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(54) **METHOD AND APPARATUS FOR USING NON-LINEAR GROUND PENETRATING RADAR TO DETECT OBJECTS LOCATED IN THE GROUND**

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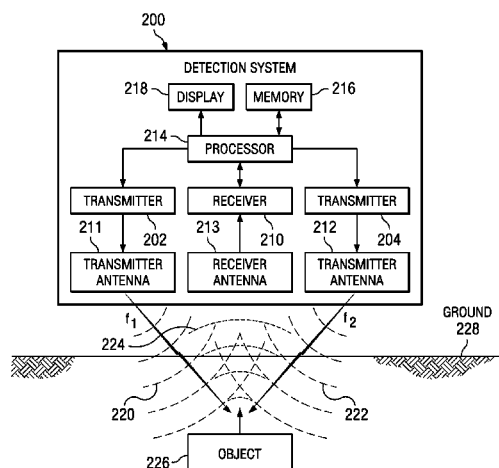
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See application file for complete search history.

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(57) **ABSTRACT**

A method and apparatus for detecting objects located underground. In one advantageous embodiment, a detection system detects objects having electrical non-linear characteristics located underground. The detection system comprises a transmitter unit, a receiver, and a processor. The transmitter transmits a plurality of pulsed radio frequency signals having a first frequency and a second frequency into a ground. The receiver monitors for a response radio frequency signal having a frequency equal to a difference between the first frequency and a second frequency, wherein the response radio frequency signal is generated by an object having the non-linear conductive characteristics in response to receiving the plurality of electromagnetic signals. The processor is connected to the transmitter unit and the receiver, wherein the processor controls an operation of the transmitter unit and the receiver, wherein the object is detected when the response radio frequency signal is detected by the receiver.

20 Claims, 5 Drawing Sheets

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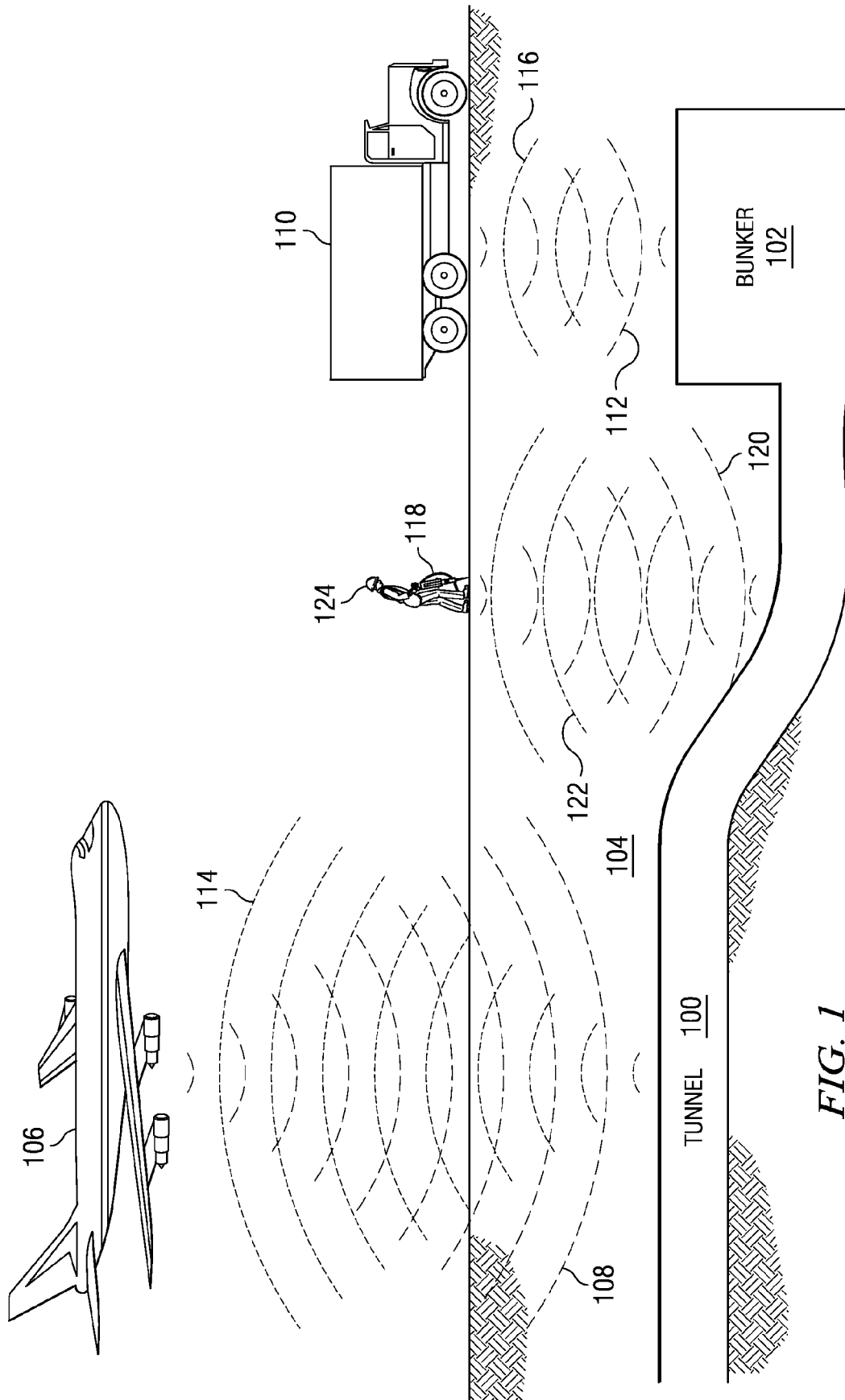USPTO Office Action dated Apr. 28, 2010 for U.S. Appl. No. 12/026,918, pp. 22.

