Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 2784187 C 2019/05/14

(11)(21) **2 784 187**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(22) **Date de dépôt/Filing Date:** 2012/07/31

(41) **Mise à la disp. pub./Open to Public Insp.:** 2013/02/24

(45) **Date de délivrance/Issue Date:** 2019/05/14

(30) **Priorité/Priority:** 2011/08/24 (EP11178586.1)

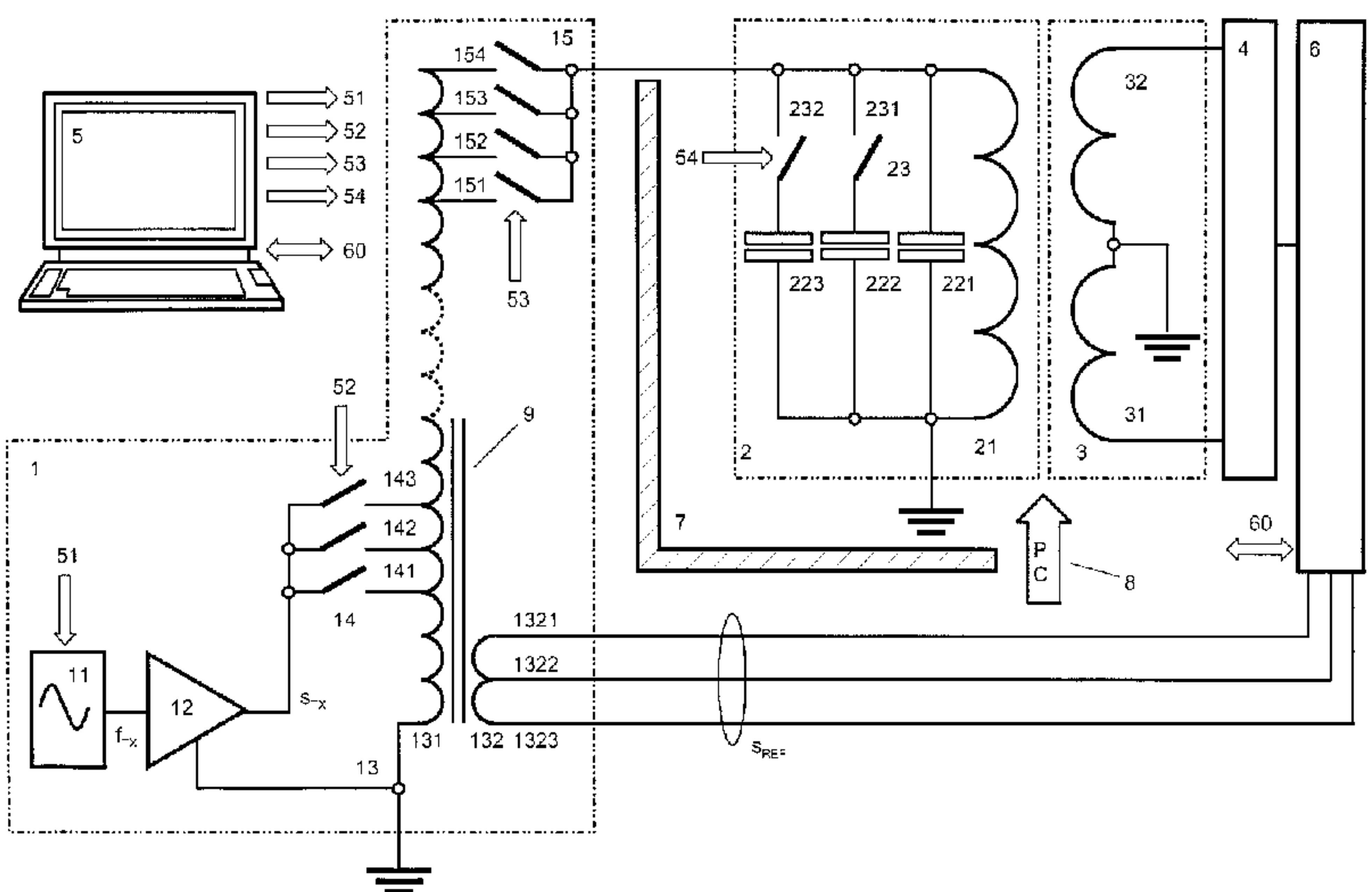
(51) **Cl.Int./Int.Cl.** *G01V 3/11* (2006.01), *G01N 27/72* (2006.01)

