer marked as the air-on index, a solenoid valve is energized to initiate the flow of air used to eject material. When the buffer index points to the buffer position marked as the air-off index, the solenoid valve is deenergized, interrupting the flow of air. Of course, this method could be employed to activate and deactivate any material ejection mechanism. In addition, the circular buffer can be used as an index for any relatively timed events in the system.

Thus, the circular buffer used by the detector board software is designed to store the more recent N data points measured, as well as function as a relative time clock to schedule events accurately. The use of the circular buffer provides an efficient method of handling data storage and time scheduling activities, which can be very intensive if implemented using other conventional approaches.

As previously mentioned, a processor, such as microcontroller **513**, can be used to direct operation of the system. In the initialization sequence shown in FIGS. **6**a–**6**h the system can be checked so that overall system operation or individual channel operation can be verified and appropriate indicators illuminated. Steps **601** and **603** initialize processor functions and variables, respectively. To assure that the program code is operational, a checksum test is performed in step **605**. Since the correct program code is necessary for system operation, if step **607** determines that the checksum test was not passed, control is routed to block **609**, which causes all the channel OK lights to blink on and off permanently until the error is corrected. Assuming the checksum test did pass, then a read/write test is performed on a first portion of random access memory in step **611**. This assures that the first 8K of the RAM is operational. If the test does not pass as determined in step **613**, an error code **4** is set in step **16** and the test mode is entered in step **617**. If the test did pass, then the second RAM is subjected to a read/write test in step **619**. If this test does not pass, then step **621** sets a different error code in step **623** and the test mode in step **617** can again be entered.

The system can operate in two modes. In the first mode, the detectors are independent, while in the second mode the detectors are paired for the purpose of measuring the speed of the objects on the conveyor. The mode can be set by a DIP switch whose position is read in step **625**. In step **627** a number of detectors variable is set as required by the switch setting. If step **629** determines that the detectors are not independent, step **631** sets the variable indicating the detectors are paired to measure speed. In this case, detectors **1** and **2** are paired, detectors **3** and **4** are paired, etc. On the other hand, if the detectors are independent, the variable is set indicating the detectors are independent as indicated in step **633**.

As previously indicated, the number of detectors and the number of pressure transducers is typically the same. FIG. **6**b shows that positions **1–2** of the DIP switch indicate the number of detectors connected to the board. Switch positions **3** and **4** determine the number of pressure transducers connected to the board. The number of pressure transducers must be equal to the number of detectors, unless the detectors are not independent, in which case more than one detector is used to activate an ejection mechanism. It is also possible to combine multiple detection channels into a single ejection channel. Thus, in step **635** the number of pressure transducers is set as required by the switch setting.

In step **637**, the controller determines if the test mode is selected. If this is the case, test mode is entered as step **617**. If not, in step **639** the input to detector number **1** is read and recorded as a lower limit. This is done with the electromagnetic radiation source (e.g., X-ray source) turned off. If the level is not correct as determined in step **641**, a channel fault flag and corresponding error code is set as shown in step **643**. In step **645**, the number of detectors is tested to determine if the detectors have been exhausted. Steps **646–656** illustrate corresponding steps performed for four channels. As previously mentioned, any number of channels can be implemented. It should also be noted that an error code corresponding to a failure in a particular channel can be set.

Step **657** illustrates that a next step in the initialization sequence is determining if the reference amplitude for the A/D converter is correct. If this is not the case, as determined in step **658**, an error code is set in step **659** and the test mode is entered via step **617**. If the amplitude is correct then, in step **660**, the controller commands the input of the first pressure transducer to be read and recorded as a lower limit. If the level is not correct as determined in step **661**, then an error code for that channel is set in step **662** and step **663** tests to determine if the number of transducers has been exhausted. Steps **664** through **674** perform corresponding tests for the remaining channels.

If step **675** determines that any faults are set, then the channel OK lights for channels without faults are activated in step **676** and test mode is entered via step **617**. If no faults have been set, then the board fault light is turned off in step **677** to allow system initialization to continue and to permit activation of the electromagnetic radiation source.