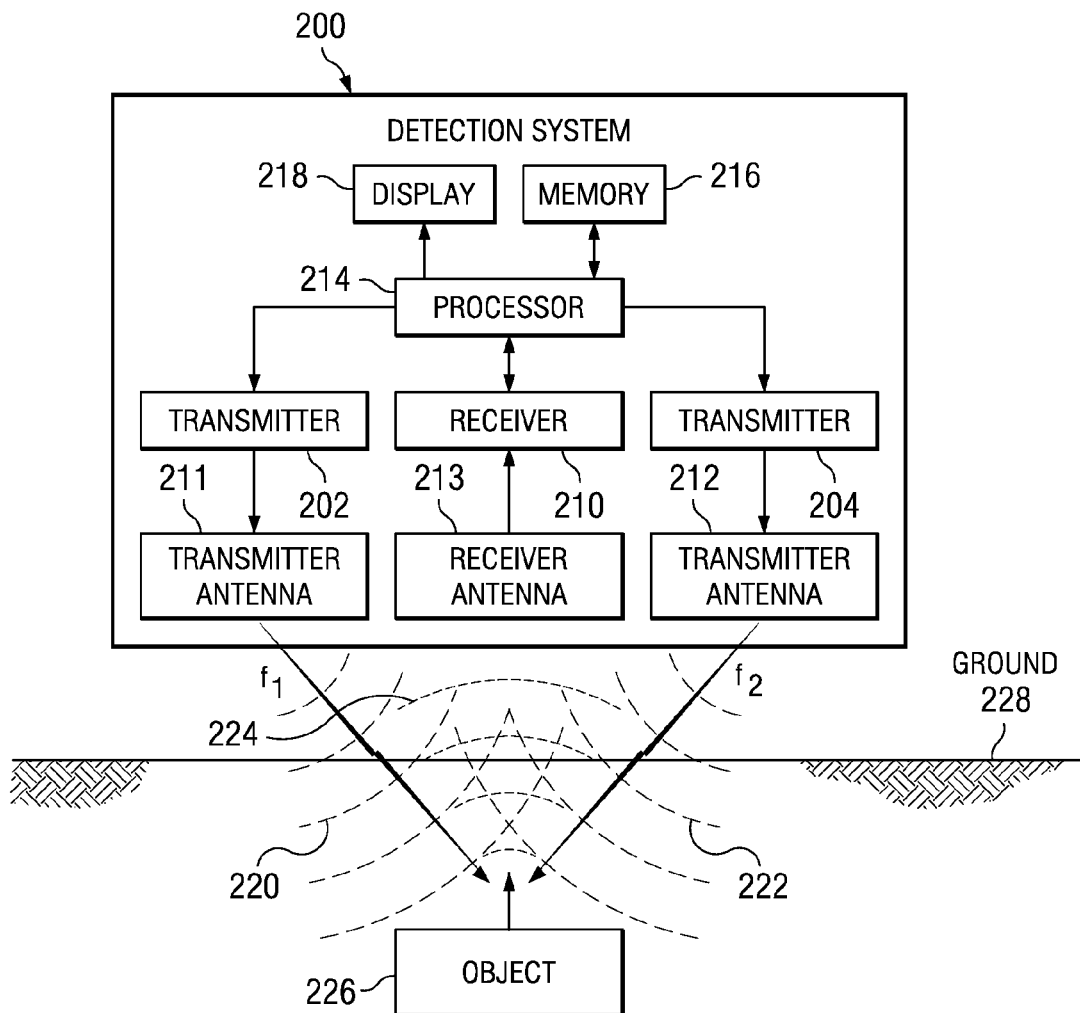USPTO Final Office Action dated Aug. 27, 2010 for U.S. Appl. No. 12/026,918, pp. 14.