(72) **Inventeur/Inventor:**
LYON, DAVID GREGORY, GB

(73) **Propriétaire/Owner:**
METTLER-TOLEDO SAFELINE LTD., GB

(74) **Agent:** BORDEN LADNER GERVAIS LLP

(54) Titre : APPAREIL DE DETECTION DE METAL
(54) Title: METAL DETECTION APPARATUS



(57) **Abrégé/Abstract:**
The metal detection apparatus comprises a transmitter unit, which provides transmitter signals to a transmitter coil that is coupled to a receiver coil, which is connected to the input of a receiver unit, said transmitter unit comprises a frequency generator that provides an operating frequency (f_{TX}) to the input of an amplifier stage, whose output is connected via a transformer to the transmitter coil. According to the invention the output of the amplifier stage is connected to a first tap and the transmitter coil is connected to a second tap of the same transformer winding of the transformer, having a number of n winding coils between the first tap and a common potential and a number of n+m winding coils between the second tap and the common potential, wherein the transmitter coil comprises the number of q winding coils and is connected in parallel to a capacitor thus forming a resonant circuit that is tuned to the operating frequency (f_{TX}) and wherein the ratio (n+m)/q of the winding coils of the transformer winding and the winding coils of the transmitter coil is selected such that the inductance of the transformer winding is at least ten times higher than the inductance of the transmitter coil.

ABSTRACT

The metal detection apparatus comprises a transmitter unit, which provides transmitter signals to a transmitter coil that is coupled to a receiver coil, which is connected to the input of a receiver unit, said transmitter unit comprises a frequency generator that provides an operating frequency (f_{TX}) to the input of an amplifier stage , whose output is connected via a transformer to the transmitter coil. According to the invention the output of the amplifier stage is connected to a first tap and the transmitter coil is connected to a second tap of the same transformer winding of the transformer, having a number of n winding coils between the first tap and a common potential and a number of n+m winding coils between the second tap and the common potential, wherein the transmitter coil comprises the number of q winding coils and is connected in parallel to a capacitor thus forming a resonant circuit that is tuned to the operating frequency (f_{TX}) and wherein the ratio (n+m)/q of the winding coils of the transformer winding and the winding coils of the transmitter coil is selected such that the inductance of the transformer winding is at least ten times higher than the inductance of the transmitter coil.

Metal Detection Apparatus

The present invention relates to a metal detection apparatus that uses one ore more operating frequencies.

A metal detection apparatus is used to detect metal contamination in edible goods and other products. As described in WO 02/25318, modern metal apparatuses utilise a search head comprising a "balanced coil system" that is capable of detecting all metal contaminant types including ferrous, nonferrous and stainless steels in a large variety of products such as fresh and frozen products.

A metal detection apparatus that operates according to the "balanced coil"-principle typically comprises three coils that are wound onto a non metallic frame, each exactly parallel with the other. The transmitter coil located in the centre is energised with a high frequency electric current that generates a magnetic field. The two coils on each side of the transmitter coil act as receiver coils. Since the two receiver coils are identical and installed with the same distance from the transmitter coil, an identical voltage is induced in each of them. In order to receive an output signal that is zero when the system is in balance, the first receiver coil is connected in series with the second receiver coil having an inversed sense of winding. Hence the voltages induced in the receiver coils, that are of identical amplitude and inverse polarity are cancelling out one another in the event that the system, in the absence of metal contamination, is in balance.

As a particle of metal passes through the coil arrangement, the high frequency field is disturbed first near one receiver coil and then near the other receiver coil. While the particle of metal is conveyed through the receiver coils the voltage induced in each receiver coil is changed typically in the range of nano-volts. This change in balance results in a signal at the output of the receiver coils that can be processed, amplified and subsequently be used to detect the presence of the metal contamination in a product.

The signal processing channels split the received signal into two separate components that are 90° apart from one another. The resultant vector has a magnitude and a phase angle, which is typical for the products and the contaminants that are conveyed through the coils. In order to identify a metal contaminant, "product effects" need to be removed or reduced. If the phase of the product is known then the corresponding signal vector can be reduced. Eliminating unwanted signals from the signal spectrum thus leads to higher sensitivity for signals originating from contaminants.

Methods applied for eliminating unwanted signals from the signal spectrum therefore exploit the fact that the contaminants, the product and other disturbances have different influences on the magnetic field so that the resulting signals differ in phase.

The signals caused by various metals or products, as they pass through the coils of the metal detection apparatus, can be split into two components, namely resistive and reactive components, according to conductivity and magnetic permeability of the measured object. The signal caused by ferrite is primarily reactive, while the signal from stainless steel is primarily resistive. Products, which are conductive typically cause signals with a strong resistive component.

