PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01R 31/08	A1	(11) International Publication Number: WO 93/05404
		(43) International Publication Date: 18 March 1993 (18.03.93)

(21) International Application Number: PCT/US92/07603

(22) International Filing Date: 9 September 1992 (09.09.92)

(30) Priority data:
757,176 10 September 1991 (10.09.91) US

(71) Applicant: ELECTRIC POWER RESEARCH INSTITUTE [US/US]; 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303 (US).

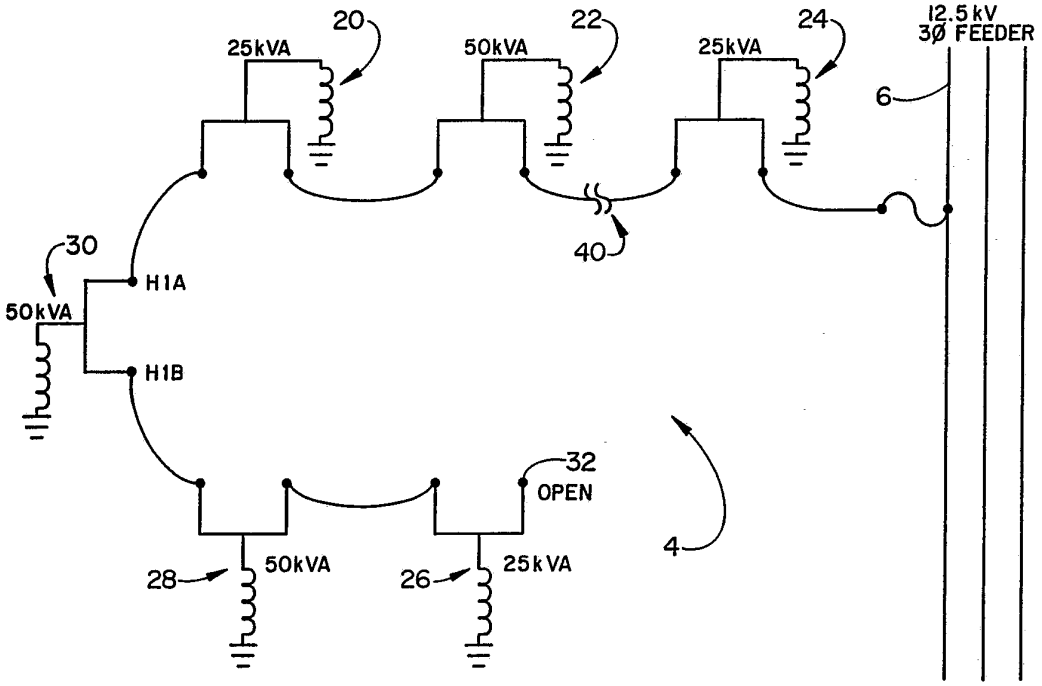
(72) Inventors: WIGGINS, Carl, M. ; 11600 Academy Road, N.E., Apt. #4615, Albuquerque, NM 87111 (US). NICKEL, Frank, S. ; 7400 Elderwood Drive, N.W., Albuquerque, NM 87120 (US). THOMAS, David, E. ; P.O. Box 1017, Peralta, NM 87042 (US). HALKO, Stephen, J. ; P.O. Box 558, Corrales, NM 87048 (US). SALAS, Thomas, M. ; 1704 Cliffside, N.W., Albuquerque, NM 87105 (US). SHAPIRO, Gary, H. ; 3317 Valley Haven Court, N.W., Albuquerque, NM 87107 (US).

(74) Agent: CRAIG, Royal, W.; Law Offices of Leonard Bloom, 401 Washington Avenue, Suite 905, Towson, MD 21204 (US).

(81) Designated States: AU, CA, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE).

Published
With international search report.

(54) Title: ADVANCED CABLE FAULT LOCATOR



(57) Abstract

A simple and inexpensive system for real-time location of a fault (40) occurring anywhere in an underground residential distribution (URD) system (schematically represented by circuit model (4)) by analyzing the propagating fault signal at an open point (32) in light of the predetermined propagating velocity of the fault signal.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**FI**	Finland	**MN**	Mongolia
AU	Australia	**FR**	France	**MR**	Mauritania
BB	Barbados	**GA**	Gabon	**MW**	Malawi
BE	Belgium	**GB**	United Kingdom	**NL**	Netherlands
BF	Burkina Faso	**GN**	Guinea	**NO**	Norway
BG	Bulgaria	**GR**	Greece	**NZ**	New Zealand
BJ	Benin	**HU**	Hungary	**PL**	Poland
BR	Brazil	**IE**	Ireland	**PT**	Portugal
CA	Canada	**IT**	Italy	**RO**	Romania
CF	Central African Republic	**JP**	Japan	**RU**	Russian Federation
CG	Congo	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CH	Switzerland			**SE**	Sweden
CI	Côte d'Ivoire	**KR**	Republic of Korea	**SK**	Slovak Republic
CM	Cameroon	**LI**	Liechtenstein	**SN**	Senegal
CS	Czechoslovakia	**LK**	Sri Lanka	**SU**	Soviet Union
CZ	Czech Republic	**LU**	Luxembourg	**TD**	Chad
DE	Germany	**MC**	Monaco	**TG**	Togo
DK	Denmark	**MG**	Madagascar	**UA**	Ukraine
ES	Spain	**ML**	Mali	**US**	United States of America

ADVANCED CABLE FAULT LOCATOR

Technical Field

This invention relates to the locating of faults in power distribution systems and, more particularly, to a method and apparatus for pinpointing the location of a fault occurring in an underground residential distribution (URD) system by real-time analysis of the fault signal.

Background Art

It is known that faults occurring along a power distribution system can immediately be detected by monitoring a fault signal which propagates as a consequence of the fault. Both phase-to-phase and phase-to-ground faults produce a fault signal in the form of a step-function which reflects throughout the system. Several conventional devices are currently available for detecting such fault signals.

