United States Patent [19]

Burney et al.

[11] **3,763,482**

[45] **Oct. 2, 1973**

[54] **COAXIAL CABLE TRANSDUCER**

[75] Inventors: **Charles F. Burney**, Milpitas; **Vytautas V. Pazemenas**, San Jose, both of Calif.

[73] Assignee: **GTE Sylvania Incorporated**, Mountain View, Calif.

[22] Filed: **Feb. 1, 1971**

[21] Appl. No.: **111,291**

[52] **U.S. Cl.** ..... **340/258 R**, 179/111 E, 340/88 ET, 340/261, 174/115

[51] **Int. Cl.** **G08b 13/12**

[58] **Field of Search** .... 179/111 E; 340/88 ET, 261, 258; 174/115

[56] **References Cited**

UNITED STATES PATENTS

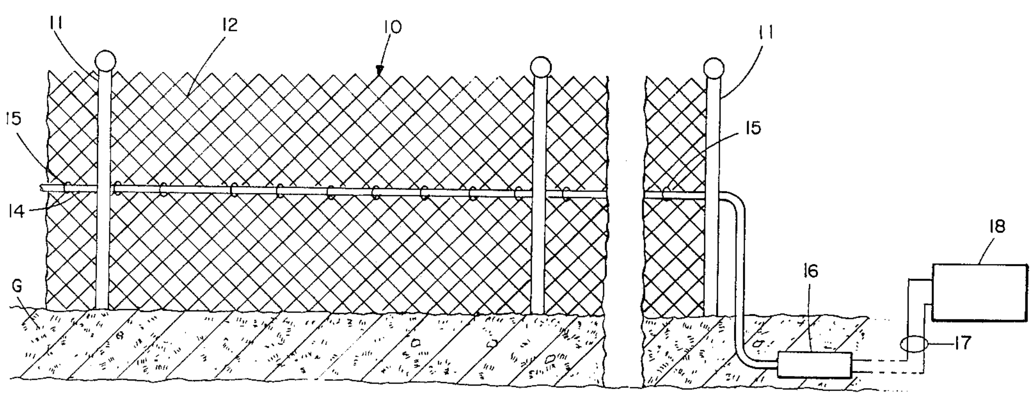
3,632,443	1/1972	Rodera et al.	307/88 ET
3,610,808	10/1971	Horwinski	174/115
3,449,094	6/1969	Baxt et al.	307/88 ET
2,403,503	7/1946	Coulter	340/261
2,345,771	4/1944	Reynolds	340/261

Primary Examiner—Benjamin A. Borchelt
Assistant Examiner—N. Moskowitz
Attorney—Norman J. O'Malley, John F. Lawler and E. J. Nealon

[57] **ABSTRACT**

A coaxial cable with a dielectric filler comprising a radially polarized electret develops and transmits a signal along the cable in response to deformation of the cable at any point along its length. Such a cable, when clamped to chain link, barbed wire, or similar fences, generates an electrical signal in response to attempts of intruders to climb or cut the fence and transmits that signal to remote alarm equipment. Standard coaxial cable is modified to form such a transducer by heating the entire cable, applying a dc potential across the ends of the outer and inner conductors while the dielectric filler is heat-softened, cooling the cable while maintaining the electrical stress on it, and finally removing the bias voltage. Signal amplification and processing eletronics, which are connected to the cable, detect intrusions and discriminate against false alarm signals.