Steps **678–680** are used to determine if a request has been received from a remote computer to turn the electromagnetic radiation source on and if the request has been processed. Step **678** checks to see if the electromagnetic radiation source has been turned on. If it has, control is passed to step **681**. If the source has not been turned on, a serial interface is checked to see if a request has been made by the monitor or master computer for data from the board. Control is transferred from step **678** to **679** and **680** until the output of step **678** indicates that the electromagnetic radiation source should be turned on. When this occurs, step **681** activates a fifteen second delay. With the X-rays on, step **682**a reads detector number **1** and records the value read as an upper limit. Step **682**b tests if this level is OK. If not, step **682**c indicates a fault and sets a corresponding error code for the channel. Step **682**d then determines if the number of detectors has been exhausted. Steps **682**e–**682**o perform the same steps for each of the channels until the channels are exhausted. The processor then checks to determine in step **683**a if any faults have been indicated in channel **1**. If so, the corresponding fault light is turned on in step **683**b. If not, the channel OK light is turned on in step **683**c. This process is repeated until the channels are exhausted, as illustrated in steps **683**d–**683**l.

Step **684** then queries if any faults have been set. If so, the test mode is entered at step **617**. If not, step **685** sets a watch dog timer, which is used as a timing mechanism to verify the system does not become idle or (hang up) for any period of time.

Control then passes to step **687** which configures the interrupt system and enables the interrupts. As discussed below, the system is an interrupt driven system which employs a timing routine which activates interrupts to perform specific functions at specific times.

Step **688** performs the foreground task which is used to monitor flags set by various tasks, to save data in the EEPROM and to monitor the serial port for data requests from a remote computer.

The foreground task is illustrated in FIG. **10**. As just discussed, the primary functions of the foreground task are to monitor flags, errors and requests received from a remote computer. Step **1001** indicates that the only entry to the foreground task is through the update history flag. The foreground task monitors this flag to determine when the foreground task will perform the remaining steps. Thus, if the update history flag has not been set, control merely passes back to the same step **1001** and the flag is checked again.

Periodically, the update history flag is set. When this occurs, the total number of hours will be incremented in step **1003** and history data stored in EEPROM as shown in step **1005**. If no errors have occurred, as determined in step **1007**, the foreground task is complete. If an error has occurred, error code **20** is set in step **1009**. Step **1011** then determines if a request had been received from the remote computer. If this is not the case, processing is complete. If a request has been received from the remote computer, then that request is processed in step **1013** and the foreground task is complete.

As previously indicated, the system is interrupt driven from a timer routine. FIGS. **7**a–**7**d illustrate the steps in the timer interrupt routine which form the heart of system control. An interrupt occurs every one millisecond. Thus, step **701** resets the one millisecond timer. Next, the watchdog timer is reset in step **702**. Step **703** tests to determine if the electromagnetic radiation source is being commanded to generate radiation. If not, step **704** determines if the electromagnetic radiation source has just been turned off. If this is the case, the update history flag is set in step **705**, which will cause activation of the foreground routine as previously discussed. If this is not the case or when step **705** has set the history flag, control is transferred via step **706**.

If the electromagnetic radiation source is being commanded to generate, e.g. X-rays, then a detector hold signal on signal line **517** is set high to activate the sample mode. FIG. **7**a indicates that this can be accomplished by setting bit **3** of a I/O port of microcontroller **513**. However, any other means known to those of ordinary skill would also be acceptable and the notation in FIG. **7**a is by way of illustration and not limitation. In step **709** microcontroller **513** commands analog multiplexer **509** to select detector number **1**. In step **711** the hold signal is set low, which disables the sampling and enables the hold mode. This is accomplished by setting the same bit **3** of the I/O port to the low state. Microcontroller **513** next activates step **713** which causes A to D converter **511** to begin the A to D conversion of the output from multiplexer **509**. This analog to digital conversion is discussed below in more detail relative to FIGS. **8**a and **8**b.

While the detector analog to digital conversion takes place, microcontroller **513** sets the pressure sensor hold signal high on line **517** in step **715**. This enables the sample mode for the pressure transducers. In step **716**, the pressure transducer is selected so that samples of the first pressure transducer are obtained. In step **717** the hold signal is set low so that the pressure transducer analog to digital conversion in step **718** can begin. The pressure transducer analog to digital conversion is discussed in more detail below relative to FIGS. **9**a and **9**b.