For example, U.S. Patent No. 3,710,239 to Nakamura discloses a fault monitoring device which operates with sensors placed at both ends of an isolated section of transmission line. One sensor detects the leading edge of a fault signal and thereupon activates a counter. When the fault signal reaches the second monitor it activates a transmitter which signals the counter to stop. As long as the fault occurs between the sensors, the contents of the counter will be proportional to the fault location. Hence, the contents of the counter can be used to localize the fault.

U.S. Patent No. 4,857,854 to Matsushima discloses a digital fault locator which measures voltage and phase currents due to a fault signal. This device implements a digital filtering technique in calculating the fault location based upon the fault signal.

U.S. Patent No. 4,797,805 to Nimmersjo uses a travelling wave model to describe the voltage distribution along the transmission line. The model results are compared to actual measurements of the voltage at both ends of the transmission line. Given the length of the transmission line, the distance to the fault can be calculated.

Although the above-described patents provide an instantaneous indication of the fault location, they all disclose devices which require a plurality of sensors positioned along a transmission line, and the sensors must monitor both line current and voltage. Moreover, the technique used in calculating the fault location is exceedingly complex, which necessitates costly implementing circuitry.

U.S. Patent No. 4,500,834 to Ko et al. suggests a less complicated and more economical fault locator for an overhead transmission system. Ko et al. use a single monitor placed along the transmission line. The monitor is placed in an isolated zone of the transmission line which is protected by relays. The monitor detects the leading edge of a fault signal and monitors the amount of time required for the signal to reflect from the monitor to the end of the isolated zone and back to the monitor. The elapsed time is then compared to a preset time to determine whether the fault occurred within the isolated zone. If so, the device triggers the appropriate relay. Unfortunately, the applications of the Ko et al. device are limited. This is because the device was designed only for use with an overhead transmission system. Consequently, a number of design constraints arise. The Ko et al. device must be used in a relay-protected zone, and it merely indicates when a fault occurs within the zone. It does not disclose a means for accurately pinpointing the location of the fault. Moreover, the device must ascertain the direction in which a fault signal is propagating. For this, dual sensors are required to sense both current and voltage, and a complex directional fault detection unit is required.

U.S. Patent No. 4,766,549 issued to Schweitzer et al. discloses a passive reflectometer for detecting faults along a transmission line. In the Schweitzer et al. '834 arrangement a fault 16 occurring along the transmission line (see FIG. 1) generates a fault wave which propagates bi-directionally along paths 30 and 32 (see FIG. 3) toward the respective ends. A

sensor at one end 14 of the transmission line picks up the following three impulses:

1) a negative impulse A corresponding to the propagation of the fault wave directly to end 14 (along path 30);

2) a negative impulse B corresponding to the continued propagation of the above-described wave back to the fault 16, where it is again reflected back to end 14; and finally,

3) a positive impulse C corresponding to the propagation of the original fault wave to the opposite end 12 (along path 32) and the reflection therefrom back (along paths 34, 36) to end 14.

The time between points A and B divided by two represents the propagation time from the fault 16 to the opposite end 12 (see column 6, lines 47-56), and the fault location may be determined by multiplying said propagation time by the velocity of propagation (see column 6, Eqn. 4). Likewise, the time between points A and C divided by two represents the propagation time from the sensor end 14 to the fault 16, and the fault location may be determined by multiplying this propagation time by the velocity of propagation.

The Schweitzer et al. '834 reflectometer results in uncertainty insofar as impulse B may come before impulse C, or vice versa, depending upon the location of the fault. Given this uncertainty, the polarity of received pulses must be stored (as described in column 4, lines 30-64), and the polarity pattern of three received pulses must be characterized as one of -,-,+ or -,+,- before the fault location can be determined. This precipitates a need for multiple sensors 42, 43 and a computer 44 with memory. Moreover, the sensors 42, 43 and computer 44 must be polarity-sensitive and must be capable of discerning extraneous signals.

The unique characteristics of an underground residential distribution system (URD) can be exploited to eliminate the inherent complexities of the Schweitzer et al. '834 device. A far simpler and more reliable method and apparatus is

facilitated by a focussed design which is tailored to the particular fault waveform characteristics in a URD system.

Disclosure of Invention

According to the present invention, a method for locating a fault occurring in an open loop underground residential distribution system is provided. The method includes the steps of sensing a leading edge of a fault signal propagating from a line fault using a sensor positioned proximate to an open point of the distribution system, sensing a reflection of the fault signal with the sensor, measuring a time interval occurring between the sensing of the leading edge and the reflection, determining the distance of the fault from the sensor based on the time interval, and indicating the precise distance of the fault from the sensor. The sensed reflection is the reflection of the original leading edge of the fault signal from the open point to the fault and back to the sensor, which is a signal of opposite polarity travelling in the same direction of the original fault signal. The signal-reflection properties within residential distribution systems make it possible to monitor the entire underground system using a single voltage or current sensor placed at the open point of the system. In addition, the method can be practiced irrespective of the direction in which the fault signal is propagating.

In addition, an apparatus is provided for carrying out the above-described method. The apparatus includes an electrical sensor positioned proximate to an open point along a radial power distribution circuit for sensing the leading edge of the fault signal propagating from a line fault, and for sensing the reflection (which likewise is a reflection of the original fault signal from the open point to the fault and back to the sensor), a timer connected to the sensor for measuring a time interval occurring between the leading edge and the reflection, a processor for determining the distance of the fault from the sensor, and an indicator for displaying said distance of the fault from the sensor.

Brief Description of Drawings

FIG. 1 illustrates a circuit model of a representative underground residential distribution system commonly used in the power industry.

FIG. 2 is a block diagram illustrating one embodiment of the present invention.

FIG. 3 is a schematic diagram illustrating the placement of sensor 50 near the open point 32 of an underground residential distribution circuit.

FIG. 4 illustrates the propagation path of a fault signal in the circuit of FIG. 3.

FIG. 5 illustrates the timing characteristic of the fault signal as it propagates along the path shown in FIG. 4.

FIG. 6 illustrates the actual electrical response of the circuit of FIG. 3 as measured by sensor 50.