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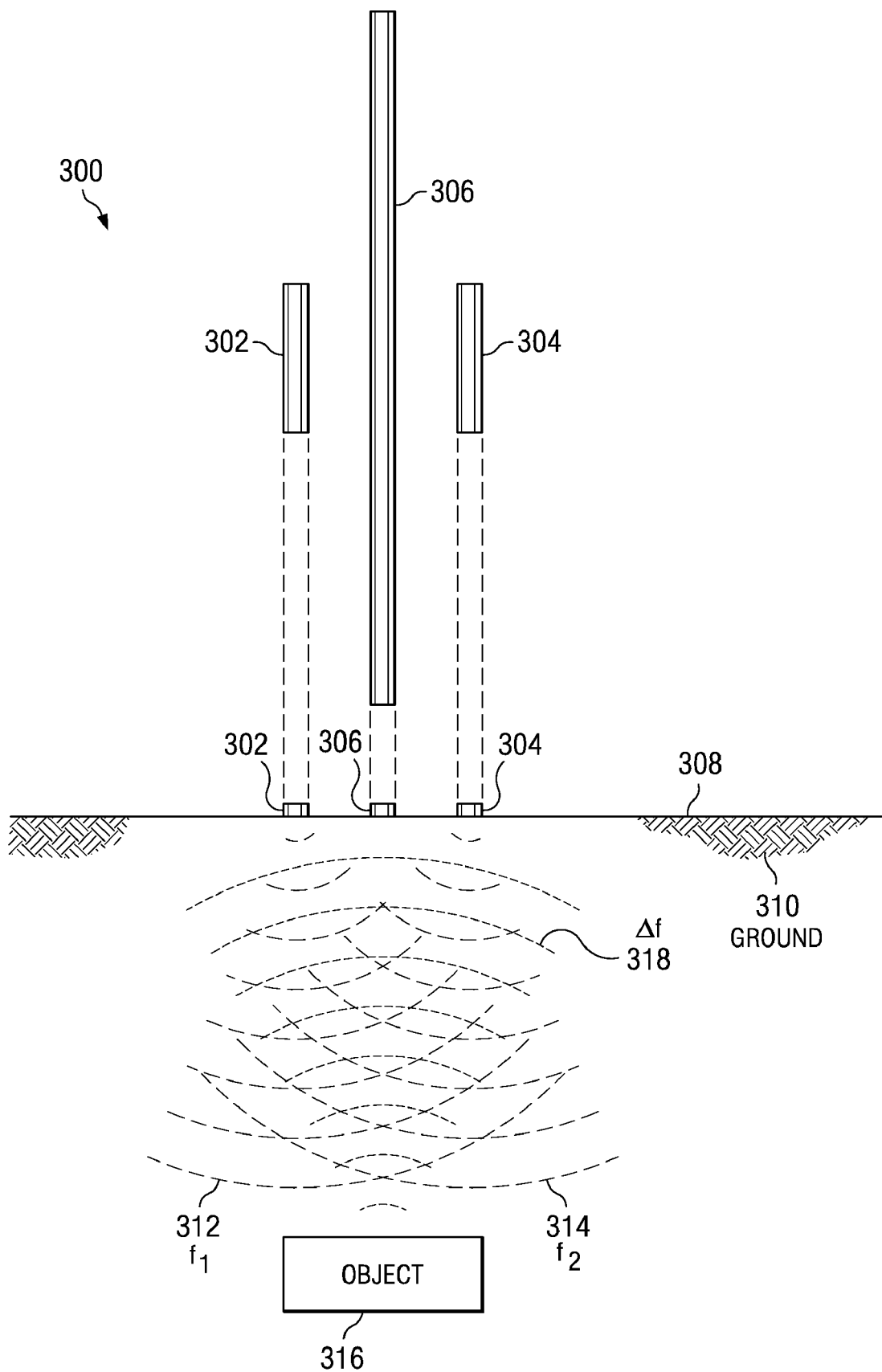
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FIG. 1