9 Claims, 7 Drawing Figures



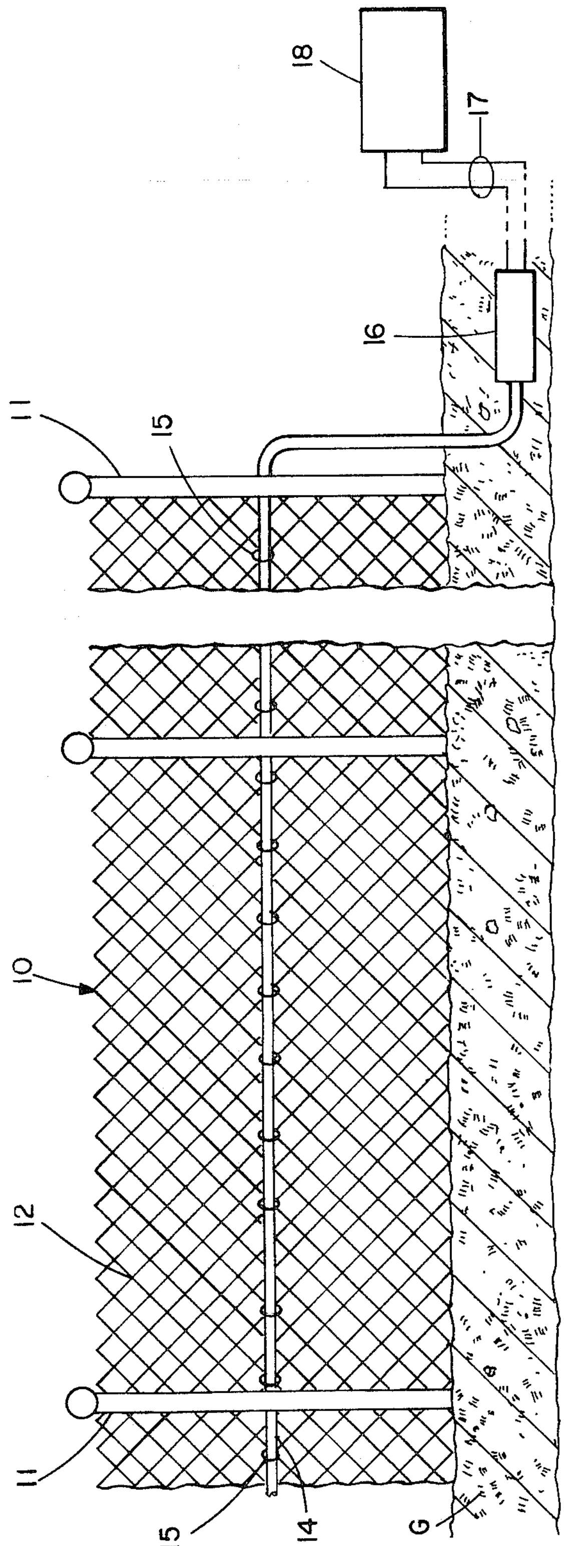


FIG-1

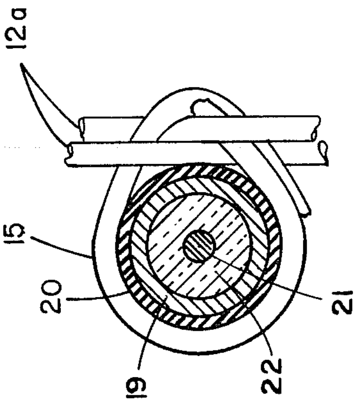


FIG-3

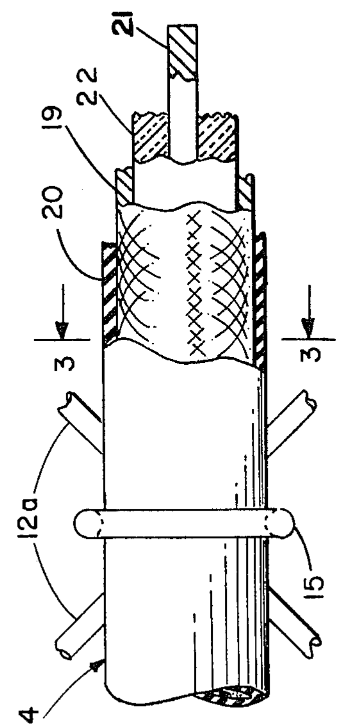


FIG-2

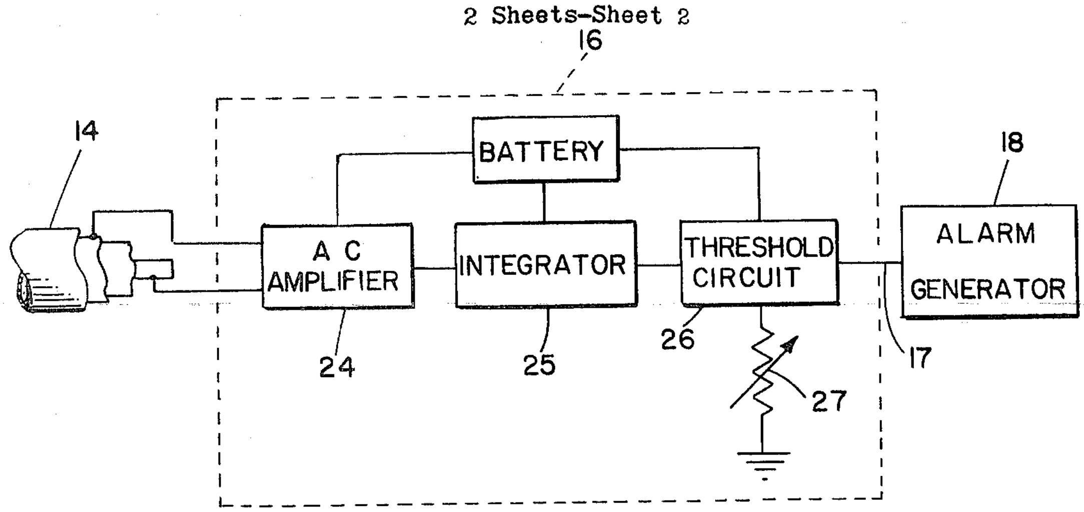


FIG - 4

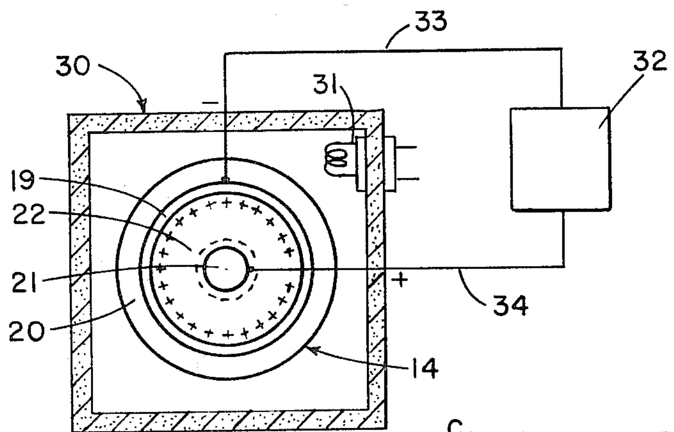


FIG - 5

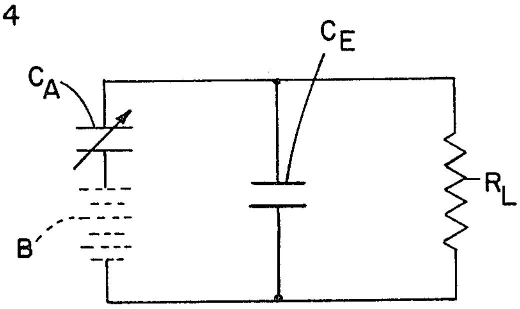


FIG - 7

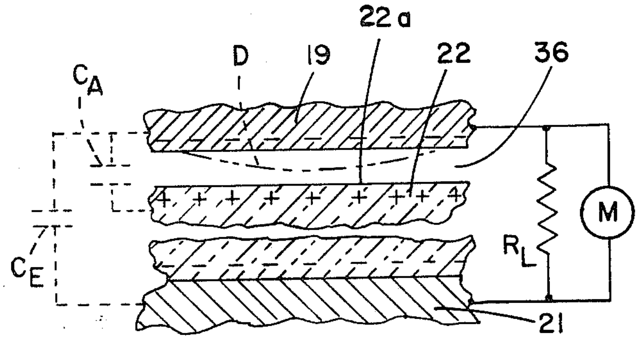


FIG - 6

COAXIAL CABLE TRANSDUCER

BACKGROUND OF THE INVENTION

The invention herein described was made under a contract with the Department of the Army.

This invention relates to transducers, and more particularly to a coaxial cable transducer and its method of fabrication.

The chain link or barbed wire fence is a commonly used barrier to prevent unauthorized intrusions into a secured or protected area. The effectiveness of such a fence, however, is limited when security of the protected area requires that an alarm or warning be given whenever any compromise of the fence is attempted. Various techniques have been proposed for providing sensitized barriers or fences but these have proven to be either ineffectual or costly or both. Moreover, the complexity and cost of modifying existing fences to provide intrusion detection capability have not produced satisfactory results.