FIG. 7 lists the propagation velocities characteristic of various types of cable commonly used in underground residential distribution systems.

FIG. 8 illustrates an alternate embodiment of the present invention in which two sensors are used with a single device to monitor a pair of radial circuits arranged where both open points occur at the same location. On three-phase open-looped systems all six circuits can be monitored by connecting six sensors to a single unit located at the common open point.

Best Mode(s) for Carrying Out the Invention

An exemplary underground residential distribution (URD) system of the type commonly employed in the power industry comprises an open-loop primary distribution cable feeding a plurality of pad-mount transformers. One or more residential loads may be supplied by each transformer.

FIG. 1 illustrates a circuit model of a single radial tap underground residential distribution system (URD) as described above. Model distribution circuit 4 comprises a 15 kV open-loop primary distribution cable feeding three 25kVA transformers 20, 24, and 26, and three 50kVA transformers 22,

28, and 30. The primary distribution cable terminates at an open point 32.

A fault 40 is shown occurring between transformers 20 and 22, although it should be understood that the present invention is capable of locating faults occurring anywhere along underground distribution circuit 4.

Upon the occurrence of fault 40, it is of paramount importance to detect the fault immediately, and to pinpoint its location as quickly as possible. The present invention accomplishes both of these tasks in real-time as the fault occurs.

FIG. 2 is a block diagram illustrating one embodiment of the present invention which is especially suited for locating faults occurring in the residential distribution circuit of FIG. 1. Sensor 50 may be a replica waveform response current sensor incorporating a toroidal clamp-on probe placed around only the center conductor of the load break elbow. This type of probe produces an output voltage proportional to the current flowing therethrough. Alternatively, sensor 50 may be a time-derivative response voltage sensor placed on a capacitive test voltage tap on the load break elbow. Sensor 50 is connected to signal conditioner 60, which is in turn connected to a threshold detector 70. Signal conditioner 60 may be a conventional variable attenuator calibrated to provide optimal signal strength to threshold detector 70. Threshold detector 70 detects a pulse output of sensor 50 corresponding to the leading edge of a fault signal received thereby. Upon detecting a positive (or negative) pulse, threshold detector 70 triggers an interval counter 80. Similarly, upon detecting a negative (or positive) pulse from sensor 50, threshold detector 70 stops interval counter 80. The inverted pulse from sensor 50 corresponds to the reflection of the fault signal from the open point 32 (near sensor 50), back to the fault, and back again to the sensor 50. Interval counter 80 is clocked by clock 90. The interval counter 80 is also connected to decoder 100 which calculates the distance to the fault based upon the contents of counter

80. The calculated electrical distance is output to display 110 which provides a visual indication of the fault location. In the preferred embodiment, the indication comprises a measure of the distance from sensor 50 to the fault.

FIGS. 3-6 illustrate the operation of the advanced cable fault locator according to the present invention. It is an integral feature of the invention that sensor 50 is placed immediately before the open point 32 of the radial distribution circuit 4 shown in FIG. 1, preferably within approximately twelve inches from open point 32.

As shown in FIG. 3, a fault occurring at point 40 will generate a fault signal in the approximate form of a step-function which propagates in the direction of sensor 50.

FIG. 4 illustrates the propagation path of the fault signal. As shown, the fault signal travels along the distribution circuit 4 until it reaches open point 32, just past the point at which the leading edge reaches sensor 50.

FIG. 5 illustrates the timing characteristics of the fault signal as it propagates along the path shown in FIG. 4 reflecting between the open point 32 and the fault 40 (a short circuit). The fault signal can be detected as a current or voltage wave, hence sensor 50 may be either a current or a voltage sensor. The reflection characteristics of current and voltage waves are opposite from each other at open and short circuits. Therefore, a current sensor will be used for the purpose of the following discussion to illustrate the process described in FIG. 5. The leading edge of the (assumed positive amplitude) step function fault signal initiated at time t=0 travels a distance l_1 and arrives at sensor 50 at time t_1 as shown in FIG. 5. Where a current sensor is used, the leading edge of the fault signal appears at sensor 50 to be a transient positive current pulse 300 beginning at time t=0 as shown in FIG. 5. A voltage sensor will detect the corresponding voltage pulse.

The fault signal current will then reflect with inverted polarity from open point 32 (designated 200 in FIG. 4), producing an equal and opposite (negative amplitude) reflected

signal propagating in the reverse direction back toward sensor 50 and fault 40. The negative amplitude, reflected fault signal will begin to cancel with the original (positive polarity) fault signal at sensor 50 at time t_2, producing a nearly zero amplitude signal level at sensor 50 until time t_3 as explained below. Since sensor 50 is a short distance l_2 from open point 32 (designated in FIG. 5), there is a small time delay t_2-t_1 before the incident and reflected signals begin to cancel resulting in the positive pulse 300 shown in FIG. 5. Meanwhile, the reflected (and negative polarity) current signal from open point 32 will reach fault 40 (designated by point 210 in FIG. 4) and will be re-reflected back toward the sensor 50 and open point 32. The current signal re-reflected from the fault (a short circuit) will have the same negative polarity, but nearly twice the amplitude of the once-reflected incident signal. The twice-reflected fault current signal reaches sensor 50 at time t_3, and is seen as a negative polarity, unit amplitude step function. This signal then reaches open point 32 (at point 220 in FIG. 4), reflects and inverts polarity (to positive), travels back to sensor 50 arriving at time t_4, and cancels the negative polarity, twice-reflected signal. Because of the time difference t_4-t_3 between the two signals arriving at sensor 50, the cancellation results in a negative current pulse 310 as shown in FIG. 5.