It should be apparent that the detector and pressure sampling and analog to digital conversions take place simultaneously. In a preferred embodiment, there is a 30 microsecond delay from the start of the detector analog to digital conversion in step **713** and the setting of the pressure sensor hold signal high to enable the sample mode in step **715**. The processes continue in parallel. In the event that at the end of a cycle there is a conflict, priority is resolved for detector interrupts. However, the timer interrupt routine has highest priority.

For convenience, before completing our discussion of the timer interrupt routine in FIG. **7**b–**7**d, we will next discuss the detector analog to digital interrupt routine in FIGS. **8**a–**8**b. In steps **801** and **802**, the low and high bytes are read from the detector analog to digital converter **511** and are respectfully combined into a single word **803**. In step **804** the combined detector data is stored in a data buffer for that particular channel. Step **805** then transfers control to perform the detect/eject algorithm.

The detect/eject algorithm is illustrated in FIGS. **11**a–**11**c. In step **1101**, the detector data is test to determine if it exceeds a predetermined fail threshold. If not, in step **1102** a fail counter is incremented and, in step **1103**, the new value of the fail counter is tested against a predetermined fail time. If the fail counter exceeds the fail time, the a failure has been detected and step **1104** sets a fail and board fault for that particular channel. If the detected data exceeds the fail threshold in step **1101**, then the fail counter is reset in step **1105**.

Whether the fail counter is reset or the fail counter does not exceed the fail time, a material detected flag is tested in step **1106**. If the material detected flag is set, the detector data is next tested against a start threshold in step **1107**. If the detector data exceeds the start threshold, the material detected flag is reset in **1108** and the detect/eject algorithm is terminated. If the result of step **1007** is that the detector data does not exceed the start threshold then, in step **1109**, an air off index is incremented to the next buffer position in step **1109**. This is repeated in step **1110**. The detect/eject algorithm is then terminated. In summary, if the material detected flag has been set, but the detector data is beneath the start threshold, a large unit of material has been detected and it is necessary to extend the air on time until the material has cleared the detector. Thus, the air off index is moved several positions forward, so that the air pressure ejection mechanism remains turned on for an additional period of time.

As previously discussed, it is necessary to ignore a portion of the material being detected. Thus, when the material detected flag is not set in step **1106**, step **1111** determines if an ignore count is greater than or equal to a start time. If not, the detector data is tested to determine if it exceeds the start threshold in step **1112**. If it does, the "reset all" step **1113** resets the ignore count, an ignore total, the sample count, and the sample count total, and the detect/eject routine is estimated. On the other hand, if the ignore count is not greater than or equal to the start time, as determined by step **1111**, and the detector data does not exceed the start threshold, as determined by step **1112**, step **114** increments the ignore count and terminates the detect/eject algorithm.

When the ignore count is greater than or equal to the start time in step **1111**, in step **1115**, the ignore count is tested to determine if it is greater than or equal to a predetermined ignore time. If this is not the case, an ignore total is summed with its previous value and the detector data is tested to determine if it exceeds a start threshold in step **1117**. If this is not the case, the ignore count is incremented in step **1114** and the detect/eject algorithm is terminated. If, on the other hand, the ignore count is greater than or equal to the start time, but is not greater than or equal to the ignore time, and the detector data exceeds the start threshold, then an ignore average is calculated in step **1117** to equal the ignore total divided by the difference between the ignore count and the start time.

If the ignore count is greater than or equal to the start time, as determined in step **1111**, and greater than or equal to the ignore time, as determined in step **1115**, a sample interval can begin. In step **1119**, the sample count is incremented. The sample total is determined to be the previous sample total plus the detector data in step **1120**. In step **1121** the sample count is tested against a predetermined sample time. If the sample count is not greater than or equal to the predetermined sample time, then in step **1122** the detector data is tested against the start threshold. If the detector data does not exceed the start threshold, the detect/eject algorithm is terminated. On the other hand, if the result of step **1122** is that the detector data is greater than the start threshold, a short sample check is indicated. In step **1123** the sample count is tested to determine if it is greater than or equal to the minimum number of samples. If this is not the case then an ignore average is calculated in step **1118**, previously discussed.

If the sample count is greater than or equal to the minimum number of samples or, if in step **1121** the sample count is greater than or equal to the sample time, then a sample average is calculated in step **1124**. The sample average is the sample total divided by the sample count.