An object of this invention is the provision of a simple low-cost transducer for sensitizing fences to produce an alarm when an intrusion or compromise of the fence is attempted.

Another object is the provision of a process for converting standard coaxial cable into a continuous transducer capable of converting disturbances into electric signals and for transmitting the signals to a remote location.

A further object is the provision of an inexpensive transducer which may be readily mounted on existing chain link fences or the like for sensitizing them to disturbances caused by intruders.

SUMMARY OF THE INVENTION

The dielectric filler in a coaxial cable is conditioned in such a manner that it becomes an electret "polarized" in the direction of a unidirectional (dc) electric field applied across the inner and outer conductors, i.e., radially. The entire cable is conditioned in this manner. The sensitized cable is so mounted or deployed that the condition to be detected causes a localized radial deformation of the outer conductor, which produces a signal voltage on the cable capable of being detected at the end of the cable by appropriate electronic apparatus. The transducer responds to rate of change of diameter of the outer conductor in producing the signal which then may be processed by a bandpass amplifier, integrator, and threshold circuitry to discriminate against false alarms. The process of sensitizing the cable consists of applying a dc electric field across the outer and inner conductors when the dielectric filler is heat-softened and maintaining this bias voltage until the filler cools and hardens thereby making it an electret.

DESCRIPTION OF DRAWINGS

FIG. 1 is a side elevation of a portion of a chain link fence to which a coaxial cable embodying the invention has been connected;

FIG. 2 is an enlarged cut-away portion of the coaxial cable of FIG. 1 showing the fence mounted clamp ring;

FIG. 3 is a transverse section taken on line 3—3 of FIG. 2;

FIG. 4 is a schematic diagram of the signal processing and alarm circuits to which the transducer is connected;

FIG. 5 is a schematic view of the interior of a coaxial cable illustrating the technique of sensitizing it;

FIG. 6 is a greatly enlarged partially schematic longitudinal section of the cable illustrating the theory of operation of the transducer; and

FIG. 7 is a schematic view of the equivalent circuit of the sensitized coaxial cable.