200
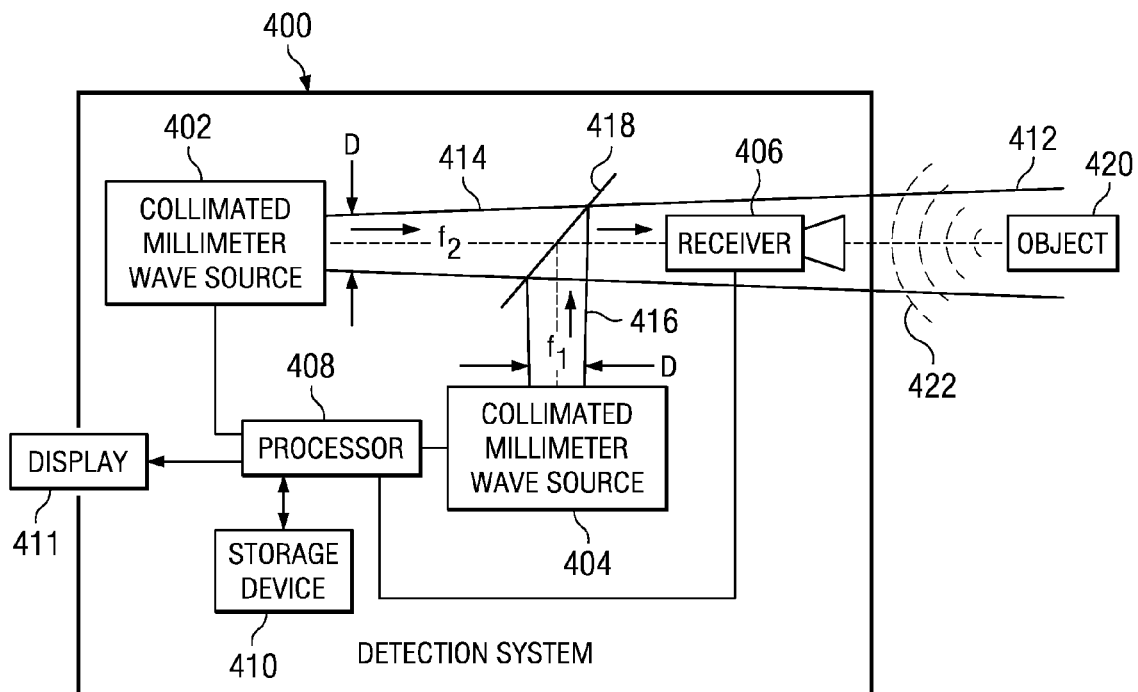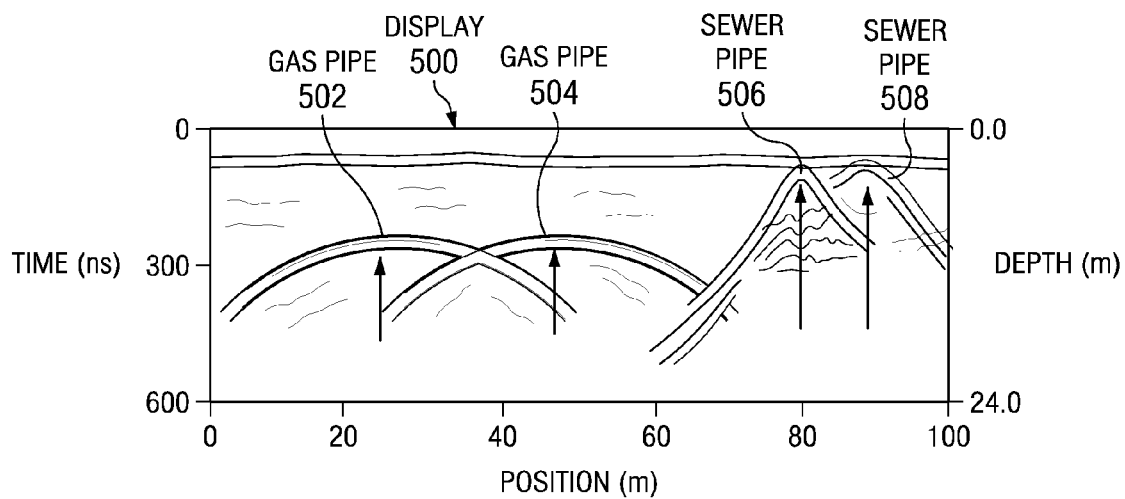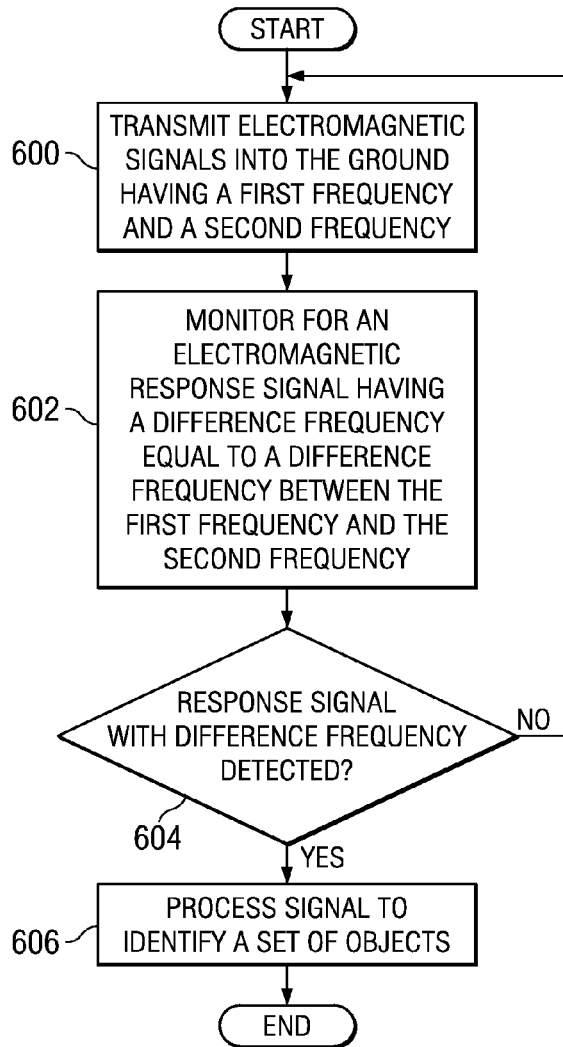
DETECTION SYSTEM

218 — DISPLAY   MEMORY — 216

214 — PROCESSOR

TRANSMITTER   RECEIVER   TRANSMITTER

211   202   213   210   212   204

TRANSMITTER ANTENNA   RECEIVER ANTENNA   TRANSMITTER ANTENNA

f_1 f_2 GROUND 228

224

220   222

226 — OBJECT

FIG. 2

300

306

302

304

302 | 306 | 304

308

Δf
318

310
GROUND

312
f₁

314
f₂

OBJECT

316

FIG. 3

400

402

D

414

418

406

412

420

COLLIMATED
MILLIMETER
WAVE SOURCE

f_2

RECEIVER

OBJECT

416

408

f_1

D

DISPLAY

PROCESSOR

COLLIMATED
MILLIMETER
WAVE SOURCE

422

411

404

STORAGE
DEVICE

410

DETECTION SYSTEM

FIG. 4

DISPLAY
500

SEWER
PIPE
506

SEWER
PIPE
508

GAS PIPE
502

GAS PIPE
504

TIME (ns)

0

0.0

300

DEPTH (m)

600

24.0

0   20   40   60   80   100

POSITION (m)

FIG. 5

START

600 — TRANSMIT ELECTROMAGNETIC SIGNALS INTO THE GROUND HAVING A FIRST FREQUENCY AND A SECOND FREQUENCY

602 — MONITOR FOR AN ELECTROMAGNETIC RESPONSE SIGNAL HAVING A DIFFERENCE FREQUENCY EQUAL TO A DIFFERENCE FREQUENCY BETWEEN THE FIRST FREQUENCY AND THE SECOND FREQUENCY