Distinguishing between the phases of the signal components of different origin by means of a phase detector allows obtaining information about the product and the contaminants. A phase detector, e.g. a frequency mixer or analogue multiplier circuit, generates a voltage signal which represents the difference in phase between the signal input, such as the signal from the receiver coils, and a reference signal provided by the transmitter unit to the receiver unit. Hence, by selecting the phase of the reference signal to coincide with the phase of the product signal component, a phase difference and a corresponding product signal is obtained at the output of the phase detector that is zero. In the event that the phase of the signal components that originate from the contaminants differ from the phase of the product signal component, then the signal components of the contaminants can be detected. However in the event that the phase of the signal components of the contaminants is close to the phase of the product signal component, then the detection of contaminants fails, since the signal components of the contaminants are suppressed together with the product signal component.

In known systems the transmitter frequency is therefore selectable in such a way that the phase of the signal components of the metal contaminants will be out of phase with the product signal component.

GB2423366A discloses a metal detection apparatus that is designed to switch between at least two different operating frequencies such that any metal particle in a product will be subject to scanning at different frequencies. The frequency of operation is rapidly changed so that any metal particle passing through on a conveyor belt will be scanned at two or more different frequencies. In the event that for a first operating frequency the signal component caused by a metal particle is close to the phase of the signal component of the product and thus is masked, then it is assumed that for a second frequency, the phase of the signal component caused by the metal particle will differ from the phase of the signal component of the product so that this signal components can be distinguished. By switching between many frequencies, it is expected that one frequency will provide a suitable sensitivity for any particular metal type, size and orientation.

The drive circuit of the transmitter disclosed in GB2423366A comprises an electrically programmable logic device and a driver connected to four field effect transistors, which form a full wave bridge circuit with the transmitter coil connected across.

JP2007278719A discloses a further metal detection apparatus that is designed to switch between at least two different operating frequencies in order to improve metal detection sensitivity. This apparatus comprises a transmitter with an amplifier whose output is connected to primary windings of a transformer having a first secondary winding that is connected to the transmitter coil and a second secondary winding that is connected to tuning capacitors that can be switched on or off by means of control switches.

Sensitivity is not only dependent on the selected frequency. Important is correct calibration of the apparatus as described in US20110074401A1 and optimal performance of the receiving and signal processing unit.

In JP2007278719A is described that capacity adjustments with the capacitors connected to the transformer may get complicated, thus resulting in restrictions that will not allow reaching optimal sensitivity. Further, losses in the transformer have a negative impact on resonant circuits that are formed by capacitors and transformer coils.

With regard to GB2423366A it is important to note that the applied switching technology provides of flexibility but may have a negative impact on the quality of the transmitter signals. Due to the rapid signal switching off transistors directly connected to the transmitter coil disturbances may appear particularly in the upper range of operating frequencies.

The present invention is therefore based on the object of creating an improved metal detection apparatus that uses one or more operating frequencies.

Particularly, the present invention is based on the object of creating a metal detection apparatus that operates with improved signal sensitivity.

More particularly, the present invention is based on the object of providing a metal detection apparatus with a transmitter that allows efficient generation and transfer of drive signals with high signal quality to a transmitter coil.

SUMMARY OF THE INVENTION

The above and other objects of the present invention are achieved by a metal detection apparatus.

The metal detection apparatus that operates with one or more frequencies comprises a transmitter unit, which provides transmitter signals to a transmitter coil that is coupled to a receiver coil, which is connected to the input of a receiver unit. The transmitter unit comprises a frequency generator that provides an operating frequency to the input of an amplifier stage, whose output is connected via a transformer to the transmitter coil.

According to the invention the output of the amplifier stage is connected to a first tap and the transmitter coil is connected to a second tap of the same transformer winding of the transformer, which exhibits a number of n winding coils between the first tap and a common potential and a number of n+m winding coils between the second tap and the common potential. The transmitter coil comprises a number of q winding coils and is connected in parallel to a capacitor thus forming a resonant circuit that is tuned to the operating frequency. The ratio (n+m)/q of the winding coils of the transformer winding and the winding coils of the transmitter coil is selected such that the inductance of the transformer winding is at least ten times higher than the inductance of the transmitter coil.

With this arrangement the resonant circuit, which consists of the transmitter coil and one or more tuning capacitors, can be tuned optimally and independently of other parts of the transmitter unit. Due to the difference in inductances the transformer is decoupled from the resonant circuit allowing individual optimization of the different parts of the transmitter. A standard class A or B amplifier can be selected providing an output signal in a suitable voltage range, e.g. 20Vpp. The transformer can be optimised for reduced losses and voltage conversion, while the resonant circuit is optimised for having a high Q factor. Voltage conversion is done with a single transformer winding that comprises with regards to the transmitter coil a relatively high number of winding coils resulting in a high inductance, which practically decouples the transformer from the tuned resonant circuit.