The phenomenon of electrets or polarized dielectric substances has been the subject of investigation and study for many years. In 1925 M. Eguchi demonstrated that cooling carnauba wax in an applied electric field produced permanent polarization charges, see Philosophical Magazine, Vol. 49, page 178 (Taylor and Francis, London, 1925). British Pat. No. 966,018, issued in 1965, and U. S. Pat. No. 3,316,620 disclose processes for producing electrets from thermosetting materials. The present invention is concerned with a specific adaptation of the electret phenomenon in coaxial cables such that this conventional low-cost transmission line is converted into an extremely sensitive transducer capable of translating slight mechanical deformations of the cable into detectable electrical signals. A specific application for such coaxial cable transducer is as an anti-intrusion sensor for chain link fences described below as a preferred embodiment of the invention. Other embodiments include using the transducer on barbed wire and other types of fences, burying it below the ground to detect seismic vibrations, integrating it with concrete floors and vaults as a sensor for a security system, stringing it with a chain barrier across a passageway, or any combination of these and other applications wherein the condition to be detected directly or indirectly changes the spacing of the outer and inner conductors. A particularly important feature of the coaxial cable transducer is that it may readily be adapted to include a continuity monitor so that attempts to sever the cable also generate an alarm signal.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, FIG. 1 shows a chain link fence **10** comprising vertical posts **11** secured in the ground G and supporting wire mesh fencing material **12.** In accordance with this invention, a coaxial cable **14,** described in greater detail below, is secured by clamping rings **15** to the fencing material **12** throughout the entire length of the fence. Cable **14** is connected to a signal processor **16** preferably buried adjacent to the fence, and an output line **17** from the processor transmits an alarm signal to a remote control and alarm station **18** preferably by an underground route for security reasons.

Clamp rings **15** tightly grip the outer surface of cable **14** and hold it against the fencing material so as to couple vibrations from the fence to the cable in such a manner as to produce an electrical signal within the cable as explained below. Processor **16** has a predetermined passband preferably of 200 Hz to 4 kHz so that low frequency disturbances such as wind-induced fence movements which typically generate within the cable signals having a frequency characteristic below 200 Hz do not produce an alarm signal on output line **17.** The system therefore is capable of discriminating against false alarms from such conditions. Disturbances which produce signals having frequencies within the passband such as severing of fence strands with a wire cutter (approximately 4 kHz), the climbing of the fence by a human, or snagging of clothing by the barbed wire strands do produce an output from processor 16 and provide an indication at station 18 that such compromises of the fence have been attempted.

Cable 14 initially is a conventional commercial product having a braided sleeve-type outer conductor 19, see FIGS. 2 and 3, covered by an insulating sheath 20 made of polyvinylchloride or the like, an inner conductor 21 and a dielectric filler 22 in the space between the inner and outer conductors. These coaxial layers are tightly formed around the inner conductor and normally are flexible and radially resilient. By way of example, a coaxial cable used in the practice of the invention with satisfactory results had an outside diameter of about ⅛ inch, a dielectric filler made of tetrafluoroethylene (sold under the trademark Teflon by E. I. duPont de Nemeurs & Co.) and is currently available on the commercial market. Clamping rings 15 tightly engage the periphery of the cable and lock it to strands 12*a* of fencing 12 so that no play exists between the cable and the fence strands at the point of connection. This insures that vibrations induced in the fence are coupled directly to the cable so as to move the outer conductor relative to the inner conductor.

Signal processor 16 comprises an ac amplifier 24, see FIG. 4, which places a resistive load between outer and inner conductors, an integrator 25, and a threshold circuit 26 connected in series. Amplifier 24 has a high gain, preferably about 100 db, and has a predetermined passband which may be and preferably is about 200–4000 Hz. The threshold level of circuit 26 is adjustable by a variable resistor 27 to provide further discrimination against unwanted or spurious signals. The output of circuit 26 is an alarm signal transmitted by line 17 to remote station 18 containing an alarm generator such as a bell or flashing light.

Referring now to FIG. 5, the technique for converting standard coaxial cable into a sensitive transducer will be explained. Cable 14 is heated in an oven 30 having a heating element 31 to a temperature sufficient to heat-soften dielectric filler 22, i.e., to the critical temperature below its melting temperature. While in this state, the filler is subjected to a strong unidirectional electric field from a high voltage source 32 connected by leads 33 and 34 to outer conductor 19 and inner conductor 21, respectively. In other words, bias voltage leads 33 and 34 are so connected to the outer and inner conductors that the entire cable is electrically stressed. The effect of this electrical bias on the entire body of heat-softened dielectric filler is to convert it into an electret as indicated in the drawings by the positive and negative charges at the outer and inner boundaries thereof. The cable including the electret filler are then cooled so that the latter again hardens and the bias voltage is maintained on the cable throughout this cooling period and for some time thereafter. This permits the polarization of the electret filler to "freeze" and assume a permanent set. The bias voltage is then removed and the cable is and remains substantially permanently sensitized.