RESPONSE SIGNAL WITH DIFFERENCE FREQUENCY DETECTED?   NO

604

YES

606 — PROCESS SIGNAL TO IDENTIFY A SET OF OBJECTS

END

FIG. 6

START

700 — SELECT A FIRST FREQUENCY AND A SECOND FREQUENCY

702 — SET FIRST AND SECOND FREQUENCY FOR TRANSMITTING

704 — TRANSMIT ELECTROMAGNETIC SIGNALS INTO THE GROUND

END

FIG. 7

START

800 — MONITOR FOR RESPONSE ON A DIFFERENCE EQUAL TO A DIFFERENCE BETWEEN THE FIRST FREQUENCY AND THE SECOND FREQUENCY

802

RESPONSE SIGNALS DETECTED WITH DIFFERENCE FREQUENCY?   NO

YES

804 — PROCESS DATA FROM RESPONSE SIGNALS

806 — DISPLAY PROCESSED DATA

END

FIG. 8

METHOD AND APPARATUS FOR USING NON-LINEAR GROUND PENETRATING RADAR TO DETECT OBJECTS LOCATED IN THE GROUND

CROSS REFERENCE TO RELATED APPLICATION

The present invention is related to the following patent application: entitled "Method and Apparatus for Locating Objects Using Radio Frequency Identification", Ser. No. 11/758,787, filed even date hereof, assigned to the same assignee, and incorporated herein by reference.

BACKGROUND INFORMATION

1. Field

The present invention relates generally to improved method and apparatus for identifying objects. Still more particularly, the present invention relates to a method and apparatus for detecting objects located in the ground using electromagnetic radiation.

2. Background

An increasing demand is present for an approach to detect and locate tunnels, underground infrastructure, and for identifying objects located within the ground. A threat is posed by tunneling. Tunnels may be deeply bored. Deep urban bunkers with interconnecting tunnels also may be present. These types of tunnels are often used to smuggle illegal contraband into and out of a country. Many of these facilities are deeply buried or significantly hardened in an attempt to preclude detection and characterization by sensors.

Various approaches that have been considered for detecting tunnels include electromagnetic and gravity gradiometry, thermal, seismic, or other nondestructive and noninvasive investigations. These approaches have been used by active and passive systems through unattended ground vehicles and unmanned aerial vehicles, as well as other land mobile platforms as mountings for these types of sensors. Invasive techniques that have been used include drilling techniques for tunnel detection and verification. With respect to detecting tunnels at different ranges, a need has developed for detecting near surface tunnels. These types of tunnels typically have a depth range anywhere between a few feet to a hundred feet or more under the surface. Currently available techniques do not have the depth range and resolution needed to detect tunnels at the deeper end of this depth range.

SUMMARY

The advantageous embodiments of the present invention provide a method and apparatus for detecting objects located underground. In one advantageous embodiment, a detection system detects objects having electrical non-linear characteristics located underground. The detection system comprises a transmitter unit, a receiver, and a processor. The transmitter transmits a plurality of pulsed radio frequency signals having a first frequency and a second frequency into a ground. The receiver monitors for a response radio frequency signal having a frequency equal to a difference between the first frequency and a second frequency, wherein the response radio frequency signal is generated by an object having the non-linear conductive characteristics in response to receiving the plurality of electromagnetic signals. The processor is connected to the transmitter unit and the receiver, wherein the processor controls an operation of the transmitter unit and the

receiver, wherein the object is detected when the response radio frequency signal is detected by the receiver.

In another advantageous embodiment, an apparatus comprises a transmitter unit and a receiver. The transmitter transmits a plurality of electromagnetic signals having a first frequency and a second frequency into a ground. The receiver monitors for an electromagnetic signal having a frequency equal to a difference between the first frequency and a second frequency that is generated by an object having an electrical non-linear conductive characteristic in response to being exposed to the plurality of electromagnetic signals. The object is detected when the electromagnetic signal is detected by the receiver.

In a different advantageous embodiment, a method is used to detect an object with electrical non-linear characteristics. A plurality of electromagnetic signals having a first frequency and a second frequency are transmitted into a ground. Monitoring is performed for an electromagnetic signal having a frequency equal to a difference between the first frequency and a second frequency, wherein the electromagnetic signal is generated by an object in the ground having an electrical non-linear characteristic in response to receiving the plurality of electromagnetic signals. The object having the electrical non-linear characteristic is detected when the electromagnetic signal is detected.

The features, functions, and advantages can be achieved independently in various embodiments of the present invention or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an advantageous embodiment of the present invention when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a diagram illustrating a method and apparatus for detecting structures buried under the ground in accordance with an advantageous embodiment of the present invention;

FIG. 2 is a diagram of a detection system in accordance with an advantageous embodiment of the present invention;

FIG. 3 is a diagram illustrating another configuration for a detection system in accordance with an advantageous embodiment;

FIG. 4 is a diagram illustrating a detection system in accordance with an advantageous embodiment of the present invention;

FIG. 5 is a diagram illustrating an example of data obtained using a detection system in accordance with an advantageous embodiment of the present invention;

FIG. 6 is a flowchart of the process for detecting an object with electrical non-linear characteristics in accordance with an advantageous embodiment of the present invention;

FIG. 7 is a flowchart of a process for transmitting electromagnetic signals in accordance with an advantageous embodiment to the present invention; and

FIG. 8 is a flowchart of a process for detecting a response signal in accordance with an advantageous embodiment to the present invention.