With the implementation of the invention higher voltages and higher drive currents can be obtained for driving the transmitter coil. Values of voltage and current of the tuned resonant circuit may be increased up to a factor of two or more. Simultaneously, interferences and degradations of the drive signal are avoided so that overall a significant increase of sensitivity can be reached.

CA 2784187 2018-08-16

Preferably the single transformer winding comprises a first and second group of taps allowing selection of the desired voltage that is applied to the resonant circuit.

The invention can be implemented in an apparatus that uses only one operating frequency or that comprises a controllable frequency generator that allows the selection of two or more operating frequencies preferably in the range of 300 kHz to 850 kHz.

In the event that the metal detection apparatus is designed for the operation with two or more operating frequencies two or more tuning capacitor are provided that are individually or in combination connectable to the transmitter coil such that a resonant circuit is formed that is tuned to the selected operating frequency.

In preferred embodiments the ratio of the inductance of the transformer winding and the inductance of the transmitter coil is selected in the range of 100:1 up to 2000:1.

Preferably the ratio of the inductance of the transformer winding and the inductance of the transmitter coil is provided in the range of 100:1 up to 200:1 in the range of the lowest operating frequencies and in the range of 1000:1 of to 2000:1 in the range of the highest operating frequencies. Hence, in every field of operation a desirable decoupling of the resonant circuit can be reached.

In a further preferred embodiment a control unit is provided that is designed in such a way that said first tap is selectable from a first group of taps and/or wherein said second tap is selectable from a second group of taps so that the ratio (n+m)/n of the winding coils of the transformer winding is raised for higher operating frequencies and reduced for lower operating frequencies. The ratio (n+m)/n is selected such that a desired voltage is generated across the transmitter coil for each operating frequency. Preferably the ratio (n+m)/n is selected in such a way that the current flowing through the amplifier does not alter significantly when the operating frequency is changed. The taps are selected so that when the transmitter coil has the desired voltage then the current in the amplifier is at an optimum value. Preferably the amplifier current does not deviate more than 10% - 20% from the optimum amplifier current value when the operating frequency is changed.

In preferred embodiments the number n+m of winding coils of the transformer winding up to the second tap of the transformer winding is higher by a factor 2 to 3 at the lower end of the frequency range of the operating frequencies and higher by a factor 5 to 15 at the higher end of the frequency range of the operating frequencies than the number n of winding coils of the transformer winding up to the first tap of the transformer winding.

In a further preferred embodiment the transformer comprises a secondary winding having a first tap, a second tap and centre tap, from which a reference signal is provided to a signal processing unit provided in the receiver unit, which reference signal is used to detect signal changes induced by products or contaminants that are passing through the transmitter coil and through separate symmetric coil sections of the centre tapped receiver coil. With this measure a reference can be obtained that exactly corresponds to the transmitter signal applied to the transmitter coil.

In a further preferred embodiment, the tuning capacitors of the resonant circuit are directly attached to the taps of the transmitter coil. In this way the resonant circuit is kept compact and losses are minimised that would otherwise degrade sensitivity. Preferably, shielding is provided that isolates the resonant circuit from electrical or electronic parts of the metal Detection apparatus.

The core of the transformer is for example a ferrite core preferably of the type of a pot core. This type allows manufacturing the inventive transformer that comprises in the main embodiment only a single transformer winding turned around a cylindrical core. This transformer exhibits in the present application preferred characteristics with minimal insertion losses.

BRIEF DESCRIPTION OF THE DRAWING

Some of the objects and advantages of the present invention have been stated, others will appear when the following description is considered together with the accompanying drawing, in which:

Fig. 1 shows a block diagram of an inventive metal detection apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a block diagram of an inventive metal detection apparatus, which comprises a transmitter unit 1, a balanced coil system with a transmitter coil 21, a first and a second receiver coil 31, 32, a receiver unit 4, a signal processing unit 6, and a control unit 5 that comprises standard interfaces, input devices and output devices, preferably a keyboard and a monitor. Figure 1 further symbolically shows a conveyor 8, on which products P, which may comprise contaminants C, are transferred through the transmitter coil 21 and the receiver coils 31, 32.

