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DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Method and Apparatus for the Remote Detection of Conducting Bodies

We, BARRINGER RESEARCH LIMITED, of 145, Belfield Road, Rexdale, Ontario, Canada, a corporation organized and existing under the laws of Canada, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method and apparatus for the remote detection of conducting bodies.

The present invention represents improvements in the methods and apparatus described in our co-pending application Serial Number 18551/59 (Serial No 883465).

Present day airborne electromagnetic geophysical systems normally operate by continuously transmitting one or more audio-frequencies from coils mounted on aircraft, and detecting the secondary response from conductors in the ground by using receiving coils mounted on the aircraft or towed behind in a bird. Since the wave forms transmitted are continuous, it is necessary to detect the secondary field in the presence of the primary field which involves elimination of the primary field from the receiving system. This is generally achieved by one of two methods: Firstly by holding the receiving and transmitting coils in some fixed orientation relationship and electronically balancing out the component of the primary field detected in the receiving coil, or secondly by eliminating all components which are in phase with the transmitted field and detecting only that component in the receiving coil which may be resolved into quadrature phase relationship

with the transmitted field. The receiving coils may be mounted in the aircraft or towed behind in a bird. If the receiver is mounted in the aircraft, the sensitivity of the receiving coil to vibration and attendant variations in the pick-up of the transmitted field is acute since minute movements of the receiving coil will strongly modulate the coupling with the transmitted field. Where quadrature components only are measured, a high noise is introduced by close coupling of the receiver coil in the aircraft with quadrature components of the induced currents in the metal aircraft frame. If the receiving coil is towed behind the aircraft in a bird, limitations on sensitivity are determined by the inevitable variations in position of the bird in relation to the aircraft and the geometry of the transmitted field. Only the pure quadrature system after suitable compensation for the aircraft frame currents is virtually free from misorientation noise when a towed bird is used and this system suffers the disadvantage that considerable information is lost when only quadrature measurements are made. Some attempts have been made to overcome the latter disadvantage by the use of two frequencies simultaneously, the quadrature responses at two frequencies being equated as roughly the same as the use of in-phase and quadrature measurements at one frequency. This technique however is not wholly satisfactory because different current paths are energized at different frequencies in naturally occurring conductors in the ground and consequently the interpretation of the results is considerably increased in ambiguity.

Another limitation of quadrature systems

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together with all existing airborne electromagnetic systems is that in practice the receiving coil must be used in maximum coupling with the transmitted field since slight changes in orientation in the position produce a much smaller percentage change in coupling (a function of the cosine of the displacement angle) than in other positions, particularly as compared with the null coupling position (a function of the sine of the displacement angle.) Consequently, existing airborne electromagnetic systems almost exclusively measure the one component of the secondary field which is resolved along the direction of the axis of the receiving coil.

In contrast to the above, it has been found that it is possible with the present invention in which transient responses are used, to measure the secondary field of a conductor during a period when the primary field is either absent or not time varying, regardless of the orientation of the receiving coil.

Using this technique, it becomes possible to measure secondary fields without any noise levels due to the interference of the primary field regardless of variations in coupling between the receiving and transmitting coils. Furthermore, all three components of the secondary field can be measured using three mutually perpendicular receiving coils. This added information is of value for the following reasons. Firstly, universal coupling is maintained with conductors in the ground regardless of flight direction. In other systems conductors may be missed if they are accidentally crossed at an angle where the receiving coil is in null coupling with the ground conductor. Secondly, information can be deduced from the three component response on the dip of the ground conductor enabling positive discrimination between conductive overburden such as swamp and dipping conductors of possible economic value.

A further very important advantage of the invention as compared with other airborne electromagnetic systems, particularly of the quadrature or out of phase type, is that transient analysis gives information on the inductive response equivalent to the use of a large number of frequencies. When two conductors are present, e.g. a good conductor underlying a swamp, transient analysis enable the responses to be distinguished.

Thus the invention provides apparatus for the detection of conducting bodies and comprising signal generating means for radiating primary electromagnetic waveforms produced in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, receiving means for detecting said secondary signals, reradiated by a conducting body and

occurring after said abrupt discontinuities in said primary waveforms, electronic sampling means normally blocking said signals and operable intermittently to sample portions of said secondary signals, and means for recording the presence of the sampled portions thereby to provide evidence of the presence of conducting bodies.