The principle of operation of the cable transducer is believed to be based on the rate of change of position of the outer conductor relative to the cable interior which produces a transient though detectable signal across the inner and outer conductors. This will be better understood by reference to FIG. 6 which shows an effective air gap 36 between outer conductor 19 and the outer surface 22*a* of filler electret 22. This air gap 36 is believed to exist as a result of normal manufacturing tolerances and/or the use of a braided form of outer conductor wherein discontinuous contact is made between that conductor and the outer surface of the electret. As a consequence, the effective air gap 36 functions as a dielectric layer between adjacent faces of the outer conductor 19 and electret 22 forming therewith a capacitor C_A shown in broken lines. Outer and inner conductors 19 and 21, respectively, separated by the electret also function as plates of a larger capacitor C_E in parallel with capacitor C_A. When a portion of the outer conductor is moved inwardly toward electret surface 22*a* as indicated in broken lines at D, the capacitance of capacitor C_A changes at that point causing a transient signal to be generated between outer and inner conductors which appears as a voltage across load resistor R_L at the end of the cable measurable by meter M.

The equivalent circuit for the cable transducer is shown in FIG. 7 wherein capacitor C_A is depicted as a variable capacitor in parallel with capacitor C_E and in series with a battery B representing the static charge on the electret. Thus the variation in capacitance caused by the deformation essentially "modulates" the static charge on the line and produces a detectable signal which is transmitted by the line to the load resistance. The attenuation of this signal as it is transmitted along the cable is negligible. It should be noted that the transducer is responsive to the rate of change of position of the outer conductor toward the inner conductor to generate a transient signal or series of such signals. The characteristic frequency of such a signal is indicative of the nature of the disturbance or condition which generates it and enables discrimination against false alarms by filtering and integration techniques.

An important factor in the practical application of the coaxial cable transducer is the charge life of the filler, i.e., the length of time required for the charge to leak off the electret filler. The time rate of loss of charge or the "decay time" varies with different materials, the longest charge life having been observed in polycarbonates and tetrafluoroethylene (Teflon). The charge life of these materials is estimated to exceed 100 years at room temperature. The commercial availability of coaxial cable with a Teflon filler, therefore, makes this cable highly desirable as a microphonic detector.

By way of example, a coaxial cable 150 feet long having a Teflon filler 22 was heated to a temperature of 500° F and subjected to a bias voltage of 10 kV while at that temperature for 2 hours. Thereafter the oven was allowed to cool to room temperature with the bias voltage maintained for an additional period of one hour. This resulted in a transducer capable of developing a signal of 50 millivolts in response to application of a radial impact force of 50 grams. A pulsating or vibrating force having a frequency of 400 Hz applied to the exterior of the cable and having a peak-to-peak amplitude of less than 0.1 inch produced an ac signal of 5 millivolts at the same frequency taken at the end of the cable approximately 50 feet from the application of the force to the cable.

While satisfactory results have been obtained by heating the entire length of cable at one time in an oven during the sensitizing process, it is possible that certain non-uniformities in the formation of electrets might result from uneven heating of the cable. This possibility is obviated by passing increments of the length of the uncoiled cable progressively and continuously through an oven while electrically stressing it and similarly allowing it to cool. The cable is thus sensitized progressively in a manner that insures uniform electrical characteristics and also better adapts the process to mass production techniques.