The transmitter unit 1 comprises a frequency generator 11 that provides a signal with the operating frequency f_{TX} to the input of a power amplifier 12 that operates for example according to class A or B standard. The output of the power amplifier 12 is applied preferably via a switch of a first switch bank 14 to a tap of a first group of taps 141, 142, 143 of a single winding of a transformer 13, which comprises a second group of taps 151, 152, 153, 154 and which is turned around a core 9, e.g. a ferrite core preferably of the pot-core type having a cylindrical core.

The transmitter coil 21 is connected via a switch of a second switch bank 15 to a tap of the second group of taps 151, 152, 153, 154. Further, a tuning capacitor 221 is firmly connected to the taps of the transmitter coil 21 thus forming a resonant L-C circuit, which is tuned to a first operating frequency f_{TX} of the metal detection apparatus. Over a switch bank 23 with switches 231, 232 additional tuning capacitors 222, 223 can be connected in parallel to the first tuning capacitor 221 in order to adjust the resonant frequency of the resonant circuit to further operating frequencies f_{TX} that can be selected at the frequency generator 11. Hence, the invention can be applied not only in an apparatus that is using only one operating frequency f_{TX}, but with any metal detection apparatus that uses one or more operating frequencies f_{TX} preferably in the range of 300 kHz to 850 kHz.

The transformer winding 131 comprises a number of n winding coils between the first tap 141 of the first group 141, 142, 143 and a common potential and a number of n+m winding coils between the first tap 151 of the second group of taps 151, 152, 153, 154 and the common potential. The transmitter coil 21 comprises the number of q winding coils.

With the selection of the taps 141, 142, 143; 151, 152, 153, 154 for the interconnection of the power amplifier 12 and the transmitter coil 21 the transmission ratio can suitably be selected over a wide range.

The ratio (n+m)/q of the winding coils of the first transformer winding 131 and the winding coils of the transmitter coil 21 is selected such that the inductance of the first transformer winding 131 is at least ten times higher than the inductance of the transmitter coil 21. With this selection of the ratio (n+m)/q and the resulting difference of inductances, high impedance is obtained for the transformer winding 131 and low impedance is obtained for the transmitter coil 21 incorporated in the resonant circuit. Hence, the influence of the transformer 13 on the resonant circuit remains small. In order to avoid interferences, the resonant circuit is further protected with a metal shielding 7.

In preferred embodiments the ratio of the inductance of the first transformer winding 131 and the inductance of the transmitter coil 21 is selected dependent on the operating frequency f_{TX} in the range between 100:1 and 2000:1. With an increase of the ratio of the inductances an optimal decoupling of the resonant circuit can be obtained.

Preferably a ratio of the inductance of the first transformer winding 131 and the inductance of the transmitter coil 21 is provided in the range of 100:1 up to 200:1 in the range of the lowest selectable operating frequencies f_{TX}. In the range of the highest operating frequencies f_{TX} a ratio of the inductance of the first transformer winding 131 and the inductance of the transmitter coil 21 is provided preferably in the range of 1000:1 of to 2000:1.

In an exemplary embodiment the number n+m of winding coils of the first transformer winding 131 up to the first tap 151 of the second group 151; 152; 153; 154 is higher by a factor of 2 to 3 at the lower end of the frequency range of the operating frequencies f_{TX} and higher by a factor 5 to 15 at the higher end of the frequency range of the operating frequencies f_{TX} than the number n of winding coils of the first transformer winding 131 up to the first tap 141 of the first group of taps 141, 142, 143 of the first transformer winding 131.

The number n of winding coils between the first tap 141 of the first group 141, 142, 143 and common potential is for example equal to 5. The number m_L of winding coils between the first tap 151 of the second group 151, 152, 153, 154 and common potential is for example equal to 11. The number m_H of winding coils between the last tap 154 of the second group 151, 152, 153, 154 and a common potential is for example equal to 33. Preferably, the winding coils between the various taps 151, 152, 153, 154 are distributed equally.

The first group of taps may for example be reduced to a single tap 141. However with more than one tap 141, 142, 143 the flexibility for selecting suitable voltages is significantly enhanced.

The settings of the switch banks 14 and 15 is preferably selected in such a way that the ratio (n+m)/n of the winding coils of the first transformer winding (131) is raised for higher operating frequencies f_{TX} and reduced for lower operating frequencies f_{TX}.

With this measure the voltage generated across the transmitter coil 21 can individually be adjusted for each operating frequency f_{TX}. In preferred embodiments, the switch banks 14 and 15 are actuated in such a way that the current flowing in the power amplifier 12 is kept approximately constant independently of the selected operating frequency f_{TX}. Hence, the power amplifier operates in a preferred mode. As a result a stable performance of the metal detection apparatus over the whole range of operating frequencies f_{TX} is achieved. Adjustments and automatic control, closed loop circuitry for adjusting the receiver gain, and erroneous measurement results caused by amplitude changes together with frequency changes can be avoided.