The invention further provides a method of detecting conducting bodies and comprising initiating primary electromagnetic waveforms in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, detecting said secondary signals, sampling at least one portion of the detected secondary signals at a predetermined time interval after said abrupt discontinuities in said primary waveforms, and recording the presence of such sampled portions thereby to indicate the presence of conducting bodies.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 shows a single current pulse wave form of the type circulating in the transmitting loop;

Figure 2 shows a partially cut away perspective view of a three receiving coil bird according to the invention;

Figure 3 shows a perspective view of the suspension means for the bird;

Figure 4 shows a block diagram of one channel of the receiving system of the invention;

Figure 5 shows a received wave form of a primary pulse followed by a transient field response from a conductor of high conductivity;

Figure 6 shows a similar received wave form followed by a transient field response from a conductor of low conductivity;

Figure 7 shows a wave form of the signal received from the tuned amplifiers and the position of secondary detection gating;

Figure 8 shows a typical recorded response on a single channel picked up during flight traverse across a conductor;

Figure 9 shows a simple transient field response from a single conductor illustrating the positioning of samples which may be taken by the first detector gates;

Figure 10 shows a typical orientation of an ore body of good conductivity underlying swamp of poor conductivity;

Figure 11 shows a complex transient wave form arising from two conductors, one of high conductivity and the other of low conductivity similar to the bodies illustrated in Figure 10, broken lines illustrate the two component transients which make up the resultant complex transient;

Figure 12 shows a complex transient wave form illustrating positioning of three first detector gate samplings;

5 Figure 13 shows typical triple first detector gate samplings of the transient wave response received from the vertical transverse coil;

Figure 14 shows typical single first detector gate sampling of the transient wave response received by the horizontal coil;

10 Figure 15 shows typical single first detector gate sampling of the transient wave response received by the vertical longitudinal coil;

Figure 16 shows a block diagram of an electromagnetic detecting system of the invention utilising multiple channels;

15 Figures 17 and 17a show in two parts a schematic wiring diagram giving details of a pulse generator transmitter circuit suitable for use with the present invention; and

20 Figure 18 shows a schematic wiring diagram of a pre-amplifier for the signals received in the receiving coils suitable for use with the present invention;

25 Figure 19 shows a schematic wiring diagram of one channel of the receiving portion of the receiver in a form suitable for use with the present invention;

Figure 20 shows an example of the type of recording obtained according to the present invention.

30 Referring now to the drawings, current pulses of the form shown in Figure 1 are generated by a pulse generator adapted to produce 80 pulses per second normally into a loop transmitter thereby radiating a pulsed electromagnetic field. Primary current pulse is seen as a differentiated wave form when detected as voltage in a receiving coil.

35 A circuit diagram for a transmitter suitable for use with the instant invention is shown in Figures 17 and 17a. The loop of the transmitter may be mounted on an aircraft (not shown).

40 The bird 10 shown in Figures 2 and 3 is adapted to be towed by cable 11 at a distance of about 500 feet from an aircraft (not shown). The suspension of bird 10 is shown in more detail in Figure 3. The cable 11 which contains the electrical connections and tow cable is joined to an elastic shock cord 12 by suitable means at 13. The elastic shock cord 12 forms a loop which is joined at its ends to each side of the bird as at 14 by suitable means such as a bolt arrangement. The shock cord 12 is formed of a heavy elastic cord in a woven casing and is designed to isolate cable vibration from the bird. The bird 10 contains three inductive detectors in the form of three ferrite cored coils 15, 16 and 17 wound to a resonant frequency of 12 KC. Coil 15 is the vertical longitudinal coil responsive to the horizontal component of fields resolved in the direction of flight. Coil 16 is the horizontal coil responsive to the vertical component of fields and

coil 17 is the vertical transverse coil responsive to the horizontal component of fields at right angles to the direction of flight. In actual practice, coils 15 and 16 may consist of a plurality of coils wound on short ferrite rods and joined together in series in ladder fashion. In this way, a suitable saving of space may be effected within the bird 10. The coils may be coated in silicone rubber which cures at room temperature and must be very carefully acoustically isolated with felt and foam rubber to minimize microphonics. Each of the coils 15, 16 and 17 are independently critically damped by means of adjustable potentiometers 18, 19 and 20. The inside of the bird 10 is provided with faraday shielding 21 further to reduce interference, the faraday shielding being grounded through cable 11.

Three pre-amplifiers 22, 23 and 24 having a frequency response of 5 cps—20 KC are provided for the coils 15, 16 and 17. The amplifiers should have good transient response and noise level not more than 10 microvolts peak to peak at the input.

90 The concept of the separation of transients involves time gating in the receiver system of the type shown in Figure 4, in which a block diagram of the circuitry of a single channel is shown. (An example of the wiring diagram of the receiving portion of the circuitry shown in Figure 4 is given in Figure 19.) The use of multiple channel detection is considered more fully hereafter. Signals from a coil such as 15 in the bird 10 pass through the corresponding pre-amplifier 22. (By way of an example a schematic wiring diagram for a pre-amplifier suitable for use with the present invention is shown in Figure 18.) A high pass filter 25 having a low cut-off frequency of ten cps is interposed between the amplifier 22 and first detector gate 26. The high pass filter 25 passes the received pulse and secondary field transient without distortion. It filters out the low frequency signals generated by the movement of the bird 10 and its receiving coils in the earth's magnetic field.

110 The first detector gate 26 is conveniently adjustable between 20 microseconds and 1 millisecond in width with normal operation of 100 microseconds. It is arranged to take a sample of the signal detected immediately following the transmitted pulse. Thus, if any secondary transient field is present, it will be detected.

115 First and second tuned amplifiers 27 and 28 are two amplifiers arranged in cascade and tuned to the same frequency as the pulse repetition rate. Pulses are received at the tuned frequency of the amplifiers from the first detector gate. Thus, if the first detector gate is sampling random noise, it will pass signals of randomly varying polarity and amplitude which will tend to integrate out in

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the tuned amplifiers 27 and 28. If, however, the first detector gate is sampling a transient secondary field, as shown by the wave form of Figure 5 the signal will cohere
 5 and generate an 80 cps signal in the tuned amplifiers.

The second detector gate 29 samples the output of the tuned amplifiers at a repetition rate locked to the transmitted pulse rate, i.e. to the tuned frequency of the amplifiers.
 10 An illustration of the signal and gating is shown in Figure 7. The second detector gate is designed to be adjustable in width from 20 microseconds to 10 milliseconds. It is also adjustable in phase so that samples are taken at the peaks of the sine wave from the tuned amplifiers as shown.

The integrator 30 consists of a passive low pass filter network arranged to convert the pulse from the second detector gate into a slowly fluctuating D.C. signal. The time constant of the low pass filter or integrator 30 is conveniently adjustable between 1 and 4 seconds. The integrator or low pass filter
 20 30 has the function of integrating coherent signals over the period of the time constant of the network whilst tending to integrate out and destroy noise fluctuations of random polarity which manage to pass the tuned amplifier system. The longer the time constant the narrower the effective bandwidth of the system and the greater the reduction in noise.

Normally, a two second time constant would be used for traversing at 500 feet above ground level. Figure 8 shows a typical anomaly detected at 500 feet with the aircraft flying at 100 miles per hour from which it can be seen that the length of the time constant of the integrator may be increased to a maximum of 4 seconds to smooth out the signal and reduce noise variations, but if the time constant is made too long (e.g. 10 seconds) the shape of the anomalies produced by conductors below the aircraft will be seriously distorted.

The recorder 31 is most conveniently of the high sensitivity mirror galvanometer type. A typical such recorder which would be suitable for use with the present invention is the Visicorder (a Trade Mark of Honeywell Controls Ltd.) model 1012, manufactured by Honeywell Controls Ltd. This has the advantage of eliminating D.C. amplifiers from the system with the concomitant simplification of the system and elimination of the risk of trouble occasioned by D.C. drift.

Moreover, the mirror galvanometer permits the use of passive rather than active integrators. It also utilizes high intensity ultra violet lamps and special paper thus permitting direct recording without the need for chemical developers.

The above description relates to the receiving of pulses from a single coil. It will be appreciated that separate channels are used

to record the responses of each coil. Moreover, if more than one primary gating is to be sampled from each coil, it will require a separate channel to effect this. A schematic block diagram showing multiple channels is illustrated in Figure 16.

Thus it can be seen that by utilizing three coils such as 15, 16 and 17, it is possible to measure all the components of the secondary field. Flat conductors give a different ratio of response in the vertical and horizontal coils and a different relative positioning of the peak response as compared with inclined conductors. Thus by measuring all the components of the secondary field it is possible to estimate an orientation of the conductor in the ground and recognize the conductive bottoms of lakes and swamps and differentiate them readily from dipping conductors.

A more complicated situation arises in the case of conductors disposed as shown in Figure 10, i.e. an ore body of good conductivity underlying a body of poor conductivity such as a swamp. A consideration of the manner of distinguishing such a situation according to the present invention will be more readily understood from the following discussion of the principle of measurement of the conductivity of conductors.

The measurement of the conductivity of conductors is based upon the estimation of the time constant of the decaying transient produced when the conductor is energized with a pulse. Normally an ore body consisting of base metal values occurring in a massive sulphide deposit may be considered as a conductive sheet in which circulating current will be induced in the presence of a time varying electromagnetic field. In general a current pulse of the type shown in Figure 1 circulating in a transmitting loop adjacent to a conductive sheet will induce a similar current pulse in the conductive sheet. This pulse will tend to circulate in the loop formed by the periphery of the sheet. Transient effects at the termination of the pulse will be similar to the transient decay of current in a coil or a loop of wire. The current will decay exponentially in the following manner.

Let the current after a time t after termination of the pulse $= i(t)$

Let the voltage at the termination of the pulse $= V$

Let the resistance of the current loop $= R$

$$\text{Then } i(t) = \frac{V}{R} e^{-\frac{Rt}{L}}$$

When $t = \frac{L}{R}$ the exponent equals -1

and the current has fallen to 36.8% of its value at the moment of final collapse of the energizing field.

The value of $t = \frac{L}{R}$ is defined as the time constant T_c of the circuit.

In a conducting sheet, L is a function of the size of the sheet and the current loop which circulates around its periphery R is a function of the specific resistivity of the material of the sheet and its thickness. As an approximation for a given conductive material and a given thickness of sheet, the

time constant $\frac{L}{R}$ is constant since L and R both vary linearly with the distance around the circulating current loop. Hence a measurement of the time constant gives a measure of the conductivity characteristics of a sheet which aids in the recognition of varied ore deposits. For a simple sheet the time constant is directly related to the measurement of phase shift made with a continuous wave system.

In the case where disseminated sulphide particles are present in a naturally occurring conducting mass or sheet, the transient effects cannot be approximated solely by considering them in terms of inductance and resistance. Polarization effects and capacitance effects occur at the interface of the conductive sulphide particles with the enclosing rock material. These effects are recognized by exceptionally long decay periods and are of considerable diagnostic value. The evaluation of polarization and capacitance effects is virtually impossible with a single frequency continuous wave approach.

The time constants of conductors are measured in principal by using two channels in which samples A and B are taken with a time separation occurring between them (see Figure 9). Since the transient has an exponential form the ratio of $\frac{A}{B}$ is the same for all parts of the curve having a fixed time separation and the ratio of $\frac{A}{B}$ is related to the time constant.

Let the initial voltage $= V$
Let the voltage after time $t_1 = A$
Let the voltage after time $t_2 = B$

Time Constant
20 Microseconds—100 Microseconds
100 Microseconds—200 Microseconds
200 Microseconds—1 Millisecond
Over 1 Millisecond

Let T_c = Time constant of transient
Then in the general case for an exponential decay

$$\text{Voltage after time } t = Ve^{-\frac{t}{T_c}}$$

$$\text{Therefore } A = Ve^{-\frac{t_1}{T_c}}$$

$$B = Ve^{-\frac{t_2}{T_c}}$$

$$\text{Therefore } \frac{A}{B} = \frac{Ve^{-\frac{t_1}{T_c}}}{Ve^{-\frac{t_2}{T_c}}} = e^{\frac{t_2 - t_1}{T_c}}$$

$$\text{Therefore Log. } \frac{A}{B} = \frac{t_2 - t_1}{T_c}$$

$$\text{or } T_c = (t_2 - t_1) \left[\text{Log. } \frac{A}{B} \right]^{-1}$$

The following are some typical values of time constant for various ratios of $\frac{A}{B}$ assuming a separation of 100 Microseconds between A and B .

When $\frac{A}{B} = 1.23$	$T_c = 500$ Microseconds	
$= 1.3$	$T_c = 400$ Microseconds	60
$= 1.4$	$T_c = 300$ Microseconds	
$= 1.65$	$T_c = 200$ Microseconds	
$= 2.0$	$T_c = 140$ Microseconds	
$= 2.8$	$T_c = 100$ Microseconds	
$= 3.5$	$T_c = 80$ Microseconds	65

The time constant for naturally occurring ground conductors varies considerably and the following may be taken by way of a guide:

Classification of Conductor

Poor e.g. conductive swamp, lake water, etc.	
Medium e.g. weakly mineralized shear zones, lake bottom silts, conductive clays	
Good e.g. massive sulphide ore bodies, barren sulphides, graphite	
Polarizing conductor. Disseminated sulphide deposits exhibiting capacity and induced polarization effects	



sulphide

However, it will be appreciated that all transient wave forms will not be of a simple nature. The presence of disseminated sulphide particles or the presence of two conductors disposed as shown in Figure 10 will cause variations in the transient wave form, as illustrated by the transient wave form shown in Figure 11.

In the case of complex transients of the form shown in Figure 11, it will be seen from the Figure that the left-hand or steep portion of the curve represents a short time constant arising from a poorly conductive overburden. The lower right-hand part of the curve shows a long time constant arising from an underlying good conductor.

In order to measure complex transients, it is necessary to take three samples, A, B and C. (See Figure 12). It will be apparent that for a simple exponential transient

$$\frac{A}{B} = \frac{B}{C} \text{ or } AC = B^2 \text{ or } \frac{AC}{B^2} = 1. \text{ (See Figure 9)}$$

For a complex transient involving a mixture of exponential curves $\frac{AC}{B^2}$ is equal to

a ratio greater than 1. Thus the ratio $\frac{AC}{B^2}$ can be used to determine the degree of complexity of the transient. The ratio of A:B and B:C and AC:B² may be obtained electronically.

The long tail of a transient response from a good conductor underlying a poor conductor as shown in Figure 10 is a major feature of the invention. A relatively undistorted estimate of conductivity of a conductor masked by swamp and the like may be made. In present day continuous wave systems using only one frequency for in phase and quadrature measurement or two frequencies for quadrature measurement only, conductivity estimates based on phase shifts are severely distorted by the presence of conductive overburden since mixed phases cannot be separated.

In the present invention the parameters of a complex transient are most conveniently measured on the vertical transverse coil. Three signal samples A, B and C are taken as shown in Figure 13 and fed to respective channels designated 1, 2 and 3 in Fig. 16. By the use of suitable delays the ratios of signal B in Channel 2 to signal C in Channel 3 can be used to make a rapid determination of the true conductivity of masked conductors. (See Figure 12). If Channel 1 is set immediately to follow the pulse and Channel 2 is delayed 400 Microseconds and Channel 3 is delayed a total of 800 Microseconds, Channel 2 and Channel 3 will not receive any signal from conductors of low conduc-

tivity such as conductive swamp, clay or lake bottoms, due to the short time constant of the transient response received therefrom. They will however detect good conductors masked thereby and also disseminated sulphide zones of low conductivity which exhibit long transients due to polarization and self capacity effects. Disseminated sulphides can form commercial ore bodies and the invention gives a new approach to their discrimination from the far more numerous other types of low conductivity conductors. Signal Samples D and E shown in Figures 14 and 15 are derived from the horizontal and vertical longitudinal coils respectively and are fed to respective channels 4 and 5. They are not used to measure conductivity parameters of the conductors, but solely to assist in the determination of the orientation of the conductors both in respect to the horizontal and in respect to the direction of the flight line traverse.

A typical illustration of the type of recording obtained using all five Channels is illustrated in Figure 20. As previously explained, the deviations in the recordings on Channels 1, 2 and 3 are utilized to determine the nature of the conductor whilst the deviations in the recordings on Channels 4 and 5 give additional information as to the orientation of the conductor.

The complete system may also include a doppler radar navigation system for facilitating accurate survey traversing in parallel traverses spaced a quarter of a mile apart. Marker pulses are provided every one tenth of a mile from the doppler radar and these are recorded on the geophysical recorder facilitating computations on depth and dip based on the profiles recorded.

A radar altimeter is used to provide a continuous recording alongside the geophysical profiles of ground clearance. This enables correction for flying height to be carried out. Normal survey flying height is 500 feet.

A continuous strip 35 mm camera is used to photograph all the ground surveyed and fiducial numbers corresponding to 1/10 mile grid lines provided by an output from the doppler radar are simultaneously recorded on the camera and on the geophysical recorder. This feature enables geophysical anomalies to be located on a map prepared from aerial photographic mosaics with an accuracy of better than plus or minus 200 feet.

Referring now to the circuit diagrams shown in Figures 17, 17a, 18 and 19, the pulse transmitter is shown in Figures 17 and 17a. It consists essentially of a thyatron pulse generator in which the inductive part of the pulse forming network consists of an electromagnetic radiating loop or magnetic dipole. Two blocking oscillators indicated generally by references 32 and 33 are triggered from an external low level trigger source (not shown)

connected to terminals 34 and 35. Blocking oscillators 32 and 33 in turn develop respective output pulses which are then amplified by respective pulse amplifiers indicated generally by references 36 and 37, each of which comprises a small thyatron, 36a and 37a, and a clipper diode 36b and 37b. The amplified pulses are then communicated to the large thyatrons 38 and 39 and provide triggering pulses therefore which in turn will permit discharge of capacitor bank 40 through radiating loop 41, thus providing the desired pulse therein of high amplitude and of short duration.

Capacitor bank 40 is then re-charged by a D.C. power supply comprising the power transformer 42, the input side of which is connected through a suitable variable auto transformer 74 to an A.C. source (not shown). The outlet side of transformer 42 is fed to the full wave rectifier 75 which in turn is provided with two filter chokes 76 and connected to the storage capacitor bank 40 and re-charges the same during the zero portion of the pulse transmitter cycle.

It will also be noted that blocking oscillators 32 and 33, pulse amplifiers 36 and 37 and thyatrons 38 and 39 are provided with D.C. power from an auxiliary D.C. source generally indicated by reference 78. Source 78 is of generally conventional design, incorporating a time delay relay 79 which remains open until operating temperature is reached, and further incorporating the ready light 80 indicating that relay 79 is closed, and warning light 81 indicating that the circuit is "on".

In addition to the foregoing the instant pulse transmitter incorporates further safety devices to minimize breakdown hazards.

Thus relay 82 is provided, including contacts 83, the relay being designed to operate only when relay 79 has closed and ready light 80 has come on indicating that the transmitter is ready for operation, and will then close on momentary depression of the "on" switch and open on momentary depression of the "off" switch, thus making and breaking the supply of power to autotransformer 74. Interlock 84 is provided, consisting essentially of cut out relay 85 which is designed to remain normally closed during operation and to open when thyatrons 38 and 39 break down and remain conductive.

Similarly interlock 86 is provided consisting essentially of cut out relay 87 which is also designed to remain normally closed during operation and to open when thyatrons 36a and 37a break down and remain conductive. Master switch 88 controls the supply of power to power supply 78.

The transmitter described above is designed to give a minimum average power dissipation in the loop of 2 k.V.A.

The pre-amplifier shown in Fig. 18 is a

low noise type with approximately 70 db of gain, the principal components of which are the transistors 43, 44 and 45 which are type 2N207B, low noise audio frequency PNP transistors and transistors 46 and 47 which are type 2N44 audio frequency PNP medium power transistors. The amplifier is class A throughout and has a frequency response of 5 cycles to 20 kilocycles plus or minus 2db. The amplifier of Figure 18 is housed in the bird.

The circuitry of a complete channel less the coil and pre-amplifier is illustrated in Figure 19. The signals from the bird pre-amplifier are fed into a high pass filter 48 of conventional design with a cut off frequency of 5 cycles per second. This filter is designed to reject low frequency signals generated by slow movements of the bird detector coils in the earth's magnetic field. The signal passes from the filter into the first detector 49. The first detector in a sampling gate consisting essentially of two transistor switches 50 and 51 in cascade relationship with one another. The transistors 50 and 51 are type 2N518, which are low noise fast switching PNP transistors, each of which switches the signal to ground, two being used in cascade to ensure optimum effect. A resistor 52 provides isolation from the reactance circuitry of the filter 48.

A control 53 is provided for adjusting the amount of voltage pedestal produced by the switch and is a special feature of the circuitry used for zeroing the D.C. output of the system appearing after the second detector and integrator. The gate pulse which controls the switching action is fed in at 54, its level being regulated by the Zener diode 55. A D.C. bias is fed in at 56 to make the transistors 50 and 51 normally conduct, the transistors then being switched off by the gate pulse applied at 54. The detector or sampling gate 49 is designated to have greater than 40 db rejection in its shorted condition. The signal is passed from the first detector 49 to the first tuned amplifier 57. Transistor 58 is a 2N44 PNP type and acts as a buffer between the output of the first detector and transistor 59 which is also a 2N44 and acts as a tuned amplifier in conjunction with the high Q toroidal inductor 60. The tuned amplifier is tuned to the transmitted pulse repetition rate. Transistor 61 is a 2N44 type which acts as a further buffer between the first tuned amplifier 57 and the second tuned amplifier 62. Transistor 63 is a type 2N44 and together with inductor 64 forms a further tuned amplifier tuned to the transmitted pulse repetition rate. Transistor 65 is a type 2N44 transistor used as an audio amplifier of high dynamic range and feeds into the second detector switch 66. This switch is a single section switch similar in type to each of the switches used in the first detector 49. It functions as a

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gated sampler of the sine wave output from the tuned amplifiers and as such is in the nature of a phase detector. The switch features a wide dynamic range to cope with the considerable variations in amplitude which in practice appear in the system. The second detector feeds into a low pass filter 67 which acts as a simple integrator of the pulses delivered by the second detector 66. The values of the capacitor 68 and resistor 69 are chosen to provide suitable time constants and an additional capacitor 70 may be switched in to provide an alternative longer time constant. Typical values of time constants chosen are two seconds and four seconds. The Zener diode 71 provides a regulated bias voltage derived from voltage applied at 72, said voltage being used to maintain correct polarity on the electrolytic capacitors used for convenience in the integrator. The coil of the mirror galvanometer used in the recorder is shown at 73. As noted previously, the pedestal of the first detector gate may be used to control the D.C. output of the integrator to the mirror galvanometer. The first detector gate is locked in time relationship to the transmitted pulse and the pedestal output therefore energizes the tuned amplifiers at their resonant frequency and in coherent phase relationship. The control 53 adjusts the gate pedestal and will therefore exercise control on the amplitude of the sine wave signal generated by the tuned amplifiers. This sine wave output of the tuned amplifiers is subsequently detected by the second detector and fed to the integrator 67. Hence by adjusting the pedestal using the control 53, the output of the integrator may be varied and the mirror galvanometer thereby conveniently zeroed.

The above references to component types are according to American manufacturers' standard classification.

The invention has been described having particular reference to the use of a transmitted signal in the form of a half sine wave pulse generated at a repetition rate of 80 per second. The half sine wave shape has been chosen because it is a relatively simple and efficient discontinuous wave form to generate. Using this shape a pulse length of not less than 1 millisecond is required to obtain efficient energization of good conductors in the ground which typically exhibit time constants in the region of 500 microseconds. Shorter pulses will reach peak amplitude too rapidly to energize said ground conductors fully. On the other hand long pulses greater than 3 milliseconds in length are excessively wasteful of power and little or no additional energy is induced into the ground conductors by prolonging the pulses unduly. Furthermore if a half sine wave of greater than 3 milliseconds in length is used the slow decay of the pulse minimizes transient effects.

It is desirable to have at least 1 millisecond following waveform discontinuities such as the termination of a pulse in which to measure transient effects. Thus if half sine pulses are used a maximum practical repetition rate is 500 per second using 1 millisecond pulses and 1 millisecond intervals between pulses. Using the circuitry described, the lower limit is set at about 40 per second since the inductively tuned amplifiers which have been used become very inefficient below this frequency. However a minor modification to the circuitry in which conventional R.C. tuned amplifiers are substituted for inductively tuned amplifiers enables pulse repetition rates as low as 1 per second to become perfectly practical. In order to achieve the same efficiency and signal to noise ratio at differing repetition rates it is merely necessary to keep the average power dissipated in the radiating loop the same. Thus at low repetition rates much higher peak powers are required and vice versa. The lower rate of repetition is ultimately set by consideration of the rate of traverse of the survey aircraft over the ground; for example, the maximum desirable interval between measurements at 100 m.p.h. would be about 1 per second.

Wave shapes other than half sine pulses may be employed without any departure in principle from the procedures outlined. Suitable wave shapes include saw-tooth forms, square pulses and any wave form exhibiting discontinuities or departure from simple harmonic functions when followed by periods in which the primary field is not time varying. Modifications to the transmitter can be carried out by one skilled in the art to change the transmitted shape to alternative configurations. If discontinuities are applied at regular periodic intervals then circuitry identical to that described here can be used in the receiving system, the tuned amplifiers of the system being tuned to the periodicity of the transmitted discontinuities, and the gates being triggered in fixed time relationships to the primary field discontinuities.

Discontinuities may also be triggered at random intervals providing the receiving system is triggered in locked time relationship to the transmitted system. The only modification required to the receiving system is the substitution of wideband, wide dynamic range, A.C. amplifiers for the tuned amplifiers. By way of example, triggering may be accomplished by using a zero-crossing detector on one of the receiving coils to provide trigger pulses only when zero volts exist in the detector coils. This type of technique can be used as an alternative to a high pass filter as a means of eliminating low frequency noise due to low frequency movements of the bird and its receiving coils in the earth's magnetic field.

It will be appreciated by those skilled in

the art that variations and modifications may be made without departing from the scope of the invention as defined in the following claims.

5 WHAT WE CLAIM IS:—

1. Apparatus for the detection of conducting bodies and comprising signal generating means for radiating primary electromagnetic waveforms produced in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, receiving means for detecting said secondary signals, reradiated by a conducting body and occurring after said abrupt discontinuities in said primary waveforms, electronic sampling means normally blocking said signals and operable intermittently to sample portions of said secondary signals, and means for recording the presence of the sampled portions thereby to provide evidence of the presence of conducting bodies.

2. Apparatus as claimed in claim 1, in which the receiving means comprises three detectors disposed mutually at right angles to provide three resolved components of the secondary signals.

3. Apparatus as claimed in claim 2, in which the detectors are coil detectors and at least one is disposed to be responsive to horizontal components.

4. Apparatus as claimed in claim 2 or claim 3 in which at least one portion of each of the three resolved components is sampled by said detection means.

5. Apparatus as claimed in any of claims 2 to 4, in which each resolved component is individually sampled in passage through a channel comprising a tuned amplifier, a detector gate means, an integrator and a recorder connected in cascade.

6. Apparatus as claimed in claim 5, in which the amplifier is tuned to the pulse repetition frequency.

7. Apparatus as claimed in claim 5 or claim 6, in which the detector gate means samples predetermined portions of the amplified signal.

8. Apparatus as claimed in any of claims 5 to 7, in which the detector gate means comprises two separate detector gates sampling portions of the amplified signal spaced in time a predetermined distance apart.

9. Apparatus as claimed in any of claims 5 to 8, in which the integrator converts signals received from the detector gate means to a slowly fluctuating D.C. signal which is utilised by the recorder.

10. Apparatus as claimed in any preceding claim, in which an amplifier is included to amplify the detected secondary signals and pass them to the sampling means.

11. A method of detecting conducting bodies and comprising initiating primary electromagnetic waveforms in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, detecting said secondary signals, sampling at least one portion of the detected secondary signals at a predetermined time interval after said abrupt discontinuities in said primary waveforms, and recording the presence of such sampled portions thereby to indicate the presence of conducting bodies.

12. A method of detecting conducting bodies as claimed in claim 11, in which the secondary signals are detected in three component directions mutually at right angles thereby to provide three resolved components thereof.

13. A method of detecting conducting bodies as claimed in claim 12, in which one of said component directions is horizontal.

14. A method of detecting conducting bodies as claimed in any of claims 11 to 13, including moving said source and means for detecting the waveforms at substantially equal velocities.

15. A method of detecting conducting bodies as claimed in claim 14, when dependent on claim 13, in which said horizontal component direction is transverse to the direction of motion of the source.

16. A method of detecting conducting bodies as claimed in claim 13 or claims 14 or 15 when dependent on claim 13, including individually sampling each detected component, amplifying the sampled, detected component and sampling predetermined portions of the amplified signal.

17. A method of detecting conducting bodies as claimed in claim 16, including sampling portions of the sampled, detected component spaced apart a predetermined distance in time.

18. Apparatus for the detection of conducting bodies substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

19. A method of detecting conducting bodies substantially as hereinbefore described with reference to the accompanying drawings.

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the art that variations and modifications may be made without departing from the scope of the invention as defined in the following claims.

5 WHAT WE CLAIM IS:—

1. Apparatus for the detection of conducting bodies and comprising signal generating means for radiating primary electromagnetic waveforms produced in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, receiving means for detecting said secondary signals, reradiated by a conducting body and occurring after said abrupt discontinuities in said primary waveforms, electronic sampling means normally blocking said signals and operable intermittently to sample portions of said secondary signals, and means for recording the presence of the sampled portions thereby to provide evidence of the presence of conducting bodies.

2. Apparatus as claimed in claim 1, in which the receiving means comprises three detectors disposed mutually at right angles to provide three resolved components of the secondary signals.

3. Apparatus as claimed in claim 2, in which the detectors are coil detectors and at least one is disposed to be responsive to horizontal components.

4. Apparatus as claimed in claim 2 or claim 3 in which at least one portion of each of the three resolved components is sampled by said detection means.

5. Apparatus as claimed in any of claims 2 to 4, in which each resolved component is individually sampled in passage through a channel comprising a tuned amplifier, a detector gate means, an integrator and a recorder connected in cascade.

6. Apparatus as claimed in claim 5, in which the amplifier is tuned to the pulse repetition frequency.

7. Apparatus as claimed in claim 5 or claim 6, in which the detector gate means samples predetermined portions of the amplified signal.

8. Apparatus as claimed in any of claims 5 to 7, in which the detector gate means comprises two separate detector gates sampling portions of the amplified signal spaced in time a predetermined distance apart.

9. Apparatus as claimed in any of claims 5 to 8, in which the integrator converts signals received from the detector gate means to a slowly fluctuating D.C. signal which is utilised by the recorder.

10. Apparatus as claimed in any preceding claim, in which an amplifier is included to amplify the detected secondary signals and pass them to the sampling means.

11. A method of detecting conducting bodies and comprising initiating primary electromagnetic waveforms in radiating means by a pulse of direct current exhibiting abrupt discontinuities thereby to induce transient secondary electromagnetic signals emanating from said conducting bodies and delayed a short time after said abrupt discontinuities of said primary waveforms, detecting said secondary signals, sampling at least one portion of the detected secondary signals at a predetermined time interval after said abrupt discontinuities in said primary waveforms, and recording the presence of such sampled portions thereby to indicate the presence of conducting bodies.

12. A method of detecting conducting bodies as claimed in claim 11, in which the secondary signals are detected in three component directions mutually at right angles thereby to provide three resolved components thereof.

13. A method of detecting conducting bodies as claimed in claim 12, in which one of said component directions is horizontal.

14. A method of detecting conducting bodies as claimed in any of claims 11 to 13, including moving said source and means for detecting the waveforms at substantially equal velocities.

15. A method of detecting conducting bodies as claimed in claim 14, when dependent on claim 13, in which said horizontal component direction is transverse to the direction of motion of the source.

16. A method of detecting conducting bodies as claimed in claim 13 or claims 14 or 15 when dependent on claim 13, including individually sampling each detected component, amplifying the sampled, detected component and sampling predetermined portions of the amplified signal.

17. A method of detecting conducting bodies as claimed in claim 16, including sampling portions of the sampled, detected component spaced apart a predetermined distance in time.

18. Apparatus for the detection of conducting bodies substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

19. A method of detecting conducting bodies substantially as hereinbefore described with reference to the accompanying drawings.

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