Sept. 22, 1953 C. A. BAYS 2,653,220

ELECTROMAGNETIC WAVE TRANSMISSION SYSTEM

Filed Oct. 21, 1949 2 Sheets-Sheet 1

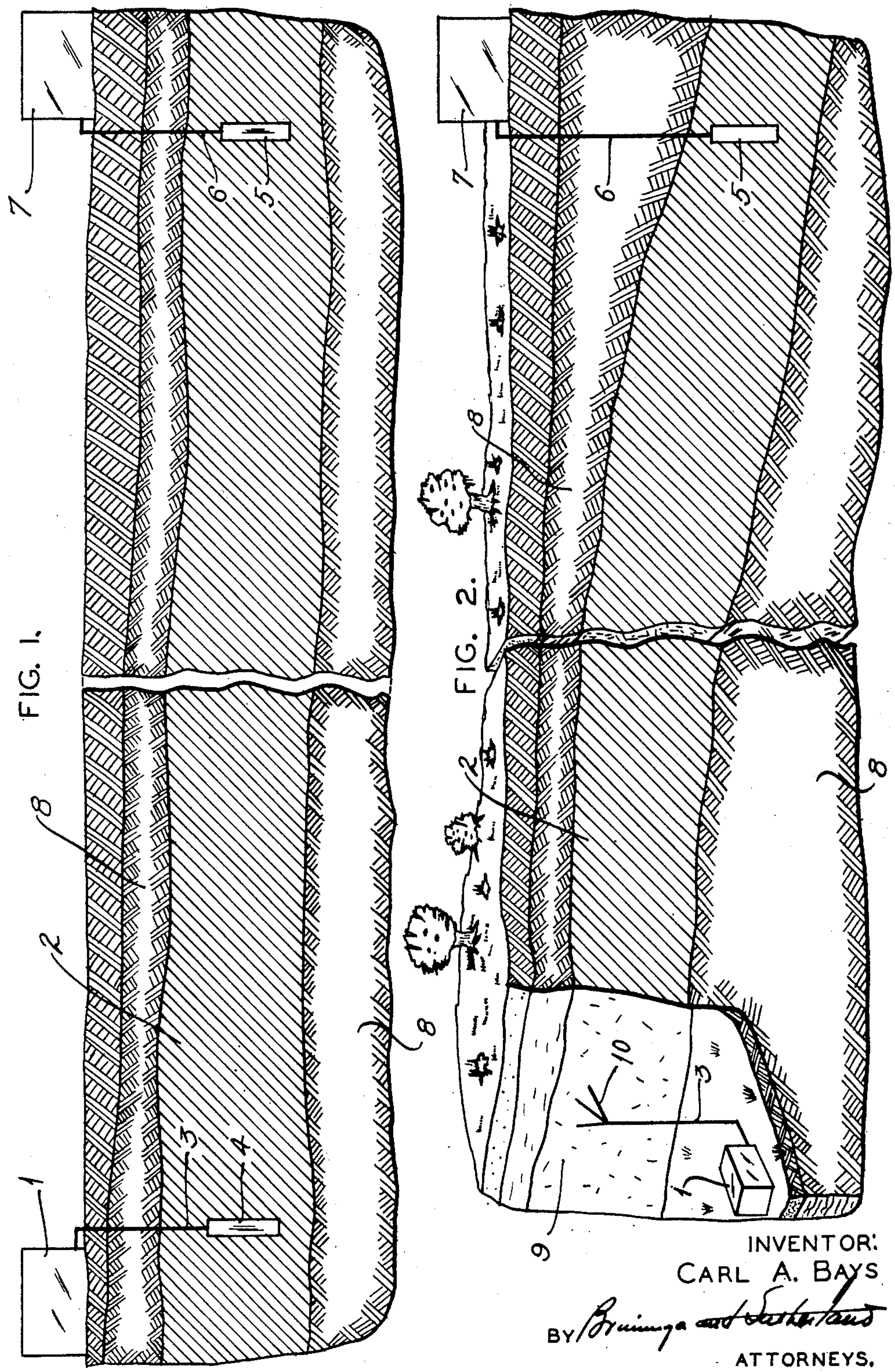

FIG. 1.