Whether an ignore average is calculated in step **1118** or a sample average is calculated in step **1124**, an event occurred flag is set in step **1125**. A material check is then initiated. Step **1126** determines if the calculated average is less than a predetermined material threshold. If this is not the case, then a non-eject count is incremented in step **1127** and in step **1129** the variables ignore count, sample count, and sample total are reset. If the calculated average is less than the material threshold in step **1126**, indices are then set. In step **1129** the air on index, which indicates when the ejection air will be turned on, is set to a value equal to the present index minus the sample count, minus the ignore count, plus the time required for the material to travel from the detector to the ejection mechanism, minus the response time for the solenoid to activate the ejection mechanism. In step **1130**, an air off index is calculated to determine when the ejection air will be turned off. This is calculated to equal the sum of the air on index and the air on time. In step **1131**, a pressure check index, which is used to determine the time when the air pressure will be checked, is calculated. The pressure check index is equal to the air off index plus the pressure check delay time. The eject index is then set to the current value of the index in step **1132** and, in step **1133**, the material detected flag is set. The use of the material detected flag in step **1106** was previously discussed.

Upon completion of the routine to perform the detect/eject algorithm, control then returns to step **806** in which the detector buffer index is incremented. Essentially, the detector buffer index is an index to the circular data buffer. In step **807**, if the index is greater than the detector buffer size, the detector buffer is set equal to zero in step **808** and, in step **809**, the current detector number is incremented. Step **810** then tests to determine if the current detector number exceeds the total number of detectors. If this is the case, step **811** sets the current detector to zero and control returns to the timer routine at step **713**.

If the incremented or next detector number does not exceed the total number of detectors, then step **812** sets the hold signal high to enable the sample mode for the incremented detector, which is now the current detector. Step **813** sets the current detector by setting the I/O port of microcontroller **513** to the current channel number. In step **814**, the hold mode for the detector is set and step **815** starts the detector A to D conversion. It should be noted that the routine in FIGS. **8**a and **8**b is the detector analog to digital conversion interrupt routine. Thus, this routine will be executed, along with the detect/eject algorithm routine for each of the detector channels.

As previously discussed, in step **718** the pressure transducer analog to digital conversion is started. This routine is illustrated in FIGS. **9**a and **9**b. As FIG. **5** illustrates, the pressure sensor sample and hold circuits **519** for air valve pressure sensors **521** have outputs which are routed directly to microcontroller **513**. Thus, step **901** involves reading an analog to digital converter which is internal to the microcontroller. In step **902** pressure transducer data is stored in a data buffer for the particular channel. In step **903** the current pressure transducer number is incremented so that data for the next channel is obtained. In step **904** the incremented transducer number is tested against the maximum number of transducers.

If the incremented transducer number exceeds the number of transducers, the transducer number is set to zero in step **905** and an air check routine, discussed below is performed. If the transducer number does not exceed the maximum number of transducers then the hold signal is set high for the new transducer number to set the sample mode for the next channel. This is done in step **906**. In step **907**, the current transducer is selected by microcontroller **513** and in step **908**, the hold mode is selected for that channel. Step **909** starts the transducer A to D conversion. Thus, steps **901–904** are repeated.

The air check-routine shown in FIG. **9**b is performed for the current channel on each pass through the transducer interrupt routine, i.e., one channel is processed per pass through the transducer interrupt routine. In step **910** a current index is checked against a check index. If the current index does not equal the check index, control returns to the timer interrupt routine at step **718**. If the current index is equal to the check index, then in step **911** the measured pressure is tested against the minimum nozzle pressure. If the measured pressure exceeds the minimum nozzle pressure, control is returned to the timer interrupt routine at step **718**. If not, step **912** causes a fault indicator to be activated and step **913** causes the channel OK light for the channel corresponding to the current detector to be extinguished. Step **914** then tests to determine if the channel fault has been set. If this is the case, control returns to the timer interrupt routine in step **718**. If not, step **915** sets the channel fault and step **916** outputs an error code for solenoid failure. FIG. **9**b illustrates error codes for solenoid failures in channels **1–4**.