In the drawing it is further shown that the first transformer winding 131 is coupled to a second transformer winding 132, which comprises between a first and second tap

1321, 1323 a centre tap 1322. The voltage appearing across the second winding 132, which is fed as a reference signal s_{REF} to the signal processing unit 6, corresponds exactly to the signal appearing across the receiver coil 3 when no products P and/or contaminants C pass through the balanced coil system 21, 3. Hence, with the reference signal s_{REF} changes of the received signal induced by products P or contaminants C can exactly be detected. Since the reference signal s_{REF} is phase-locked to the transmitter signal s_{TX} at the output of the power amplifier 12 detection of signal changes can be performed with highest accuracy. Phase shifts are avoided that may otherwise occur in logic modules of the transmitter electronics.

The inventive metal detection apparatus comprises control unit 5 that controls via control line 51 the frequency generator 11, via control line 52 the settings of the switch bank 14, via control line 53 the switch bank 15 and via control line 54 the switches 231, 232 of the tuning capacitors 222, 223 of the resonant circuit. Further, the control unit 5 is connected to the signal processing unit 6 via communication channel 60.

The control unit 5 preferably comprises a computer program that supports automated operation of the inventive metal detection apparatus.

CLAIMS:

1. Metal detection apparatus comprising a transmitter unit, which provides transmitter signals to a transmitter coil that is coupled to a receiver coil, which is connected to the input of a receiver unit, said transmitter unit comprising a frequency generator that provides an operating frequency (f_{TX}) to the input of an amplifier stage, whose output is connected via a transformer to the transmitter coil, characterised in that the output of the amplifier stage is connected to a first tap and the transmitter coil is connected to a second tap of a same first transformer winding of the transformer, having a number of n winding coils between the first tap and a common potential and a number of n+m winding coils between the second tap and the common potential, wherein the transmitter coil comprises the number of q winding coils and is connected in parallel to a capacitor thus forming a resonant circuit that is tuned to the operating frequency (f_{TX}) and wherein the ratio (n+m)/q of the winding coils of the first transformer winding and the winding coils of the transmitter coil is selected such that the inductance of the first transformer winding is at least ten times higher than the inductance of the transmitter coil.

2. Metal detection apparatus according to claim 1, wherein the first tap is selectable from a first group of taps and/or wherein the second tap is selectable from a second group of taps that are connected to the first transformer winding having a number of winding coils, allowing the selection of ratios (n+m)/n in the range from 1 to 15.

3. Metal detection apparatus according to claim 1 or 2, wherein a controllable frequency generator is provided that allows the selection of two or more operating frequencies (f_{TX}) in the range of 300 kHz to 850 kHz.

4. Metal detection apparatus according to claim 3, wherein one or more tuning capacitors are provided that are individually or in combination connectable to the transmitter coil such that the resonant circuit is formed that is tuned to the selected operating frequency (f_{TX}).

5. Metal detection apparatus according to claim 3 or 4, wherein the ratio of the inductance of the first transformer winding and the inductance of the transmitter coil is selectable in the range of 100:1 up to 2000:1.

CA 2784187 2018-08-16

6. Metal detection apparatus according to claim 5, wherein the ratio of the inductance of the first transformer winding and the inductance of the transmitter coil is provided in the range of 100:1 up to 200:1 towards the lowest operating frequencies (f_{TX}) and in the range of 1000:1 of to 2000:1 towards the highest operating frequencies (f_{TX}).

7. Metal detection apparatus according to one of the claims 2 - 6, wherein a control unit is provided that is designed that the first tap is selectable from a first group of taps and/or wherein the second tap is selectable from a second group of taps such that the ratio (n+m)/n of the winding coils of the first transformer winding is raised for higher operating frequencies (f_{TX}) and reduced for lower operating frequencies (f_{TX}).

8. Metal detection apparatus according to claim 7, wherein the ratio (n+m)/n is selectable for each operating frequency (fTX) such that a desired voltage is generated across the transmitter coil and that the current in the amplifier is substantially constant at an optimum value for all operating frequencies (f_{TX}) selected.

9. Metal detection apparatus according one of the claims 1-8, wherein the number n+m of winding coils of the first transformer winding up to the second tap is higher by a factor 2 to 3 at the lower end of the frequency range of the operating frequencies (f_{TX}) and higher by a factor 5 to 15 at the higher end of the frequency range of the operating frequencies (f_{TX}) than the number n of winding coils of the first transformer winding up to the first tap of the first transformer winding.