FIG. 2.

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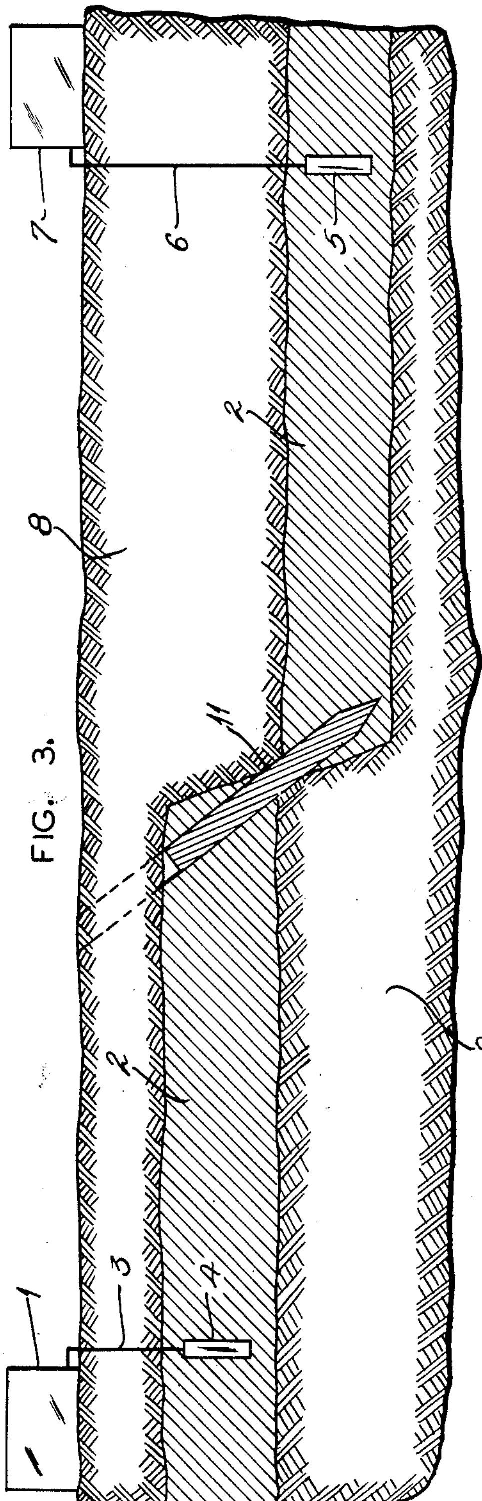

FIG. 3.