After the error code is output, control can be returned to the timer interrupt routine. Following the pressure transducer A to D conversion in step **718**, the timer interrupt routine transfers control to step **719** where the channel one air index is tested to determine if the index indicates ejection of material. If not, in step **720**, the channel one air off index is tested to determine if it indicates ejection air should be off. If this is not the case, processing of the remaining channels continues. However, if the channel one air off index indicates the ejection air should be turned off in channel one, the air solenoid with the associated detector is turned off in step **721**. If the channel **1** air on index indicates the ejection air should be turned on in step **719**, step **723** activates the air solenoid associated with the corresponding detector and step **724** increments the channel eject counter. Steps **725–739** indicate the same process takes place in each of the four channels as that described in steps **719–724**.

At the completion for all four channels, or as many channels as exist in the system, or after the history update flag has been set in step **705**, or if the electromagnetic radiation source is turned off and has not been recently turned off, as in step **704**, the timer interrupt routine executes step **740** to increment the interrupt counter. Since an interrupt occurs every one millisecond, sixty thousand interrupts occur in one minute. The elapse of one minute by the count of sixty thousand interrupts is determined in step **741**. For each elapsed minute, step **742** increments a minute counter. Step **743** then tests to determine if an hour has elapsed. If this is the case, the update history flag is set as an indicator to the foreground task to update historical information. The foreground task is always monitoring this flag.

While several embodiments of the invention have been described, it will be understood that it is capable of further modifications, and this application is intended to cover any variations, uses, or adaptations of the invention, following in general the principles of the invention and including such departures from the present disclosure as to come within knowledge or customary practice in the art to which the invention pertains, and as may be applied to the essential features hereinbefore set forth and falling within the scope of the invention or the limits of the appended claims.

What is claimed is:

1. A method of separating materials having different electromagnetic radiation absorption and penetration characteristics, the method comprising the steps of:

a) conveying materials to be separated from at least one inlet toward at least one outlet through a source of electromagnetic radiation;

b) irradiating portions of the materials conveyed with the source of electromagnetic radiation;

c) periodically polling a sequence of detectors, the detectors corresponding to channels, said polling including sampling for a sample time with the detectors the electromagnetic absorption and penetration characteristics of the material portions radiated;

d) in response to electromagnetic radiation absorption and penetration characteristics measured by the detectors in step c), activating a plurality of material ejection mechanisms at different times as the materials are conveyed, so that materials having different electromagnetic radiation and penetration characteristics are ejected at different times and locations on the conveyor into different sorting bins; and

e) during step d) verifying the operation of the material ejection mechanisms.

2. The method recited in claim **1** wherein each channel has at least one ejection mechanism.

3. The method recited in claim **1** wherein each channel has at least one the ejection mechanism, the ejection mechanisms being comprised of air pressure ejectors and wherein step d) comprises:

i) measuring and storing air pressure data from each ejection mechanism in a sequence identical to the sequence of the detectors polled;

ii) indicating a fault if the air pressure data measured and stored in step a) is less than a predetermined minimum.

4. The method recited in claim **1** wherein a leading edge portion of each item of material to be separated in each channel is ignored.

5. A method of separating materials having different electromagnetic radiation absorption and penetration characteristics, the method comprising the steps of:

a) conveying materials to be separated in from at least one inlet toward at least one outlet through a source of electromagnetic radiation;

b) irradiating portions of the materials conveyed with the source of electromagnetic radiation;

c) periodically polling a sequence of detectors, the detectors corresponding to channels, said polling including sampling for a sample time with the detectors the electromagnetic absorption and penetration characteristics of the material portions radiated wherein an ignore [table] *time* is counted from the time when a detection is made and wherein sampling taking place during the ignore time is ignored; and

d) in response to electromagnetic radiation absorption and penetration characteristics measured by the detectors in step c), activating a plurality of the material ejection mechanisms at different times as the materials are conveyed, so that materials having different electromagnetic radiation and penetration characteristics are ejected at different times and locations on the conveyor into different sorting bins.

6. The method recited in claim **5** wherein in step c) outputs of the detectors are sampled a plurality of times during a sample interval and a sample average is determined from the detector outputs and a count of the number of samples during the sample interval.

7. The method recited in claim **6** wherein the average is compared to a predetermined material threshold defined by a ratio of a predetermined amount of radiation transmitted through a material to an amount of radiation transmitted in the absence of the material.