DETAILED DESCRIPTION

With reference now to the figures and in particular with reference to FIG. 1, a diagram illustrating a method and

apparatus for detecting structures buried under the ground is depicted in accordance with an advantageous embodiment of the present invention. In these illustrative examples, non-linear ground penetrating radar technology is used to detect objects, such as tunnels and bunkers. In the depicted example, electromagnetic pulses are launched into the ground and echoes from an underground object are received and interpreted in an attempt to identify the object. The different illustrative embodiments recognize that a problem with this current method of using ground penetrating radar is that finding an appropriate radio frequency to operate the system is often difficult. The different embodiments recognize that this difficulty lies in the contradictory capabilities and limitations of low and high frequencies.

The different advantageous embodiments recognize that electromagnetic techniques in which electromagnetic pulses are launched into the ground have been used. Echoes from underground objects or discontinuities are received and interpreted. This technique is referred to as a ground penetrating radar and has been used in the past to detect various underground discontinuities, such as cables, pipes, cavities, and other objects intoned or buried deeply in ice or other formations.

The different advantageous embodiments also recognize that one of the challenges with the currently used ground penetrating radar methods is to find an appropriate frequency of operation. Often times, the frequencies either do not exist or are not available. With respect to available frequencies, if a frequency of operation is chosen to be too low, the available resolution is poor, making results unusable. These types of frequencies are usually less than 10 MHz.

If the selected frequency is too high, the available pulse penetration depth suffers. In other words, higher frequencies do not penetrate into the ground as far. A high frequency is typically considered a frequency greater than 1 GHz. As a result, high frequency ground penetrating radars are typically only used in applications in which objects are located in shallow depths, such as inches rather than feet.

Thus, the different advantageous embodiments of the present invention provide an improved ground penetrating radar technique. This technique is based on electrical non-linear characteristics of objects, such as surfaces of corroded conducting objects that are located in the ground. The technique also may be based on corroded objects located in underground tunnels. In these examples, a corroded conductive object may be oxidized or rusted. The corrosion causes a conductive non-linearity in a shallow layer on the surface of a conducting object. The corroded or oxidized portion has a different conductivity than the non-corroded portion. This technique also may be applied to other electrical non-linear characteristics of objects. For example, if an object contains two different types of metals in layers, this non-linearity also may be used to detect the object located under the ground. Another example may be discarded electronic circuits with non-linear components, such as diodes or transistors, embedded in them.

The different advantageous embodiments provide a system for detecting underground objects, such as tunnel 100 and bunker 102 within ground 104. These and other types of objects may be detected based on electrical non-linear characteristics of these objects. This non-linearity is typically found in corroded conducting elements within tunnel 100 and bunker 102. These elements also may be located as objects within tunnel 100 or bunker 102. Alternatively, these elements may be part of the infrastructure making up tunnel 100, bunker 102 or electronic equipment.

In these illustrative examples, pulsed electromagnetic fields are sent into ground 104. Aircraft 106 is an example of a source for electromagnetic signals 108. Truck 110 is a source of electromagnetic signals 112.

When electromagnetic signals 108 encounter an object that has electrical non-linear characteristics, currents are induced during the duration of these pulses. Any non-linearity within the object results in some of these currents being converted to or rectified into currents oscillating at the difference frequency between the frequencies of the two pulsed signals.

These difference currents then reradiate as electromagnetic radiation at the difference frequency. Some of these signals propagate back towards the surface as response signals 114. Response signals 114 may be detected by a receiver in aircraft 106 to identify the presence of a buried object, such as tunnel 100. The receiver in aircraft 106 is set to detect signals at the difference frequency. In a similar fashion, when truck 110 transmits electromagnetic signals 112, a portion of bunker 102 containing a non-linear conductive section generates response signals 116 at the difference frequency. In these examples, electromagnetic signals 112 are in the form of pulsed electromagnetic radiation.

In yet another embodiment, portable instrument 118 may be employed to generate electromagnetic signals 120, which cause currents to occur in a non-linear conductive section within tunnel 100. As a result, some of these currents generate response signals 122, which are radiated back to portable instrument 118. In this type of embodiment, portable instrument 118 may be moved and positioned by person 124. With this type of implementation, portable instrument 118 is carried by person 124 and periodically placed on the ground 104.

The receivers in aircraft 106 and truck 110 are insensitive to the outgoing signals in these examples. This insensitivity occurs, in the depicted examples, because the receiver operates at a much lower frequency, which is not related harmonically to either of the two transmitted frequencies. As a result, the background noise is essentially eliminated or greatly reduced. Further, higher power transmitted pulses may be emitted without having to worry about these pulses coupling into sensitive receiver circuits and blinding the receiver.

Another benefit, in many of the embodiments, is that the response generated by the buried objects in ground 104, such as tunnel 100 and bunker 102, travel only one way. Response signals 114, 116 and 122 travel toward the receiver. As a result, unwanted signals occurring from echoes created by irrelevant strata or layers in the soil, encountered by the outgoing signals, are eliminated. Also, echoes created by shallow lying trash in the soil are eliminated.

In these examples, two transmitting antennas are used in which each antenna is tuned or selected to transmit a different frequency from the other antenna. The different frequencies are generated by a transmitter unit. The different frequencies are used to create a difference frequency within the desired frequency range. This difference frequency is in the range of frequencies detected by the receiver in these examples. In these examples, the difference frequency is equal to the difference between the first frequency and the second frequency. The first frequency is at higher frequency than the second frequency in these examples.