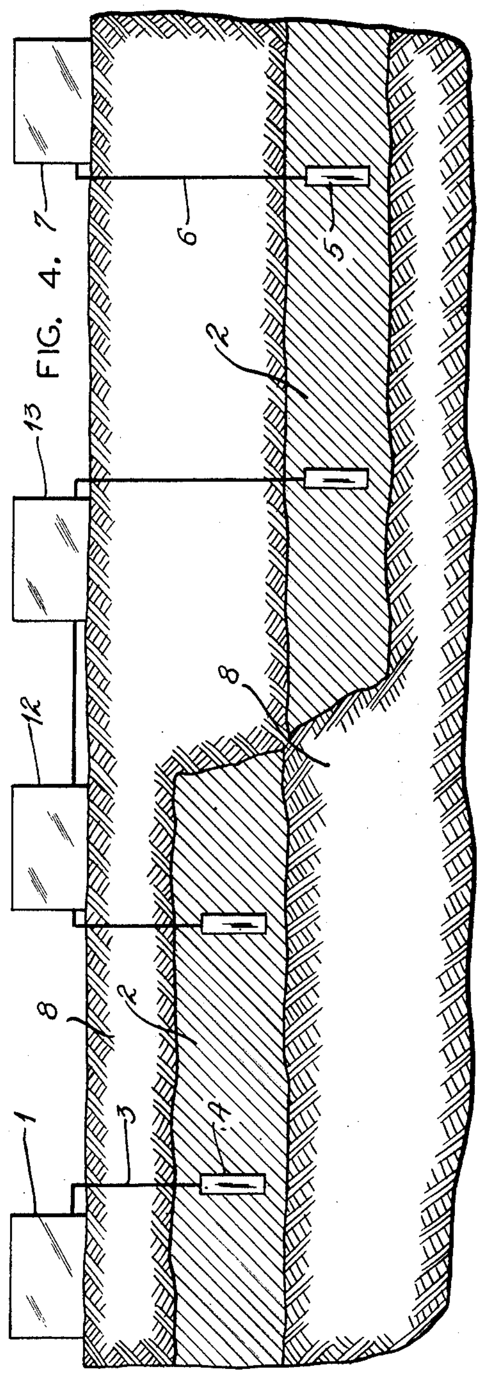

FIG. 4.

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ELECTROMAGNETIC WAVE TRANSMISSION SYSTEM

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10 Claims. (Cl. 250—3)

This invention relates generally to the transmission of electromagnetic and radio waves, and particularly to the transmission of such waves from point to point by utilizing solids of high electrical resistivity, as compared with the resistivity of metals.

Systems heretofore employed for the transmission of electromagnetic waves, especially of radio waves of broadcast and lower (under 100 kc.) frequencies and electromagnetic waves of the high frequencies used in television and frequency modulation transmission, have either propagated those waves through the ether or transmitted them through some metallic conductor. When the ether is used, the aerial systems required are expensive and cumbersome, and particularly at the higher frequencies, their effective transmitting distance is limited. Metallic conductors have serious disadvantages, among which is their high cost. Television frequencies require coaxial cable or its equivalent, which is even more expensive and difficult to handle than ordinary wire.

One object of this invention is to provide means for transmitting and receiving electromagnetic waves without reliance upon the ether or upon metallic conductors connecting the loci of transmission and reception.

Another object is to provide cheap and simple means for transmitting electromagnetic waves.

Other objects will become apparent when the following description is read in connection with the drawings.

This invention is predicated upon the discovery that certain lithologic formations which have a high order of electrical resistivity and are bounded, above and below, by formations of lower electrical resistivity, may be made to transmit electromagnetic waves laterally over great distances. Such formations as limestone and quartzite, bounded by shales, sandstones containing saline water, and the like, are particularly suitable. Such electromagnetic waves are guided through the formation of high electrical resistivity by the boundary formations of lower electrical resistivity, acting as imperfect conductors. The phrases "lithologic formations of high resistivity" and "strata of high resistivity," as used hereafter in the specification and claims, refer to formations whose electrical resistivity is sufficiently higher, relative to the formations which oppositely bound it, that the selected formation or stratum acts as a guided wave transmitting medium. The bounding lithologic for-

mations, or strata, of lower electrical resistivity are capable, to a considerably lesser extent, of transmitting electromagnetic waves, but operate more as conventional electrical conductors, being susceptible to stray electrical currents induced by power lines, radio ground waves, and the like, and power loss or attenuation. Formations of high resistivity are thus doubly valuable, being less subject to stray electrical currents, and having a high transmissive value. Suitable lithologic formations extend more or less continuously through great areas of this country. The limestone bed, known variously as the Galena Platteville formation (in the Chicago area), the Trenton (in the neighborhood of Cincinnati), and the Kimmswick (in the vicinity of St. Louis), for example, extends from the Mohawk Valley to Montana, and from Canada to Texas. Faults, folds, and stratigraphic facies changes in such formations which might make them discontinuous may be bridged by means of electrodes or by means of an intermediate receiver-transmitter system, as is later explained.

In the accompanying drawings:

Figure 1 is a diagrammatic view of a transmitter-receiver system;

Figure 2 is a diagrammatic view showing the use of an exterior antenna for introducing the waves into an exposed stratum of high resistivity;

Figure 3 is a diagrammatic view of a transmitter-receiver system showing one method of bridging separated lithologic formations, by means of an electrode; and

Figure 4 is a view showing another method of bridging the fault shown in Figure 3.