8. The method recited in claim **7** wherein the ejection mechanisms are air pressure ejection mechanisms and wherein, when the average is less than the predetermined material threshold, step d) further comprises setting an air on index to activate the air ejection mechanisms at a time and for a duration based on the sample count, the ignore count, a travel time for the material to go from the detectors to the air pressure ejection mechanism and a response time of a solenoid which activates the individual air ejection mechanisms.

9. The method recited in claim **8** wherein the air on index is determined from a current index as:

$$\text{Index} - (\text{Sample Count} - \text{Ignore Count}) + (\text{Travel Time} - \text{Solenoid Response Time})$$

10. The method recited in claim **8** wherein an air off index is defined as a sum of the air on index and the air on time and is used to turn the air ejection mechanisms off.

11. The method recited in claim **10** wherein step d) comprises:

i) measuring and storing air pressure data from each ejection mechanism in a sequence identical to the sequence of the detectors polled; and

ii) indicating a fault if the air pressure data measured and stored in step a) is less than a predetermined minimum.

12. The method recited in claim **11** wherein a pressure check index is defined as a sum of the air off index and a pressure check delay and is used to activate verification of the air pressure data in each ejection mechanism.

13. The method recited in claim **5** further comprising an initialization sequence wherein:

variables are initialized and checked via a checksum routine;

detectors and ejection mechanisms are compared for correspondence;

low and high limits of detectors and ejection mechanisms are tested; and

operation of fault indicators is verified.

14. The method recited in claim **5** wherein a foreground routine is performed, the foreground routine monitoring total operation time, recording errors and storing histories.

15. The method recited in claim **14** wherein the foreground routine is periodically interrupted to store processing histories.

16. The method recited in claim **5** wherein control is maintained by a current index representing a pointer in a circular buffer, the index being a location where current information is stored.

17. The method recited in claim **5** wherein each channel has at least one detector and at least one ejection mechanism.

18. The method recited in claim **5** wherein detections from a plurality of channels of detectors are combined to activate a same one of the ejection mechanisms.

19. An apparatus for separating materials having different electromagnetic radiation absorption and penetration characteristics, the apparatus comprising:

a) a conveyor arranged to convey materials to be separated from at least one inlet toward at least one outlet;

b) an electromagnetic radiation source arranged along said conveyor to irradiate portions of the materials conveyed;

c) a plurality of detectors, the detectors corresponding to channels, the detectors measuring electromagnetic absorption and penetration characteristics of the material portions radiated;

d) means for periodically polling a sequence of detectors, said polling means including a sampler arranged to sample the detectors for a sample time;

e) a plurality of ejection mechanisms, at least one ejection mechanism corresponding to each outlet;

f) means for activating the material ejection mechanisms at different times as the materials are conveyed, in response to electromagnetic radiation absorption and penetration characteristics measured by the detectors, so that materials having different electromagnetic radiation and penetration characteristics are ejected at different times and locations on the conveyor into different sorting bins; and

g) means for verifying operation of the material ejection mechanisms during time period when the detectors are measuring electromagnetic absorption and penetration characteristics of the material portions radiated.

20. The apparatus recited in claim **19** wherein each channel has at least one ejection mechanism, the ejection mechanisms being comprised of air pressure ejectors, the apparatus further comprising:

f) means for measuring and storing air pressure data from each ejection mechanism in a sequence identical to the sequence of the detectors polled; and

g) fault indicators indicating a fault if the air pressure data measured and stored is less than a predetermined minimum.

21. The apparatus recited in claim **19** comprising means for ignoring a leading edge portion of each item of material to be separated in each channel.

22. An apparatus for separating materials having different electromagnetic radiation absorption and penetration characteristics, the apparatus comprising:

a) a conveyor arranged to convey materials to be separated from at least one inlet toward at least one outlet;

b) an electromagnetic radiation source arranged along said conveyor to irradiate portions of the materials conveyed;

c) a plurality of detectors, the detectors corresponding to channels, the detectors measuring electromagnetic absorption and penetration characteristics of the material portions radiated;

d) means for periodically polling a sequence of detectors, said polling means including a sampler arranged to sample the detectors for a sample time;

e) an ignore time counter, said ignore time counter counting from a time when a detection is made to a later time defining the ignore time and wherein sampling taking place during the ignore time is ignored; and

f) a plurality of ejection mechanisms, at least one ejection mechanism corresponding to each outlet; and

g) means for activating the material ejection mechanisms at different times as the materials are conveyed, in response to electromagnetic radiation absorption and penetration characteristics measured by the detectors, so that materials having different electromagnetic radiation and penetration characteristics are ejected at different times and locations on the conveyor into different sorting bins.