In one embodiment, pulsed electromagnetic signals of both frequencies enter the ground and propagate until these signals encounter a conductive object in which currents are induced. The currents are induced during the duration of the electromagnetic pulses. If the object contains a component with an electrical non-linear characteristic, such as a corroded or rusted surface, some of these induced currents are converted to currents that oscillate at the difference frequency.

The currents then re-radiate electromagnetic signals at the difference frequency. A portion of the signal propagates back towards the surface and is captured as a response signal by the receiving antenna. A receiver connected to the receiving antenna is specifically tuned to the difference frequency. The received difference frequency signals are then interpreted.

One advantage of using this type of ground penetrating radar system is that the receiver is insensitive to outgoing transmitted electromagnetic signals because the receiver operates at a much lower frequency. This frequency is selected to be unrelated to the frequencies of the transmitted signal.

Therefore, background noise is greatly diminished with this type of system. Additionally, higher intensity transmitted pulses may be emitted without having to worry about these high power outgoing pulses coupling into sensitive receiver circuits and blinding the receiver. Another benefit of the different advantageous embodiments is that a received signal at the difference frequency travels only one way. The path that the signal travels is from the object to the surface. This type of propagation eliminates most unwanted signals that may occur due to echoes created by irrelevant strata or layers in the soil that may be encountered as the outgoing transmitter pulses enter the soil.

Turning now to FIG. 2, a block diagram of a detection system is depicted in accordance with an advantageous embodiment of the present invention. In this example, detection system 200 is an example of an apparatus that may be implemented for detecting objects having electrical non-linear characteristics that are buried under the ground. In particular, detection system 200 may be implemented or located in a vehicle, such as, for example, aircraft 106 or truck 110 in FIG. 1. Also, detection system 200 may be implemented as a portable instrument.

In this example, detection system 200 includes transmitter 202, transmitter 204, and receiver 210. Detection system 200 also includes antenna 211, antenna 212 and antenna 213. Processor 214, memory 216 and display 218 also are located in detection system 200.

Transmitter 202 and transmitter 204 form a transmitter unit that generates electromagnetic signals at different frequencies.

Antennas 211 and 212 receive electromagnetic energy from transmitters 202 and 204, respectively, and radiate the electromagnetic energy as electromagnetic signals 220 and 222. Depending on the implementation, a single antenna may be used in place of antennas 211 and 212. Transmitters 202 and 204 may be designed to share a single antenna in this type of implementation. In these examples, electromagnetic signals 220 and 222 take the form of electromagnetic radiation emitted as pulses. Response signals 224 collected by antenna 213 are routed to receiver 210. Receiver 210 filters and amplifies response signals 224 for further processing. This processing may include interpretation, storage, and display data for response signals 224.

In these examples, transmitter 202 and transmitter 204 may generate electromagnetic signals 220 and 222 having different frequencies. For example, transmitter 202 may generate electromagnetic signals 220 that are emitted by antenna 211 with the first frequency f1. Transmitter 204 may generate electromagnetic signals 222 that are emitted by antenna 212 with a second frequency f2.

The frequencies at which transmitters 202 and 204 generate electromagnetic signals 220 and 222 are controlled by processor 214 in these examples. Processor 214 acts as a controller to generate pulses for electromagnetic signals 220 and 222 in these examples. Processor 214 controls the timings

of the leading edges of the emitted pulses and the timing of the leading edge of the received pulses. Information about the received pulse-widths may be used to help determine the resonant nature (the Q) of electrically non-linear objects.

In these embodiments, the pulse widths of the received signals in response signals 224 will have to be referred to (compared to) the pulse widths of the outgoing (transmitted) pulses. Processor 214 may perform these and other operations based on instructions stored in memory 216. Response signals 224 received by receiver 210 may be displayed on display 218. Further, display 218 may also provide other information, such as the range or location of a response identified by receiver 210. Display 214 is also used to display cross-sections in depth of the soil as traversed on the surface along a normally straight line.

In these advantageous embodiments, processor 214 identifies a frequency at which a response is desired to be detected by receiver 210. Processor 214 sets receiver 210 to detect signals at this identified frequency. Processor 214 sets transmitter 202 to transmit electromagnetic signals 220 at a first frequency f1. Transmitter 204 is set by processor 214 to transmit electromagnetic signals 222 at a second frequency f2. In other embodiments, the frequencies transmitted by transmitters 202 and 204 are fixed and not changed or controlled by processor 214.

The difference between the first frequency f1 and second frequency f2 is equal to a difference frequency that is set for receiver 210 in these examples. The frequency selected for transmitters 202 and 204 are such that they do not affect the electronics in receiver 210. Receiver 210 is not configured or programmed to detect signals at the frequencies set for transmitters 202 and 204.

As an example, transmitter 202 may be set to transmit at 94 MHz while transmitter 204 is set to transmit at 106 MHz The difference between these two frequencies is 12 MHz Receiver 210 is set to detect signals at the 12 MHz frequency.

With these frequencies, the typical penetration depth into the ground at output power levels currently used with conventional ground penetrating radar systems is approximately 60 to 100 feet. In these examples, object 226 is located under ground 228. Object 226 contains electrical non-linear characteristics. All or a portion of object 226 may contain these characteristics in these examples.

When electromagnetic signals 220 and 222 reach object 226, currents are induced within all conductive parts of object 226. Some of these induced currents will convert to currents with difference frequency, Δf in portions of the conductive parts of object 226 with non-linear characteristics. These currents, with frequency Δf, result in the generation of an electromagnetic signal in the form of response signals 224. Response signals 224 are captured by antenna 210 in these examples.