In accordance with this invention, electromagnetic waves generated by a transmitter are introduced into a selected lithologic formation, and are transmitted laterally through said formation to a receiver. The waves may be introduced into the formation in a number of ways. At outcrops of the particular formation through which transmission is to be accomplished, the waves may be directed from an antenna, above or at the surface of the ground, or may be directly coupled to the formation at the ground surface. In the more usual situation, where the formation to be used lies at some depth below the earth's surface, the propagator may take the form of a plug or plugs of a suitable material such as salt water, lead wool, copper or other metal either dispersed in concrete or plastic or in solid form, and the like, embedded in the formation and connected to the transmitter by a suitable conductor such as coaxial cable, a single conductor or a twisted pair. The composition and dimensions of a conductor and propagating plug depend upon the frequencies to be transmitted, the impedance of the transmitter, and primarily on the impedance characteristics of the lithologic formation, which depend upon the physical characteristics such as shape, minimum cross-section and fluid content of the formation itself, and also on its boundary conditions and the characteristics of the overlying and underlying formations.

At the receiving end it is considered preferable, but not necessary, to duplicate as nearly as possible the antenna or propagator of the transmitter in the same formation. For optimum efficiency, the impedance of the transmitter's propagating plug and the receiver's terminating plug are matched as nearly as possible to the impedance characteristics of the formation between the loci of transmission and reception. The output impedance of the transmitter and the input impedance of the receiver and their respective conductors are matched to their respective plugs. It is apparent that impedance matching may also be utilized as a means of determining the impedance of a particular formation between two points in the formation.

Discontinuities in a formation may be bridged in any of several ways. A receiver-transmitter system is especially desirable where the characteristics of the formations to be joined differ. In such a case, electromagnetic waves from the original transmitter, transmitted in the first formation, are picked up by a receiving system the impedance of which is matched as well as can be to the impedance of the formation to which the receiver is connected, and are fed to a transmitter connected with the second formation, to which the impedance of the second transmitter, its conductor and plug, are matched. The impedance of a receiver from the second formation is, of course, matched to the second formation.

Alternatively, two formations may be connected by a conducting electrode bridge. Boreholes may be drilled, or trenches dug, connecting the two formations, which boreholes or trenches may be filled with materials of the character suggested for propagating and terminating plugs, the dimensions of which and characteristics of which will be determined by the impedance of the formations sought to be connected.

Referring now to the figures, **1** represents a transmitter connected to lithologic formation **2** by means of a conductor 3 and propagating plug **4**. Connected to the same formation **2** by terminating plug **5** and conductor **6** is a receiver **7**. Transmitter **1** and receiver **7** are of the types generally used for the transmission and reception of ordinary broadcast, frequency modulated, or television waves. Formation **2** is bounded by lithologically distinct formations **8**. In Figure 2 the selected formation **2** outcrops at a face **9**. Electromagnetic waves are directed into the face **9** from antenna **10**. It is understood that waves introduced into a formation by means of a propagating plug may be received by means of an external antenna, or that waves introduced by an external antenna may be received by means of an external antenna, the external antennae being directed toward the selected formation. In Figure 3 a discontinuity in formation **2** is bridged by means of electrode **11**. The electrode **11** may be made of copper or other conducting metal, either dispersed in concrete or in plastic, or in solid form, lead wool, salt water, or, when made of comparable dimensions with the two formations being bridged, of concrete or other rock-like material. In Figure 4 the discontinuity of Figure 3 is bridged by means of intermediate receiver **12**, connected with intermediate transmitter **13**, by a conventional conductor or aerial transmission-reception system.

It is apparent that except for the comparatively short distances involved in bridging faults by means of the intermediate receiver-transmitter system, and the almost negligible distance between exterior antennae and outcrops in those situations in which outcrops of the selected formation are utilized as described, a system is provided which depends neither upon the ether nor upon continuous metallic conductors between transmitter and receiver. Thus, the present invention provides means for transmitting electromagnetic waves without the use of towering aerials, without the use of coaxial cable or other metallic conductors joining the transmitter and ultimate receiver, unlimited as to distance by the curvature of the earth's surface, with comparatively cheap, simple, sturdy, propagating equipment and an almost indestructible transmitting medium.