23. The apparatus recited in claim **22** wherein outputs of the detectors are sampled a plurality of times during a sample interval and a sample average is determined from the detector outputs and a count of the number of samples during the sample interval.

24. The apparatus recited in claim **23** wherein the average is compared to a predetermined material threshold.

25. The apparatus recited in claim **24** further comprising an air on index and wherein the ejection mechanisms are air pressure ejection mechanisms and wherein, when the average is less than the predetermined material threshold the air on index is set to activate the air ejection mechanisms at a time and for a duration based on the sample count, the ignore count, a travel time for the material to go from the detectors to the air pressure ejection mechanism and a response time of a solenoid which activates the individual air ejection mechanisms.

26. The apparatus recited in claim **25** wherein the air on index is determined from a current index as:

$$\text{Index} - (\text{Sample Count} - \text{Ignore Count}) + (\text{Travel Time} - \text{Solenoid Response Time})$$

27. The apparatus recited in claim **25** wherein an air off index is defined as a sum of the air on index and the air on time and is used to turn the air ejection mechanisms off.

28. The apparatus recited in claim **27** comprising:

f) means for measuring and storing air pressure data from each ejection mechanism in a sequence identical to the sequence of the detectors polled; and

g) fault indicators indicating a fault if the air pressure data measured and stored is less than a predetermined minimum.

29. The apparatus recited in claim **28** wherein a pressure check index is defined as a sum of the air off index and a pressure check delay and is used to activate verification of the air pressure data in each ejection mechanism.

30. The apparatus recited in claim **22** further comprising an initialization sequence means wherein:

variables are initialized and checked via a checksum routine;

numbers of detectors and ejection mechanisms are compared for one to one correspondence;

low and high limits of detectors and ejection mechanisms are tested; and

operation of fault indicators is verified.

31. The apparatus recited in claim **22** further comprising means for performing a foreground routine where the foreground routine monitors total operation time, records errors and stores histories.

32. The apparatus recited in claim **31** wherein the foreground routine is periodically interrupted to store processing histories.

33. The apparatus recited in claim **22** comprising a circular buffer, wherein control is maintained by a current index representing a pointer in a circular buffer, the index being a location where current information is stored.

34. The apparatus recited in claim **22** wherein a plurality of detectors combine to activate a same one of the ejection mechanisms.

35. A method of separating *PVC and non-PVC materials, said* materials having different **[**electromagnetic**]** *X-ray* radiation absorption and penetration characteristics, the method comprising the steps of:

a) conveying *PVC and non-PVC* materials to be separated from at least one inlet toward at least one outlet through a source of **[**electromagnetic**]** *X-ray* radiation;

b) irradiating portions of the *PVC and non-PVC* materials conveyed with the source of **[**electromagnetic**]** *X-ray* radiation at a selected energy level;

c) periodically polling a sequence of *X-ray* detectors, the detectors corresponding to channels, said polling including sampling for a sample time with the detectors at least one of absolute **[**electromagnetic**]** *X-ray* radiation absorption and penetration characteristics of the material portions radiated; *and*

d) in response to the absolute **[**electromagnetic**]** *X-ray* radiation characteristics measured by the detectors in step c),

categorizing readings for portions irradiated into at least one of a plurality of classes, said classes corresponding to different X-ray radiation absorption and penetration characteristics,

determining that readings in at least one of said classes are a more reliable indication of material type than readings in another of said classes, and

based on said more reliable indication of material type, activating a plurality of material ejection mechanisms at different times as the *PVC and non-PVC* materials are conveyed, so that materials, having different absolute **[**electromagnetic**]** *X-ray* radiation and penetration characteristics, are ejected at different times and locations on the conveyor into different sorting bins.

36. A method of separating PVC and non-PVC materials, said materials having different X-ray radiation absorption and penetration characteristics, as set forth in claim 35, further comprising the step of:

e) during step d) verifying the operation of the material ejection mechanisms.

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