The availability and low cost of the type of coaxial cable shown in FIGS. 1–3 and the optimum charge-retaining lifetime of its Teflon filler make it an ideal transducer for sensitizing existing chain link fences and the like or for being integrated into the fence material at the time of manufacture or installation. Tests have been made on chain link fences equipped with this sensitized coaxial cable and vibrations resulting from cutting of the fence material as well as those generated by climbing of the fence have been detected. The severing of a chain link fence strand with wire cutters typically generates a vibration having a frequency of 4 kHz which is transmitted through the fence material to the cable for ultimate detection. Attempts to cut the coaxial cable transducer slowly may be detected by a continuity check circuit in which a direct current is passed through the cable and an indication given when it is interrupted.

What is claimed is:

1. A transducer comprising

a coaxial cable having an inner conductor and an outer conductor and a dielectric filler between said conductors,

said filler comprising an electret.

2. The transducer according to claim **1** in which said filler is tetrafluoroethylene.

3. The transducer according to claim **1** in combination with means mechanically coupled to the exterior of said cable and responsive to a condition to be detected for changing the spacing of conductors, and

detector means electrically connected across said conductors for detecting an electrical signal generated by said changed conductor spacing.

4. The transducer according to claim **1** in which said electret is polarized in the direction of a unidirectional field applied across said conductors.

5. A system for detecting intrusion of a protected area comprising in combination,

a coaxial cable disposed across said area,

said cable having inner and outer conductors and an intermediate dielectric filler comprising an electret formed by a pre-applied unidirectional electric field across said conductors,

inducer means for changing the relative radial spacing of said conductors in at least one point along the length of the cable in response to a condition of attempted intrusion of said area whereby to generate an electrical signal across said conductors, and

detector means responsive to said electrical signal remote from said one point for producing an output indicative of the attempted intrusion.

6. The system according to claim **5** in which said detector means has a bandpass circuit whereby to produce said output only in response to signals generated by intruders.

7. The system according to claim **5** including a fence comprising wire strands, said inducer means comprising clamping rings tightly mechanically connecting said cable to said wire strands whereby vibrations in said strands are converted by said cable into electrical signals.

8. The system according to claim **5** in which said cable is buried under the earth's surface, said inducer means comprising earth material surrounding the cable.

9. The system according to claim **7** which includes a station located remote from said fence and having an alarm generator, said detector means being disposed adjacent to said fence and being electrically connected to said station whereby said output activates said alarm generator.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,763,482 Dated October 2, 1973

Inventor(s) Charles F. Burney et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 1, after "electret" add:

--[.] , and

utilization means connected to at least one of said conductors and responsive to a signal produced by transducer action of said cable.--.

Cancel Claim 2.

Claim 3 should read as follows:

"In combination, a transducer comprising a coaxial cable having an inner conductor and an outer conductor and a dielectric filler between said conductors, said filler comprising an electret,

means mechanically coupled to the exterior of said cable and responsive to a condition to be detected for changing the spacing of the conductors, and

detector means electrically connected across said conductors for detecting an electrical signal generated by said changed conductor spacing."

Cancel Claim 4.

Signed and sealed this 19th day of February 1974.

(SEAL)
~~Attest:~~

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,763,482 Dated October 2, 1973

Inventor(s) Charles F. Burney et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 1, after "electret" add:

--[.] , and

utilization means connected to at least one of said conductors and responsive to a signal produced by transducer action of said cable.--.

Cancel Claim 2.

Claim 3 should read as follows:

"In combination, a transducer comprising a coaxial cable having an inner conductor and an outer conductor and a dielectric filler between said conductors, said filler comprising an electret,

means mechanically coupled to the exterior of said cable and responsive to a condition to be detected for changing the spacing of the conductors, and

detector means electrically connected across said conductors for detecting an electrical signal generated by said changed conductor spacing."

Cancel Claim 4.

Signed and sealed this 19th day of February 1974.

(SEAL)
~~Attest:~~

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents