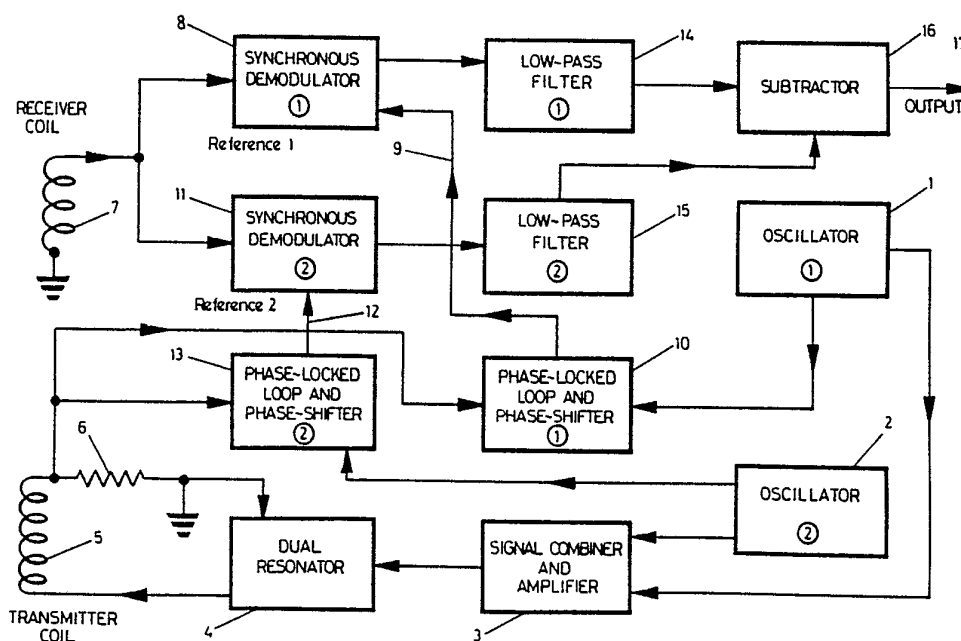




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title:** METAL DETECTION IN CONDUCTING MEDIA USING A TWO FREQUENCY SIGNAL



**(57) Abstract**

Apparatus for the electrical detection of remote metal objects in a mildly conductive environment. Transmitter coil (5) simultaneously transmits two magnetic signals of different frequency from two oscillators (1, 2). Receiver coil (7) receives two retransmitted signals from the metal objects. The two retransmitted signals are processed by different demodulators (8, 11). Information about the metal objects is obtained either by providing a resultant signal which is a linear combination of the demodulated signals, or by detecting the difference in the resistive components of the transmitted and retransmitted signals.

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Metal Detection in Conducting Media using a two  
frequency signal

This specification refers to a metal detector" of a type used for the purpose of discriminating metal within the ground which can be used as a single detector or an array of detectors where used to detect metal objects in soil on a moving conveyor system.

5. The invention is directed to some difficulties encountered when using a metal detector in the presence of ground containing substantial varying proportions of mildly electrically conducting soil components, such as brackish water and metal sulfides, and which may also contain magnetic soils which usually comprise  
10. contain ferrous oxide and various ferrites.

15. Highly conductive metal objects are different from the ground in that the ratio of resistive to reactive ratio is usually substantially different from that of the background soil. Thus in effect metal objects are located by determining statistically significant changes in this reactive to resistive ratio of the scale size typical of the objects sought. If the reactive to resistive ratio is highly variable, which is often the case with a mix of magnetic soils and brackish water, the object detection sensitivity is thus reduced substantially compared to relatively homogeneous ground.

20. There are a number of types of metal detectors each having a different type of operation. The best of these that are used for location of metal objects such as coins, gold nuggets, treasure caches etc., all have certain properties which are outlined below:

25. They all consist of electronic circuitry in which an alternating current signal is produced which is fed to a transmitting coil, and detection electronics which compares an emf signal induced in a receiver coil with the transmitted signal. The induced signal in the received coil results from two sources, namely, from varying currents flowing in the transmitting coil, and varying  
30. (retransmitting) magnetic sources in the local environment under the influence of the transmitted magnetic field. For each Fourier component transmitted, the received signals resulting from local

environmental sources induce both resistive and reactive components in the receiving coil.

5. The dominant "magnetic" ground component has a reactive (magnetic) component usually much greater than the resistive (loss) component (usually by about 30 to 200 times). The dominant electrically conductive components at typical metal detecting frequencies (1 to 30 kHz) and scale sizes of the order of 10cm, have a resistive component much greater than the reactive component. It should be noted the sign of the ironstone reactive component is opposite to that of the electrically conductive reactive component. The ratio of the loss component in the ironstone to its magnetic component is spatially correlated in ground, but the ratio of resistive electrically conducting component to reactive ironstone component is not correlated.
- 10.
15. The best of the existing metal detectors transmit a single frequency sinusoidal magnetic signal (distortion < 30dB) at between 1kHz to a few 10's of kHz. The received signal is synchronously demodulated and passed through a low-pass filter to remove both noise and carrier related signals.
20. The better metal detectors have a "ground balance" control which enables the detector to be set to be insensitive to a local area of ground. This is normally performed by the user by varying a potentiometer or is performed automatically. In effect varying the "ground balance" selects a varying linear combination of the reactive and resistive components. This can be represented by standard phasor diagrams, where the "Y" axis represents the reactive component and the "X" the resistive component. Vector mathematics can then be applied.
- 25.
30. Usually the detector "null" is settable between the reactive axis and about 10 degrees between this axis toward the resistive axis. This accommodates most ground conditions. In the more difficult environments described above, this adjustment need be made very frequently for best results. Worse, most detectors do not have sufficient "ground balance" control range to accommodate the

extremes of ground containing predominately ironstone or predominantly salt water.

5. There is proposed according to this invention a means of substantially reducing the signal components resulting from mildly conductive soil components, thus enabling a detector that requires only moderate ground balance adjustment, to accommodate the "usual" ironstone reactive to resistive ration changes, as the detector interrogates ground containing varying electrical conductivities and ironstone (if present). This requires  
10. interrogation at at least two frequencies. In addition a means of power efficiently transmitting at least 2 frequencies simultaneously is described.

15. According to this invention then there is proposed apparatus for detecting remote metal target objects in soil by interrogation including means to transmit at least two substantially sinusoidal magnetic transmitted signals of different frequency, the apparatus being characterised in that there are means to effect at least two signals each derived from the synchronous demodulation of the composite incoming interrogation signal, whereby at least one  
20. demodulator reference is derived from one of the said transmitted signals, and another demodulator reference is derived from the other said transmitted signal, the apparatus being adapted to provide a resultant signal derived from linear combinations of the said demodulated signals which will provide discernable target  
25. discrimination information when within interrogated conducting soils or background conducting fluids.

#### THEORY:

30. A "simple first order" object can be described in terms of a single characteristic frequency  $\omega_0$ , for which the resistive component is a maximum and the magnitude of the resistive component equals that of the reactive component. In the case of ferromagnetic metals, the said reactive component is to be taken as the "eddy current" associated anti-magnetic reactive component. If

the interrogating frequency is  $W$ , then the relative resistive component is proportional to  $W*W_o/(W_o*W_o+W*W)$ , and the reactive component is proportional to  $2*W*W/(W_o*W_o+W*W)$

if  $W_o \gg W$  then,  $W*W_o/(W_o^2+W^2)$  is approximately  $= W/W_o$ ,

5. and  $2*W^2/(W_o^2+W^2)$  is approximately  $= 2*(W/W_o)^2 \ll W/W_o$

10. The important result of this approximation is that the resistive component is proportional to the interrogation frequency, and the reactive component is very much less than the resistive component. Most objects or mildly electrically conducting ground components can be described as having a distributed " $W_o$ " rather than just a single frequency. However, the distributions are typically relatively fairly narrow, and for most the mildly electrically conducting soil components, the resistive component is proportional to the interrogation frequency at the operating frequencies and scale sizes described above.

15. One means of substantially reducing sensitivity to mildly conductive components is to measure resistive components at two frequencies and subtract these after scaling each by the inverse of the associated frequency of each:

20. Let the 2 frequencies be  $F_1$  and  $F_2$ , the associated instantaneous ground components be  $X_{1e}$ ,  $X_{1m}$ ,  $R_{1e}$ ,  $R_{1m}$ ,  $X_{2e}$ ,  $X_{2m}$ ,  $R_{2e}$ , and  $R_{2m}$ , where "X" stands for "reactive", "R" for "resistive", "1" for " $f_1$ ", "2" for " $F_2$ ", "e" for mildly electrically conductive and "m" for "ironstone". Using standard conventions, X and R may be represented as 2 vectors at right angles. If the system gains for each frequency are assumed equal:

$$R_{1e}*F_2 \text{ is approximately } = R_{2e}*F_1 \quad [i]$$

$$X_{1e} \ll R_{1e} \quad [ii]$$

$$X_{1m} \text{ is approximately } = X_{2m} \quad [iii]$$

30. Typically  $X_{1m} \gg X_{1e}$ , and  $X_{1m} \gg X_{2e}$  [iv]

where " $_{-}$ " stands for either "1" or "2"

It should be noted that owing to [ii], in areas containing no magnetic soils, only the resistive components give rise to significant signals. If the output "out" is selected so that

5.           
$$\begin{aligned} \text{out2} &= R2 + k2 * X2, \\ \text{out1} &= R1 + k1 * X1, \\ \text{and } \text{out} &= F2 * \text{out1} - F1 * \text{out2} \end{aligned}$$

10.           where "R\_" and "X\_" stand for the measured resistive and reactive components respectively, at the indicated frequency, and k1 and k2 have magnitudes of the order of .01, then the output will approximately be insensitive to the mildly conductive soil components, bu substitution of (i to iv) into the output expression.

The "ground balance" constant "k2" may be factory set and the value of "k1" altered to adjust the detector ground balance. "k1" may be adjusted manually or automatically.

15.           For a better understanding of this invention it will now be described with reference to a preferred embodiment with the assistance of drawings.

FIG. 1 shows the block diagram of a preferred embodiment,

FIG. 2 is a circuit of a dual frequency resonator,

20.           FIG. 3 is a circuit of a dual frequency resonator,

FIG. 4 is the impedance frequency response of Fig. 2 and 3,

FIG. 5 is a circuit of a triple frequency resonator,

FIG. 6 is a circuit of a triple frequency resonator, and

FIG. 7 is the impedance frequency response of Fig. 5 and 6.

25.           Referring to these in detail an oscillator 1 produces a frequency of W1 radians per second, and an oscillator 2 produces a

frequency of  $W_h$  radians per second, where  $W_h > W_l$ . Sinusoidal outputs from these are fed into a combiner and amplifier 3. This combined and amplified signal is applied to the transmitting coil 5 across which a dual resonator 4 is connected, which is described later. Current flowing through the transmitting coil is passed through a low valued resistor 6, across which a resultant voltage appears which is used as a magnetic field phase sensor. The receiver coil 7 picks up retransmitted signals from the interrogated environment (as well as directly from the transmitting coil). The induced emf across the receiver is demodulated by a synchronous demodulator 8. The digital reference 9 to this demodulator is driven by a phase-locked loop and phase-shifter 10. This phase-locked loop is locked to the frequency of oscillator 1 and the phase of the current of  $W_l$  flowing through the resistor 6. This phase may be shifted for ground balancing purposes. Similarly the induced emf across the receiver is demodulated by a synchronous demodulator 11. The digital reference 12 to this demodulator is driven by a phase-locked loop and phase-shifter 13. This phase-locked loop is locked to the frequency of oscillator 2 and the phase of the current of  $W_h$  flowing through the resistor 6. This phase may be shifted for ground balancing purposes. The output of the demodulator 8 is passed through a low-pass filter 14 and the output of the demodulator 11 is passed through a low-pass filter 15. The output of the low-pass filter 15 is scaled and subtracted by a subtracter 16 to produce an output 16. The scaling factor is selected so that, when the phases of the digital references 9 and 12 are adjusted so that both the outputs of the low-pass filters 14 and 15 give substantially no response to the interrogation of a substantially lossless ferrite, then for these phase settings the output is substantially insensitive to the interrogation of objects with characteristic frequencies at least 20 times greater than  $W_h$ .

A useful resonator for power efficiency and impedance frequency response is given in figure 2 to 7. Figure 2 and 3 show dual frequency resonators, while figure 5 and 6 show triple resonators. The resultant impedance frequency response is shown in figure 4 for the dual resonators and figure 7 for the triple resonators.

As indicated in these figures, "Wh" and "Wl" refer to the high and low frequency resonant frequencies, and "Wo" to the "zero" of the impedance response. Equations for the dual resonator are contractable, and the solutions are:

5. For figure (2);

$$C2 = [k1[(Wh^2 + Wl^2) - Wo^2] - 1/Wo^2] / L1$$

$$L2 = 1 / (C2 * Wo^2)$$

$$C1 = Wo^2 * k1 / L1$$

$$\text{where } k1 = 4 / [(Wh^2 + Wl^2)^2 - (Wh^2 - Wl^2)^2]$$

10. For figure (3);

$$C2 = k2 * C1 / (1 - k2)$$

$$L2 = 1 / [Wo^2 * (C1 + C2)]$$

$$C1 = [Wh / [4 * (Wh^2 - Wl^2)] - 1 / Wo^2] / L1$$

$$\text{where } k2 = Wo^2 / [4 * (Wh^2 - Wl^2) * L1 * C1]$$

15. For example, for the network a figure (2), if the high frequency is set at 16kHz, the low at 2kHz, Wo is set as the geometric mean of Wh and Wl, and the transmission coil "L1" is 1mH, then L2=.16mH, C1=.79mfd, C2=4.9mfd.

20. Several metal detectors have been constructed and tested spanning the range from 1 to 16kHz utilizing the principles described herein, with heads up to 30 cm in size, and all substantially reduce the effects of salt water. For example, if any conventional detector using a single frequency is ground balanced inland on typical dry magnetic soils, and then, without altering the
25. ground balance setting, if the detector is used to interrogate wet

sea beach sand or sea water, substantial unbalanced ground signals result. This is substantially not the case with the art described herein, for which the sea-side ground signals are similar to the inland ground signals.

1. Apparatus for detecting remote metal target objects in soil by interrogation including means to transmit at least two substantially sinusoidal magnetic transmitted signals of different frequency, the apparatus being characterised in that there are  
5 means to effect at least two signals each derived from the synchronous demodulation of the composite incoming interrogation signal, whereby at least one demodulator reference is derived from one of the said transmitted signals, and another demodulator reference is derived from the other said transmitted signal, the  
10 apparatus being adapted to provide a resultant signal derived from linear combinations of the said demodulated signals which will provide discernable target discrimination information when within interrogated conducting soils or background conducting fluids.

2. A metal detection system for detecting the presence of an electrically conducting metal target in soil or brackish water or both, including means for transmitting a first and second substantially sinusoidal magnetic interrogation signal, where the  
5 second signal is of higher frequency than the first, whereby the said frequency range and interrogation spacial scale size is chosed such that for brackish water, such as sea water, the resistive magnetic response is substantially proportional to the interrogation frequency, including detector means, including a coil means for  
10 transmitting the said magnetic field and detecting any retransmitted magnetic signal from the ground or any target, the detection of the said retransmitted signal processing means including a first synchronous demodulator referenced to the said first transmitted signal, and a second synchronous demodulator  
15 referenced to the said second transmitted signal, to interrogate the said retransmitted signal, and provide a first and second low-passed signal from the first and second synchronous demodulator output respectively, with the said demodulator reference phases selected whereby the said low-passed signals contain information  
20 substantially distinctive of background resistive components, an output signal is derived from a linear combination of the said first

25. and second low-passed signals, such that the said combination is directly proportional to or at least directly proportional to changes in, the frequency of the second transmitted signal multiplied by the system gain of the said second low-passed signal multiplied by the first output signal, minus the frequency of the first transmitted signal multiplied by the system gain of the said first low-passed signal multiplied by the second output signal, where the system gain is defined as the relative sensitivity of the low-passed outputs to the interrogation of a lossless ferrite when the synchronous demodulator reference phases are set so as to maximise the low-passed signal components resulting from the interrogation of the said ferrite.

30...

3. Apparatus as in claim 2 further including means for controlling the phase of the synchronous demodulators.

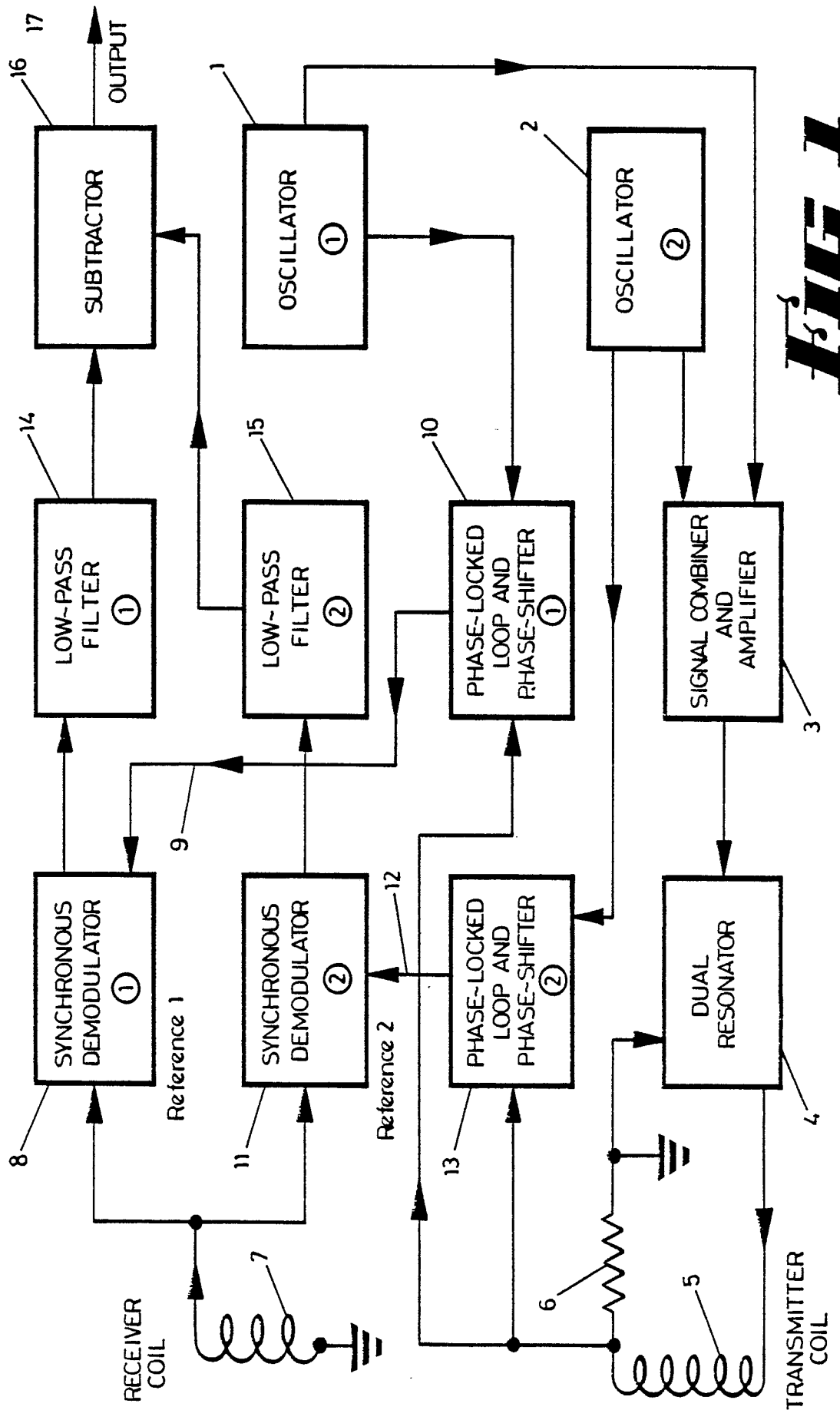
4. Apparatus as in claim 1,2 or 3 including means for efficient multi-frequency resonator, whereby the impedance measured across the transmitter coil terminals is relatively high at the transmission frequencies, and the impedance frequency response has local maxima at these said frequencies.

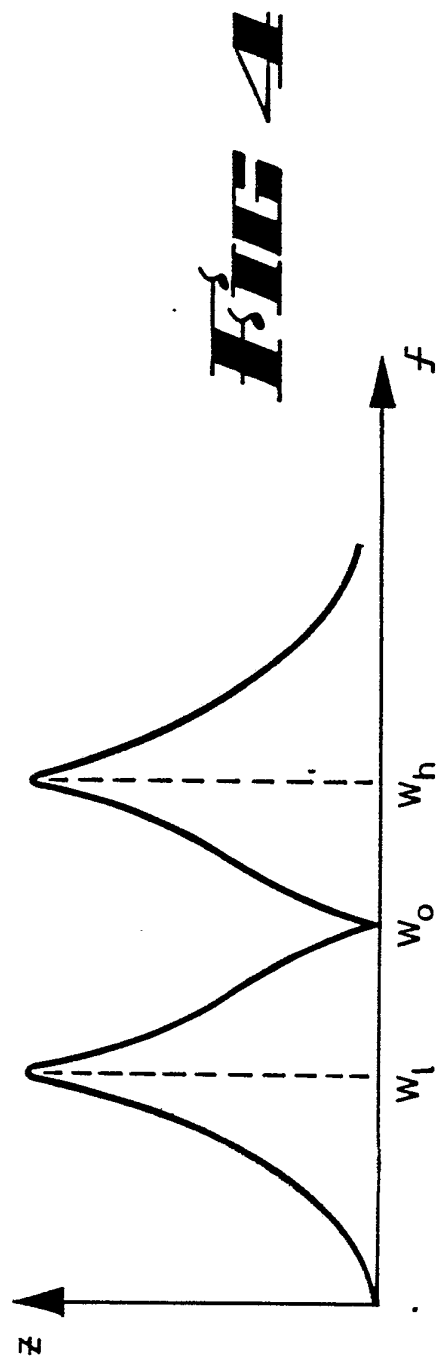
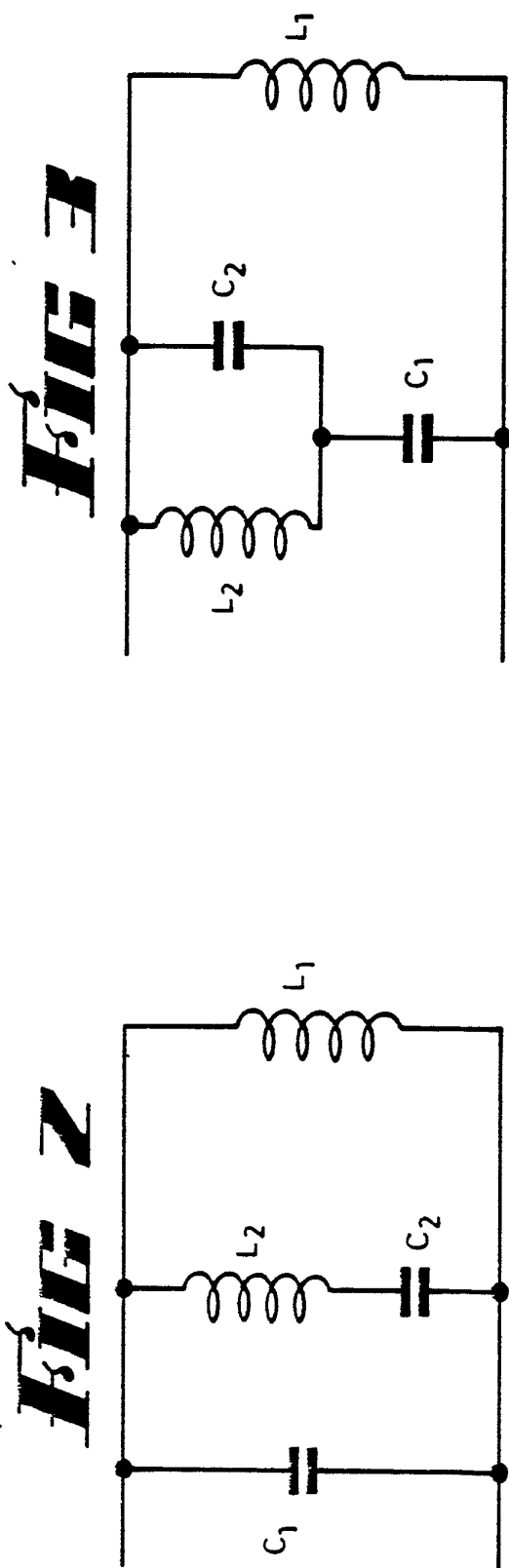
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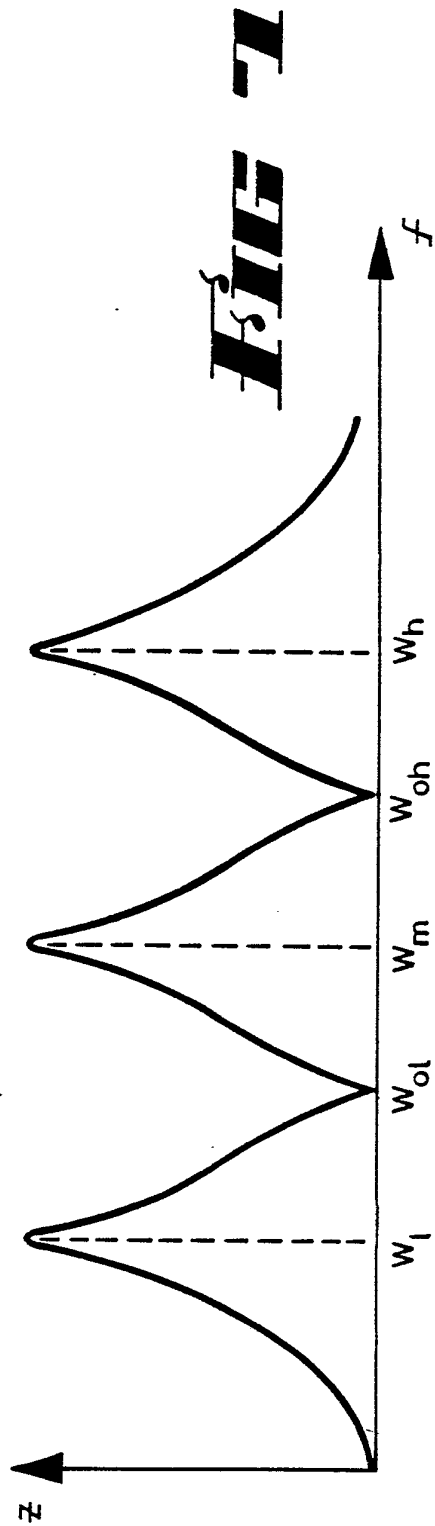
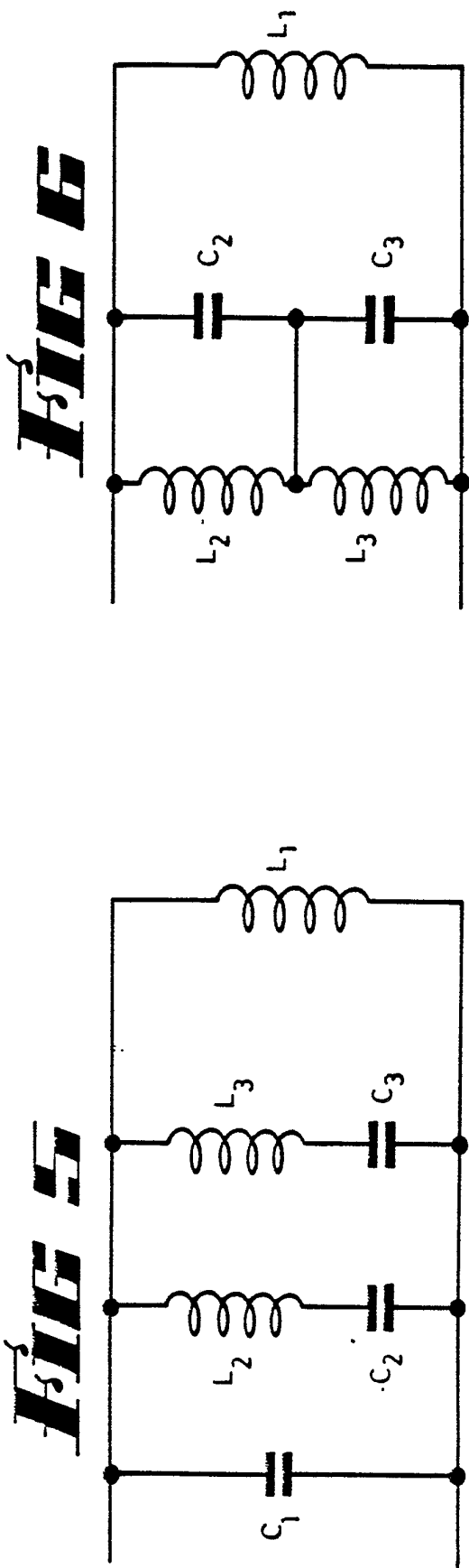
5. Apparatus as in claim 4 further comprising the said transmission coil, across which is connected parallel networks; one type contains a capacitor connected in series with a parallel combination of a capacitor and inductor, another type consisting of a capacitor connected in series with an inductor, another type consisting of a capacitor, and yet another type consists of a series circuit of two networks of a capacitor connected in parallel with an inductor, whereby the values and combinations are selected to fulfil the requirements of claim 4.

5 6. A method of detecting a metal target in a mildly electrically conducting environment which comprises the steps of transmitting a magnetic field which incorporates two sinusoidal components, the frequency being different one from the other, detecting any retransmitted signal from the environment, distinguishing the resistive component for each of the said transmitted frequencies from the retransmitted signal, and detecting any difference in magnitude between the respective resistive components thus detected.

5 7. A method as in claim 6 further characterised in that the frequencies selected and the gains of the measured resistive components of the signals are selected whereby a direct subtraction results in cancellation of interrogated objects with characteristic frequencies at least twenty times the higher interrogation frequency, but not for those objects with less than 10 times the characteristic frequency of the higher interrogation frequency.








# INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 87/00029

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int. Cl. <sup>4</sup> G01V 3/08, 3/10		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
IPC	G01V 3/08, 3/10, 3/11	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched <sup>8</sup>		
AU : IPC as above		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	GB,A, 1350273 (WESTINGHOUSE ELECTRIC CORPORATION 18 April 1974 (18.04.74))	(1)
X	US,A, 4563644 (LENANDER et al) 7 January 1986 (07.01.86)	(1)
X	US,A, 3893020 (MEADOR et al) 1 July 1975 (01.07.75)	(1)
X	US,A, 3181057 (BRAVENEC) 27 April 1965 (27.04.65)	(1)
X	AU,B, 46546/79 (528607) (GEORGETOWN UNIVERSITY) 30 October 1980 (30.10.80)	(6)
X	US,A, 2955250 (SHAW et al) 4 October 1960 (04.10.60)	(6)
X	US,A, 4473800 (WARNER) 25 September 1984 (25.09.84)	(6)
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"&amp;" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
12 March. 1987 (12.03.87)	(05.05.87) 5 MAY 1987	
International Searching Authority	Signature of Authorized Officer	
Australian Patent Office	 R. OLNEY	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON  
INTERNATIONAL APPLICATION NO. PCT/AU 87/00029

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report			Patent Family Members		
GB	1350273	CA 924779 IL 37351	DE 2149371 US 3686564	FR	2111094
US	4563644	EP 91034	SE 8202094		
US	3893020	AR 211513 CA 1008131 FR 2242691 NO 742893 CA 1000358	AU 71550/74 DE 2440676 GB 1460186 CA 1017000 US 3891916	BR 7407050 DK 4541/74 NL 7410456 US 3893021	
AU	46546/79	GB 1603578			
US	4473800	US 4392109			

END OF ANNEX