FIG. 6 illustrates the actual response of the circuit of FIG. 3 as measured at sensor 50. A primary advantage of the invention is readily apparent from the graph. The placement of sensor 50 near the open point of the radial distribution circuit 4 results in a waveform which yields an unambiguous and accurate indication of the time difference between the arrival of the incident fault wave and its first reflection from the fault at sensor 50. This is because the original fault signal nearly cancels with its reflected counterpart. Hence, an interval will pass between pulses 300 and 310 during which sensor 50 sees a signal of essentially zero amplitude. The unequivocal positive (or negative) pulse 300 and negative (or positive) pulse 310 results from the placement of the

single sensor 50 near, but not exactly at, the open point 32. The time difference (time at 310 minus time at 300 in FIG. 6) is equal to the time required for the fault wave to travel from sensor 50 to the fault, reflect from it, and travel back to sensor 50. FIG. 6 also illustrates how the accuracy of determining this time difference is enhanced by the manner in which sensor 50 is installed on the circuit. It is an integral feature of the invention that sensor 50 is placed immediately before the open point 32 of the radial distribution circuit 4 shown in FIG. 1, preferably within about twelve inches from open point 32, in order to minimize the width of peaks 300 and 310 in FIG. 6, thereby reducing the ambiguity in determining the times at which the peaks occur, and to cause the fault waveshape measured by sensor 50 to be invariant with circuit length and fault distance. The invariant waveshape is an integral feature of the invention providing a predictable signal pattern upon which an automatic signal processing algorithm for fault location is based. This simplification eliminates the need for complex and costly equipment, signal processing and skilled operators required in the prior art devices to differentiate between the many fault signal components appearing on the distribution lines.

Referring back to FIG. 4, if the total time taken for the signal to traverse points 200 and 220 may be represented by t, then the distance d from the sensor 50 to fault 40 may be easily calculated by the expression:

$$d = v * t/2$$

where v is the propagation velocity through the cable. This calculation is easily completed by decoder 100 (of FIG. 2) because, unlike some prior art fault locators, the lengths of the distribution cables need not be known. The only variable is the propagation velocity of the fault signal through the cable, which is a value characteristic of the cable type. This propagation velocity may easily be determined in advance. Hence, a range of characteristic propagation velocities may be stored in decoder 100.

FIG. 7 shows the propagation velocities for a number of cable types commonly used in underground residential distribution systems. It should be noted that accurate fault location depends on the accuracy of the propagation velocity. Therefore, even though an average value may yield acceptable results, it is preferable to use the more exact data shown in FIG. 7.

The distance to the fault as calculated by decoder 100 is then output to display 110.

It has been demonstrated that the advanced fault locator will detect faults at a distance of at least 6000 feet when sensor 50 is either a derivative response voltage sensor or a replica response current sensor.

It has also been found that a surge arrestor may be used at the open point of the underground residential distribution system to significantly increase the amplitudes of the transient fault waveforms. Hence, a surge arrestor can be used to extend the maximum range of fault location.

In addition to the extended range of fault location, the present invention also expedites corrective measures. Following the occurrence of a fault in a residential distribution system, service can be restored most quickly by disconnecting the damaged (faulted) section of cable from the distribution system, closing the normally open point 32 (unless it is at one end of the faulted cable section), and re-energizing the URD system. The above-described procedure is only possible if the damaged section of cable can be pinpointed, and this requires an accurate determination of the fault location to within the smallest distance between two adjacent padmount transformers (typically $\geq$ 100 feet). Based on empirical data, the accuracy of the fault locator according to the present invention is between 0.5% and 2% of the distance of the fault from sensor 50. These numbers clearly show that the location of a fault can be pinpointed to within the distance between two padmount transformers on a typical distribution circuit.

FIG. 8 illustrates another embodiment of the present invention which is capable of monitoring both sides of open-looped underground residential circuits. Pairs of radial distribution circuits (or radial taps) are commonly arranged as two halves of an open loop so that their open points share a common location, ordinarily at a padmount transformer. The embodiment of FIG. 8 is especially economical because a single unit is capable of monitoring both distribution circuits in a pair. The proximity of the two open points makes it possible to connect two sensors to a single unit. Hence, the single embodiment of FIG. 8 is capable of monitoring both circuits.

Having now fully set forth the preferred embodiments and certain modifications of the concept underlying the present invention, various other embodiments as well as certain variations and modifications of the embodiment herein shown and described will obviously occur to those skilled in the art upon becoming familiar with said underlying concept. It is to be understood, therefore, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically set forth herein.

Industrial Applicability

There is a great commercial need for instantaneous detection of faults in all types of electrical transmission and distribution systems. Quickly isolating a faulty line avoids the risk of fire and injury.

Faults occurring along power transmission and distribution systems can immediately be detected by monitoring a fault signal which propagates as a consequence of the fault. However, once the fault signal has been detected, it is of equal importance to quickly locate and repair the fault. It is possible through the use of "reflectometry" to assess the location of a fault based upon the characteristics of the resulting transient fault signal. Unfortunately, extremely irregular conditions exist in many distribution systems following a fault. Conventional reflectometers must incorporate costly safeguards to insure reliability. Such

safeguards typically include isolating the monitored transmission line within a relay-protected zone, and/or use of a plurality of voltage and current sensors positioned along the transmission line, use of peripheral communication lines, and/or use of complex techniques in calculating the fault location. These burdensome safeguards inflate the cost of conventional reflectometers to the point of commercial impracticality.

There remains a significant commercial need for a simple and inexpensive reflectometer, and the answer lies in eliminating the complexities in conventional systems. This is possible with a specific reflectometer design for use in an underground radial distribution (URD) network as set forth above.

Claims

1. A method for locating a fault occurring in an underground residential power distribution (URD) circuit and having a predetermined propagation velocity, the method comprising the steps of:

positioning a sensor proximate to an open point in said power distribution circuit;

sensing a first electrical signal propagating from a line fault using said sensor;

sensing a second electrical signal with said sensor, said second signal being produced by said first signal reflecting from said open point to said fault and back to said sensor;

measuring a time interval occurring between sensing of said first and second electrical signals;

determining a distance of said fault from said sensor based on said time interval and predetermined propagation velocity; and

indicating said distance of said fault from said sensor to allow location of said fault.