Having thus described the invention, what is claimed and desired to be secured by Letters Patent is:

1. A wave transmission-reception system, comprising transmitter means, means for introducing waves from said transmitter into a uniform lithologic stratum of high resistivity bounded on either side by lithologic formations of greater conductivity so as to form, in effect, a wave guide, and means for receiving said waves from said lithologic stratum.

2. A wave transmission-reception system, comprising transmitter means, receiver means, conductors connecting each of said means to a lithologic stratum of high resistivity bounded on either side by lithologic strata of greater conductivity, the impedance of the said lithogolic stratum of high resistivity between the loci of connection with said means being matched by the impedance of said conductors.

3. A wave transmission-reception system, comprising transmitter means, a propagating plug embedded in a lithologic stratum of high resistivity bounded on either side by lithologic strata of greater conductivity and connected to said transmitter means by a conductor, receiver means, a terminating plug imbedded in said lithologic stratum of high resistivity at a distance from said propagating plug and connected to said receiving means by a conductor, the impedance of said propagating plug and said terminating plug matching the impedance of said lithologic stratum of high resistivity intermediate the said plugs.

4. A wave transmission-reception system, comprising transmitter means, an antenna above the earth connected to said transmitter means and directed toward an exposed lithologic stratum of high resistivity bounded by lithologic strata of greater conductivity, receiver means, a terminating plug the impedance of which matches that of the said lithologic stratum of high resistivity between the loci of transmission and reception, and a conductor connecting said terminating plug with said receiving means.

5. A wave transmission-reception system, comprising transmitter means, a propagating plug embedded in a lithologic stratum of high resistivity bounded on either side by lithologic strata of greater conductivity and connected to said transmitter means by a conductor, receiver means, a terminating plug embedded in said lithologic stratum of high resistivity at a distance from said propagating plug and connected to said receiving means by a conductor, the impedance of said terminating plug matching the impedance of said lithologic stratum of high resistivity intermediate said terminating and said propagating plugs.

6. A wave transmission-reception system, comprising transmitter means, a propagating plug embedded in a lithologic stratum of high resistivity bounded on either side by lithologic strata of greater conductivity and connected to said transmitter means by a conductor, receiver means, and an antenna above the earth directed toward said lithologic stratum of high resistivity and connected to said receiver means.

7. A wave transmission-reception system, comprising transmitter means, a conductor directly coupled to an outcrop of a lithologic stratum of high resistivity bounded on either side by lithologic strata of greater conductivity and connected to said transmitter means, receiver means, a terminating plug embedded in said lithologic stratum of high resistivity at a distance from said direct coupling and connected to said receiving means by a conductor, the impedance of said terminating plug matching the impedance of said lithologic stratum of high resistivity intermediate said terminating plug and said direct coupling.

8. A wave transmission-reception system comprising transmitter means, means for introducing electro-magnetic waves from said transmitter into a single uniform lithologic stratum bounded on either side by formations of such greater conductivity as to form with said lithologic stratum a guided wave transmitting medium, and means for receiving said waves from said lithologic stratum.

9. A wave transmission-reception system, comprising first transmitter means, first receiver means, conductors connecting each of said first means to a first single lithologic stratum bounded on either side by formations of such greater conductivity as to form, in effect, a wave guide, a second transmitter means, a second receiver means, conductors connecting each of said second means to a second single lithologic stratum bounded on either side by formations of such greater conductivity as to form, in effect, a wave guide, and conductors connecting said first receiver means with said second transmitter means.

10. A wave transmission-reception system comprising transmitter means, means for introducing electro-magnetic waves from said transmitter into a first lithologic stratum of high resistivity bounded on either side by formations of such greater conductivity as to form, in effect, a wave guide, and means for receiving said waves from a second lithologic stratum of high resistivity bounded on either side by formations of such greater conductivity as to form, in effect, a wave guide, said first and second lithologic stratums being connected by a conducting electrode bridge.

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