10. Metal detection apparatus according to one of the claims 1-9, wherein the transformer comprises a secondary winding having a first tap, a second tap and centre tap from which a reference signal (s_{REF}) is provided to a signal processing unit provided in the receiver unit, which reference signal (s_{REF}) is used to detect signal changes induced by products (P) or contaminants (C) that are passing through the transmitter coil and through separate symmetric coil sections of a centre tapped receiver coil.

11. Metal detection apparatus according to one of the claims 4-10, wherein the one or more tuning capacitors are directly attached to the taps of the transmitter coil.

12. Metal detection apparatus according to one of the claims 1-11, wherein the transformer comprise a ferrite core of the pot core type.

CA 2784187 2018-08-16

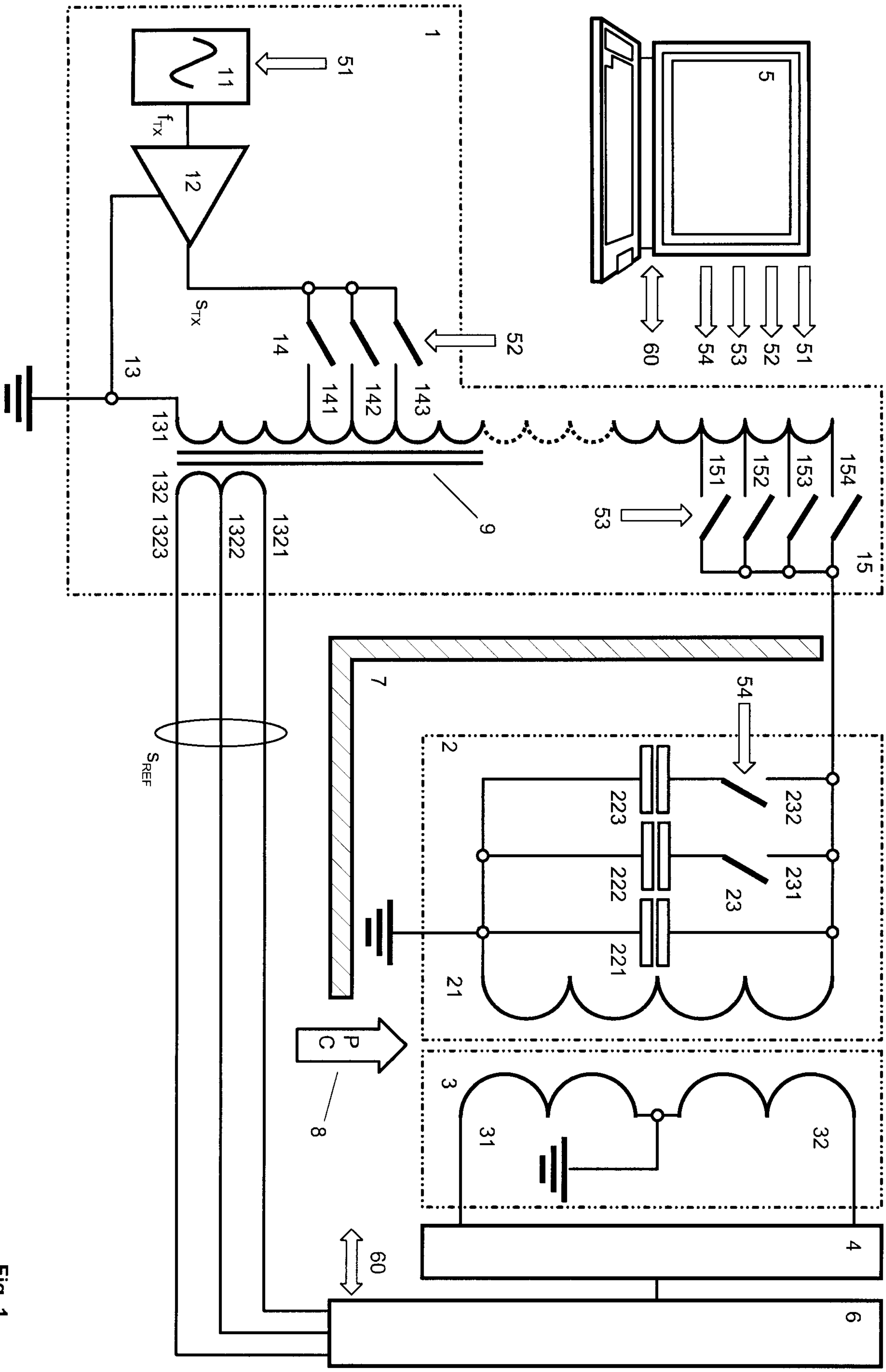
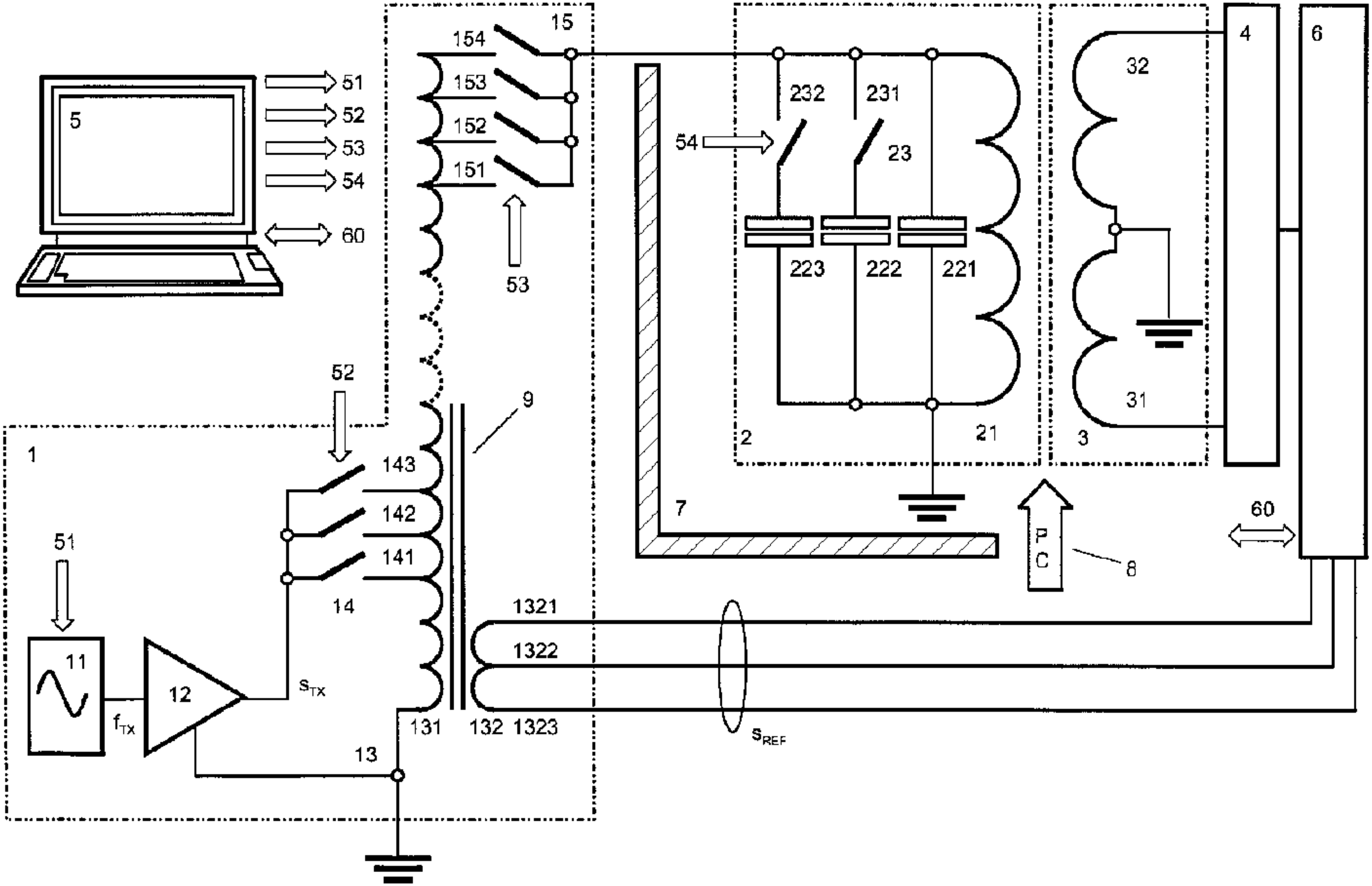

1
11
51
f_{TX}
12
S_{TX}
13
14
52
141
142
143
131
132
1323
1322
1321
9
151
152
153
154
53
15
5
60
54
53
52
51
7
54
2
S_{REF}
223
222
221
232
231
23
21
P
C
8
3
31
32
60
4
6

Fig. 1



1
11
12
f_{TX}
s_{TX}
51
52
53
54
60
5
14
141
142
143
13
131
132
1321
1322
1323
s_{REF}
9
15
151
152
153
154
7
2
21
221
222
223
23
231
232
3
31
32
4
6
P
C
8