2. The method according to claim 1, wherein said electrical signals are current waveforms.

3. The method according to claim 2, wherein said sensor is a replica response current sensor.

4. The method according to claim 1, wherein said electrical signals are voltage waveforms.

5. The method according to claim 4, wherein said sensor is a derivative response voltage sensor.

6. The method according to claim 1, wherein said distance is determined by multiplying a cable propagation velocity by one-half of said time interval.

7. The method according to claim 6, wherein said calculated distance of said fault from said sensor is within a 2% error.

8. The method according to claim 1, further comprising the step of installing a surge arrestor at said open point for increasing a range within which a fault can be located.

9. A method for locating a fault occurring in an underground residential power distribution (URD) circuit, comprising:

storing a propagation velocity in a memory, said propagation velocity being characteristic of a type of cable used in said power distribution circuit;

positioning a sensor proximate to an open point in said power distribution circuit;

sensing a first electrical signal propagating from a line fault using said sensor;

sensing a second electrical signal with said sensor, said second signal being produced by said first signal reflecting from said open point to said fault and back to said sensor;

measuring a time interval occurring between sensing of said first and second electrical signals;

calculating a distance of said fault from said sensor by multiplying said stored propagation velocity by said measured time interval and dividing by two; and

indicating a location of said fault based upon said calculated distance.

10. The method according to claim 9, wherein said electrical signals are current waveforms and said sensor is a replica response current sensor.

11. The method according to claim 9, wherein said electrical signals are voltage waveforms and said sensor is a derivative response voltage sensor.

12. The method according to claim 9, further comprising the step of installing a surge arrestor at said open point for increasing a range within which a fault can be located.

13. The method according to claim 9, further comprising the step of communicating said calculated distance to a control center.

14. The method according to claim 9, wherein said fault signal is an injected electrical signal injected in said power distribution circuit at a point opposite said open point.

15. An apparatus for locating a fault occurring in a power distribution circuit, comprising:

an electrical sensor positioned proximate to an open point along an underground residential power distribution (URD) circuit for sensing a first electrical signal propagating from a line fault, and for sensing a second electrical signal which is a reflection of said first signal from said open point to said fault and back to said sensor, said second signal being of opposite polarity than said first electrical signal;

a timer connected to said sensor for measuring a time interval occurring between sensing of said first and second electrical signals;

a processor connected to said timer for communication of said time interval, said processor determining a distance of said fault from said sensor based on said time interval; and

an indicator for displaying a location of said fault.

16. The apparatus according to claim 15, wherein said first and second electrical signals are current waveforms.

17. The method according to claim 16, wherein said sensor is a replica response current sensor.

18. The apparatus according to claim 15, wherein said first and second electrical signals are voltage waveforms.

19. The apparatus according to claim 18, wherein said sensor is a derivative response voltage sensor.

20. The apparatus according to claim 15, wherein said processor determines said distance by multiplying a cable propagation velocity by one-half of said time interval.

21. The apparatus according to claim 15, wherein said processor includes a memory for storing a propagation velocity characteristic of a type of cable used in said power distribution system, said processor determining said fault location by multiplying said stored propagation velocity by said time interval and dividing by two.

22. The apparatus according to claim 21, wherein said indicator further comprises a visual display connected to said processing means for indicating a location of said fault.

23. The device according to claim 21, wherein said processing means further comprises an interface for allowing an operator to specify said type of cable used in said power distribution circuit.

24. A device for locating a fault occurring in an underground residential power distribution (URD) circuit, comprising:

a high voltage pulse generator for injecting an electrical signal in said power distribution circuit;

electrical sensing means positioned proximate to an open point along said power distribution circuit for sensing a first reflected signal produced from said injected signal reflecting from a line fault, and for sensing a second reflected signal caused by said first signal reflecting from said open point to said fault and back to said sensing means;

timing means connected to said sensing means for measuring a time interval occurring between said first and second electrical signals;

processing means for determining a location of said fault based on said time interval, said processing means including a memory for storing a propagation velocity characteristic of a type of wire used in said power distribution circuit, whereby said processing means determines said fault location by multiplying said stored propagation velocity by said time interval and dividing by two; and

a display connected to said processing means for indicating a location of said fault.

25. An apparatus for locating a fault occurring in a pair of adjacent underground residential power distribution (URD) circuits, comprising:

a first electrical sensor positioned proximate to a first open point along a first power distribution circuit;

a second electrical sensor positioned proximate to a second open point along a second power distribution circuit;

timing means connected to said first sensor and second sensor for measuring a time interval occurring between electrical signals;

a processor connected to said timing means; and

indicating means for displaying a location of a fault;

whereby said first electrical sensor senses a first electrical signal propagating from a line fault in said first distribution circuit and a reflection thereof from said first open point to said fault and back to said first sensor, and said second electrical sensor senses a second electrical signal propagating from a line fault in said second distribution circuit and a reflection thereof from said second open point to said fault and back to said second sensor, said timing means determining a time occurring between said respective electrical signals and reflections thereof and inputting said time to said processor, whereupon said

processor calculates a distance to said faults and outputs said distance to said indicating means.

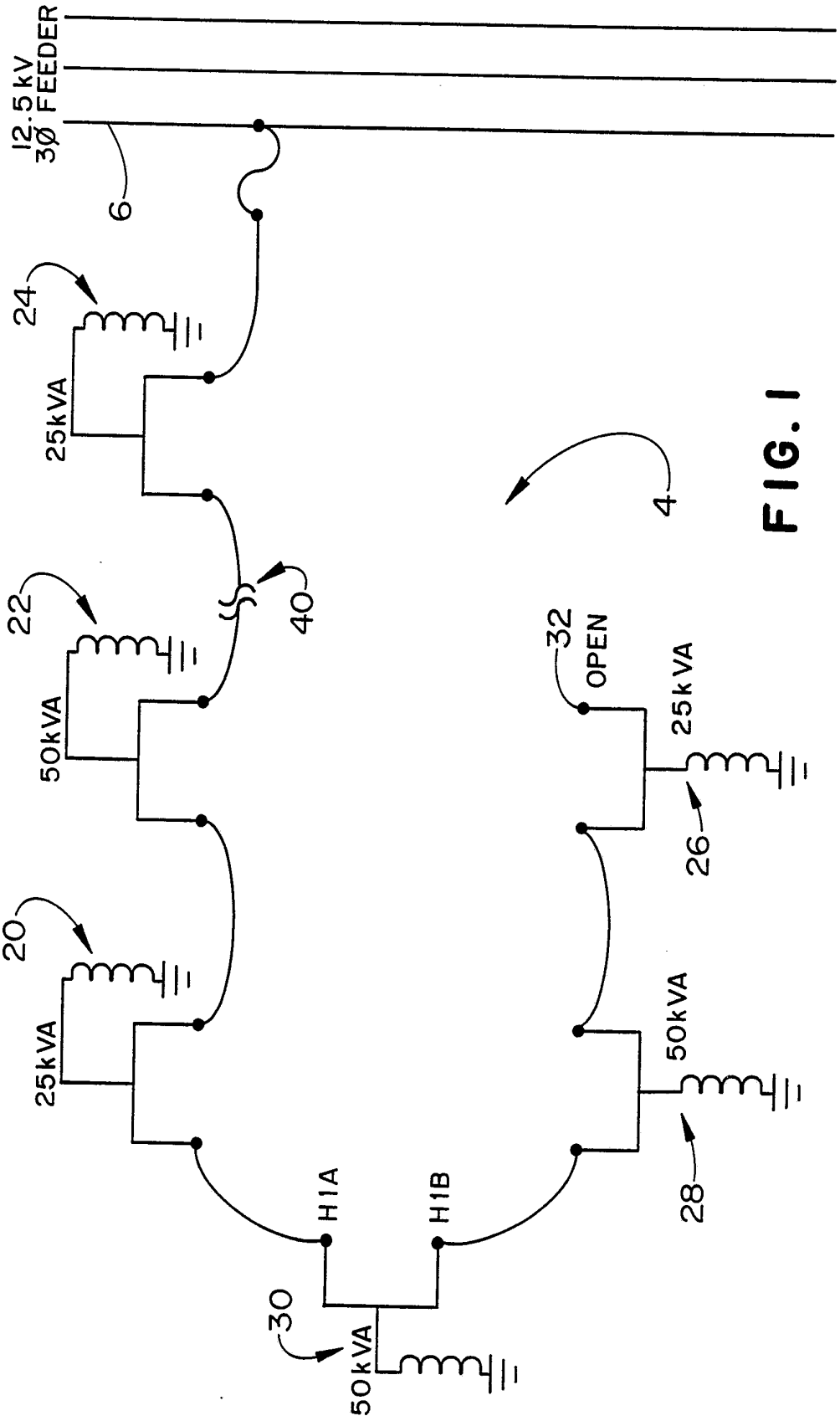

12.5 kV
3Ø FEEDER
6
24
25kVA
22
50kVA
40
4
32
OPEN
25kVA
26
20
25kVA
50kVA
28
H1A
H1B
30
50kVA

FIG. 1

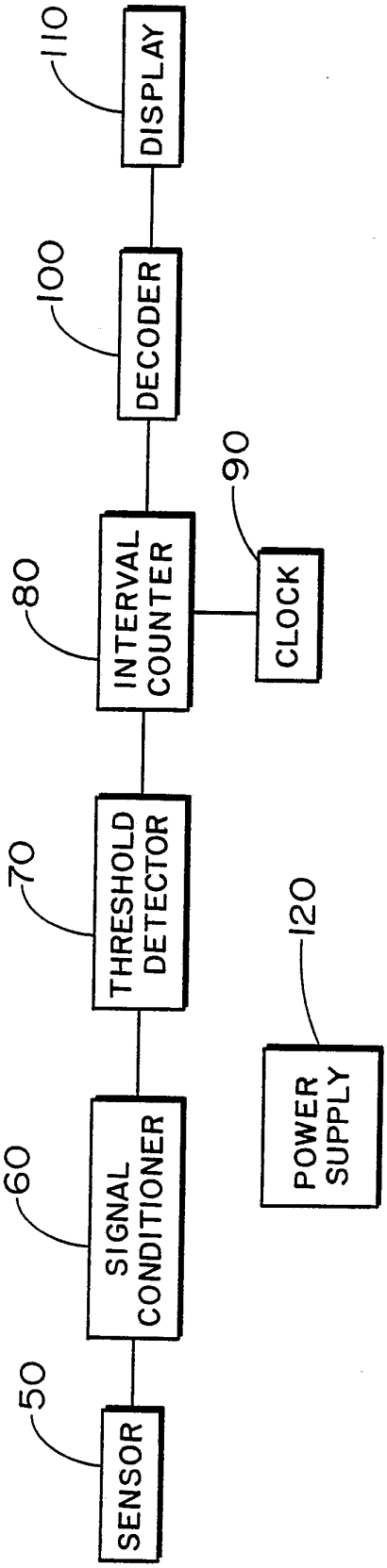

110
DISPLAY
100
DECODER
90
CLOCK
80
INTERVAL COUNTER
70
THRESHOLD DETECTOR
120
POWER SUPPLY
60
SIGNAL CONDITIONER
50
SENSOR

FIG. 2

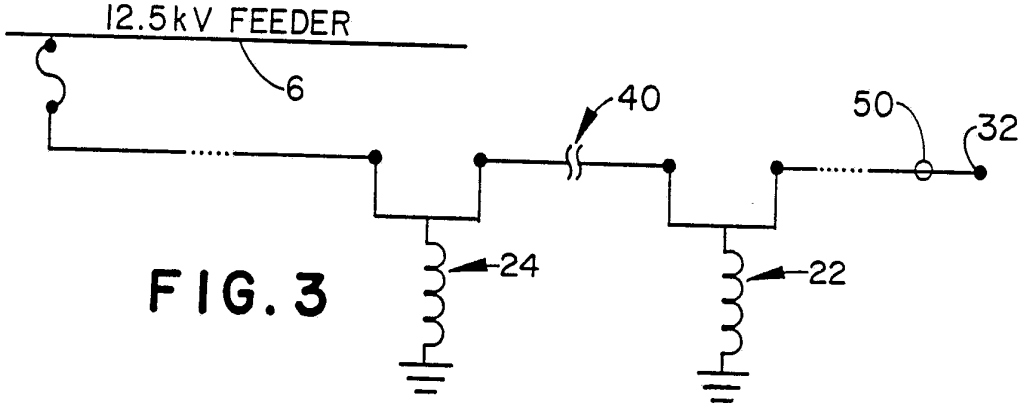


FIG. 3

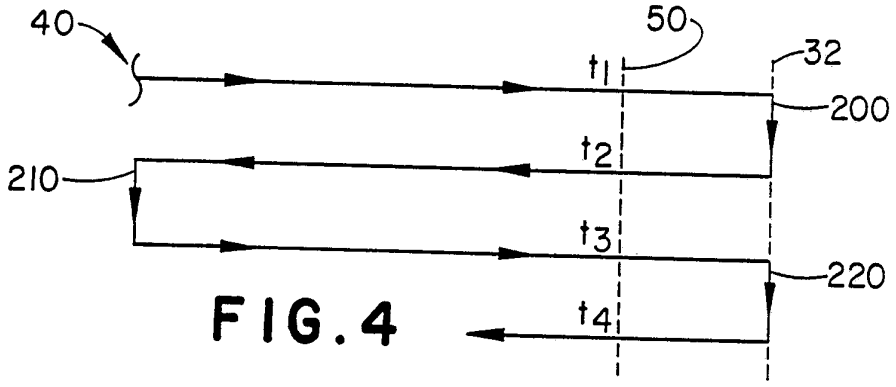


FIG. 4

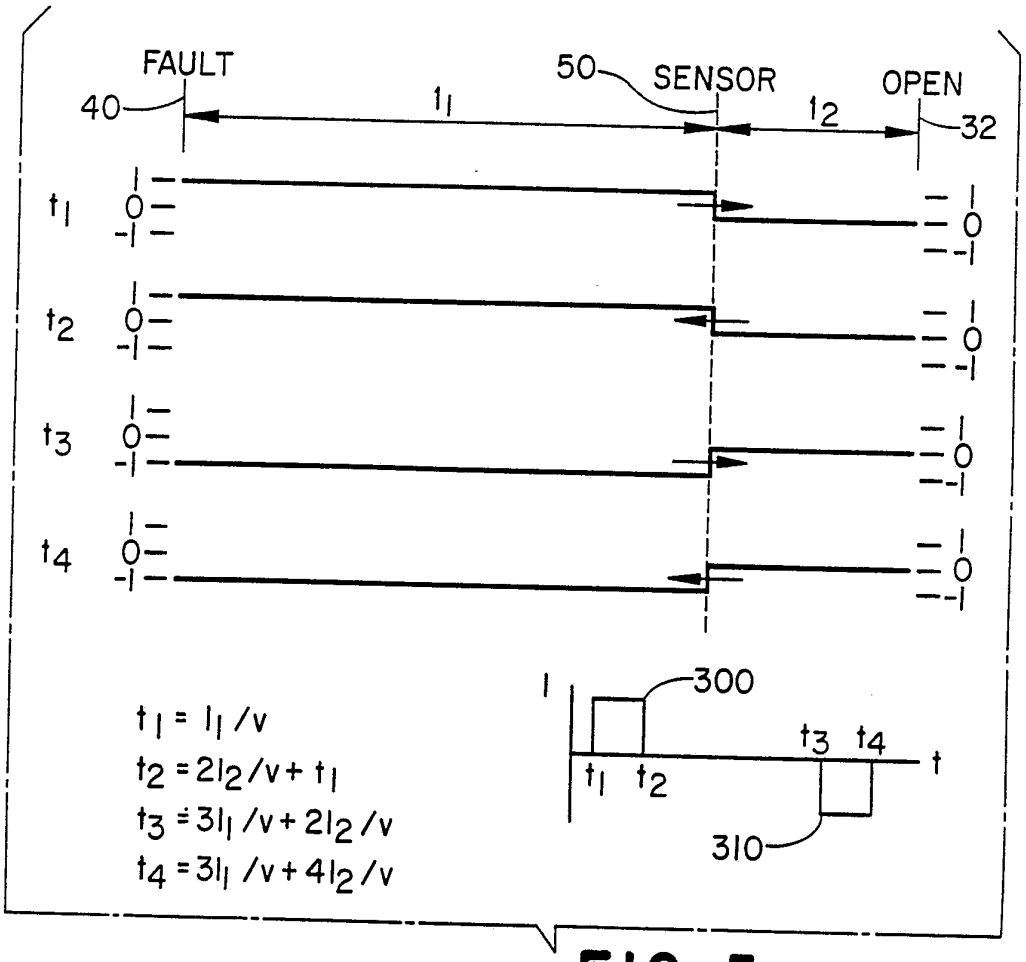

FAULT
40
50
SENSOR
OPEN
32
l_1
l_2
t_1
t_2
t_3
t_4
0
-1
$t_1 = l_1 / v$
$t_2 = 2l_2 / v + t_1$
$t_3 = 3l_1 / v + 2l_2 / v$
$t_4 = 3l_1 / v + 4l_2 / v$
I
300
310
t

FIG. 5

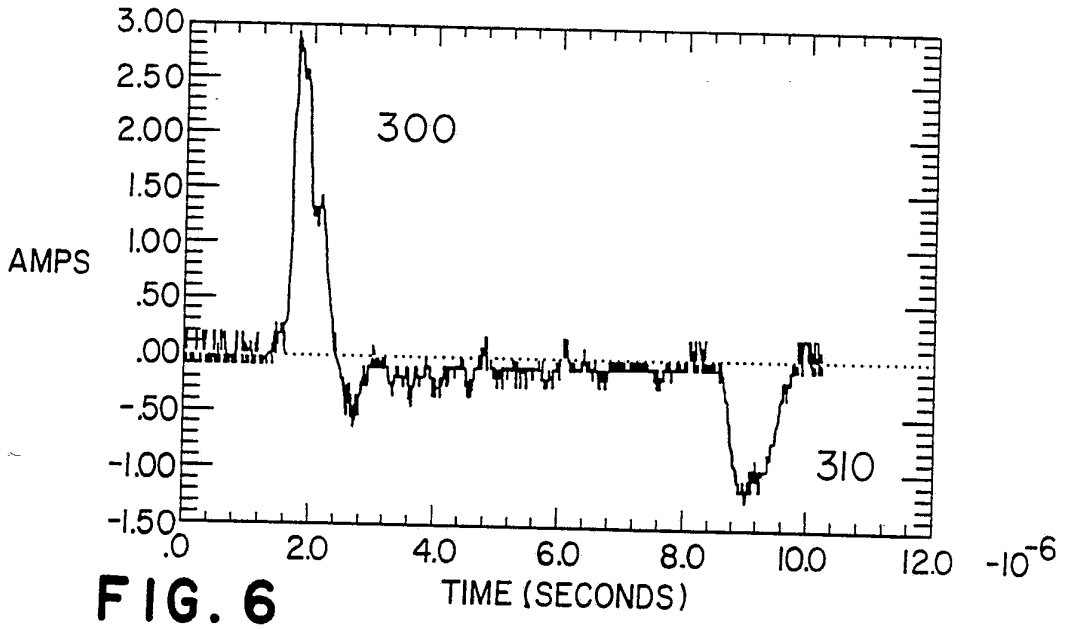

AMPS
3.00
2.50
2.00
1.50
1.00
.50
.00
-.50
-1.00
-1.50
300
310
.0
2.0
4.0
6.0
8.0
10.0
12.0
-10^{-6}
TIME (SECONDS)

FIG. 6

PROPAGATION VELOCITY IN URD CABLES

INSULATION	VOLTAGE(KV)	WIRE #	VELOCITY(ft/ns)
EPR	15 220M	1/0	0.508
EPR	15 220M	4/0	0.572
EPR	5	#6	0.560
EPR	5	#2	0.440
EPR	15	#2AL	0.540
XLPE	15	1/0AL	0.540
HMW	15	1/0	0.500
XLPE	15	1/0	0.504
XLPE	15	2/0	0.486
XLPE	15	4/0	0.478
XLPE	15	#1CU	0.554
XLPE	15	#2CU/AL	0.514
XLPE	15	#4CU	0.516
XLPE	15	750MCMCU	0.552
XLPE	25	#1CU	0.482
XLPE	25	1/0	0.500
XLPE	25	1/0	0.554
XLPE	35	1/0	0.560
XLPE	35	750MCM	0.504
PILC	15	4/0	0.482

FIG.7

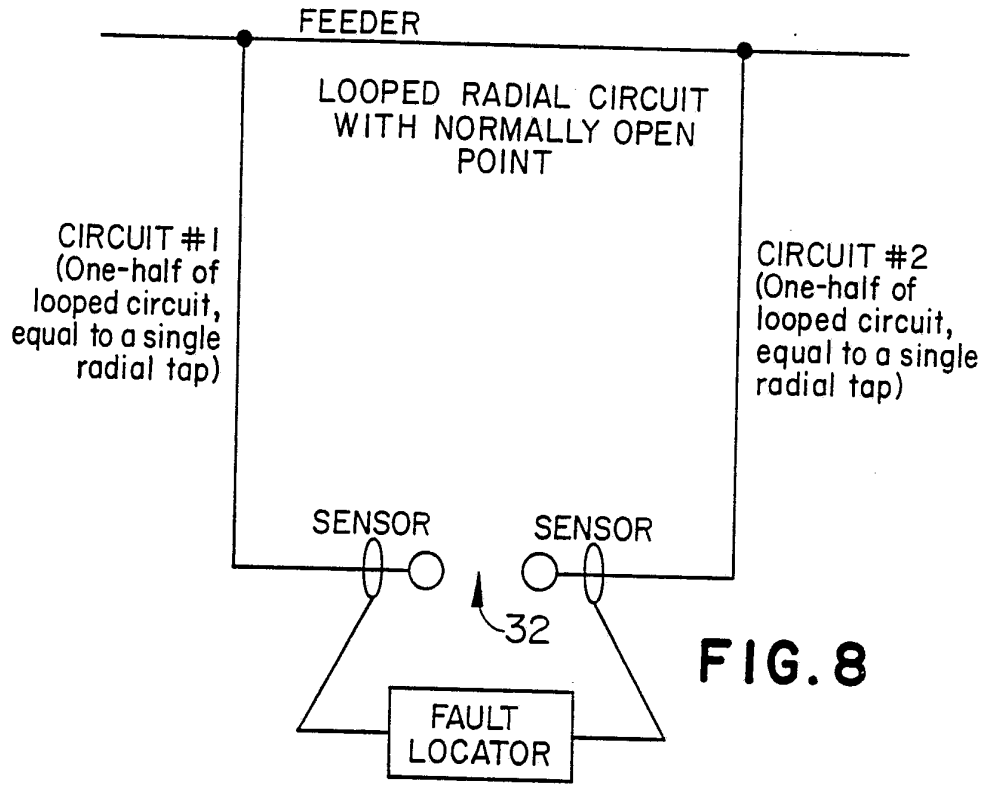


FIG.8

INTERNATIONAL SEARCH REPORT

PCT/US92/07603

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G01R 31/08
US CL :324/535, 532

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 324/532, 533, 534, 535, 527, 541, 544, 551; 379/25, 26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,766,549 (Schweitzer, III et al.) 23 August 1988, see column 1, lines 1-42.	1-25
A	US, A, 4,500,834 (Ko et al.) 19 February 1985, see figure 2.	1-25
A	US, A, 3,670,240 (Maranchak et al.) 13 June 1972, see the abstract.	1,15,24,25

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 17 NOVEMBER 1992	Date of mailing of the international search report 15 DEC 1992
Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer H. Leon Mcatt for MAURA REGAN Telephone No. (703) 305-4917

Form PCT/ISA/210 (second sheet)(July 1992)★