Receiver 210 detects response signal 224 and sends this data to processor 214 for processing and analysis. In these examples, receiver 210 does not detect electromagnetic signals 220 and 222 because receiver 210 is set only to detect a frequency that is the difference between the frequency transmitted by transmitter 202 and the frequency transmitted by transmitter 204.

The electrical non-linear characteristics may be found in objects, such as, for example, oil, gas, and water pipelines. Other examples of objects that may have non-linear elements that are buried include fuel tanks, water tanks, and cables. Electrical non-linearities may be present in these objects due to corrosion in a metallic portion of the object. The electrical non-linear characteristic within the object causes a response signal that has a frequency equal to the difference between the

two transmitted signals to be returned. This response is detected by receiver **210** in this example.

In these examples, the penetration of electromagnetic signals **220** and **222** increases as the frequencies used decrease. Resolution, however, decreases as well, as the frequencies decrease. More specifically, the spatial resolution decreases. In this illustrative example, transmitter **202** and transmitter **204** may continuously transmit at frequencies f1 and f2. With this type of operation, receiver **210** detects only the frequency that is the difference between those two frequencies.

As a result, response signals **224**, when detected by receiver **210**, is processed by processor **214** indicating the presence of object **226** under ground **228**. Further, with the movement of detection system **200** in a horizontal direction relative to the surface of ground **228**, the shape of object **226** may be identified through continued detection of response signals **224**. The change in time at which response signals **224** is received as detection system **200** moves may be used to determine the shape and depth of object **226**. This information may be stored by processor **214** and memory **216** as readings together with location (position) readings are taken by detection system **200**. The data stored in memory **216** may be processed by processor **214** to generate an image of object **226** under ground **228** and present it on display **218**. This image may be a vertical cross section.

Alternatively, processor **214** may set receiver **210** to detect signals within a range of difference frequencies. In this manner, if additional objects in addition to object **226** are located under ground **228** with different electrical non-linear characteristics at various different depths, these objects also may be detected by detection unit system **200**.

With reference now to FIG. **3**, a diagram illustrating another configuration for a detection system is depicted in accordance with an advantageous embodiment. Detection system **300** includes transmitter antennas **302** and **304** along with receiver antenna **306**. In these examples, transmitter antenna **302** transmits at frequency f1, while transmitter antenna **304** transmits at frequency f2. Receiver antenna **306** is designed to receive frequencies at frequency Δf, which is a frequency having a difference between frequency f1 and frequency f2 for transmitter antennas **302** and **304** in these examples.

In FIG. **3**, antennas **302**, **304** and **306** are placed on surface **308** of ground **310**. Antennas **302** and **304** may transmit electromagnetic signals **312** and **314**, at frequencies f1 and f2, respectively.

In this example, object **316** is located under ground **310**. Non-linear characteristics in object **316** result in response signals **318**, which are detected by receiver antenna **306**. Response signals **318** are emitted at the difference frequency Δf.

In these illustrative examples, many ground penetrating radar applications require radio frequency pulses that are at low frequencies and cannot be collimated. This type of situation may occur with many soil types which absorb radiation at an increasing rate starting at frequencies several hundred MHz and higher. With other soil types, such as dry sand and ice, millimeter waves may be used without much absorption. A collimated system, such as that depicted in FIG. **4** shown below, may be implemented.

Detection system **300**, in these examples, is especially useful with wet soils in which low transmitter frequencies are required. For this type of configuration for detection system **300**, transmitter antennas **302** and **304** may emit signals at or around 200 MHz plus and minus 15 MHz. In these examples, transmitter antennas **302** and **304** are, for example, about one half meter long at each of these frequencies. Receiver antenna

306 may be three to four meters long and operate to receive response signals **318** at around 25-30 MHz in this particular example. Of course, depending on the particular implementation, there is a range of frequencies to choose from.

Turning next to FIG. **4**, a diagram illustrating a detection system is depicted in accordance with an advantageous embodiment of the present invention. Detection system **400** is an example of another configuration that may be used in a vehicle, such as aircraft **106** or in truck **110** in FIG. **1**.

In this particular example, detection system **400** includes collimated millimeter wave source **402**, collimated millimeter wave source **404**, and receiver **406**. Detection system **400** also includes processor **408**, storage device **410**, and display **411**. This type of implementation may be used in situations when high frequencies, such as frequencies in the 100 GHz range, can be used.

Processor **408** operates to control collimated millimeter wave source **402** and collimated millimeter wave source **404**. Further, processor **408** receives data for signals detected by receiver **406**. Processor **408** executes instructions that may be located in storage device **410**. Results of response signals detected by receiver **406** may be presented on display **411**

In this example, detection system **400** generates electromagnetic signals in the form of a single beam, beam **412**. Beam **412** is generated through a combination of beams **414** and **416** which are generated by collimated millimeter wave source **402** and collimated millimeter wave source **404**, respectively. Collimated millimeter wave source **404** generates beam **416** with a first frequency f1. Collimated millimeter wave source **402** generates beam **414** with a second frequency f2. These two beams are combined into beam **412** using polarization beam combiner **418**.

Beam **412** is in essence a combined circularly polarized beam with an interference difference frequency. This interference difference frequency is the difference between frequency f1 generated by collimated millimeter wave source **404** and frequency f2 generated by collimated millimeter wave source **402**. Beam **412** may be directed into the ground in which object **420** is buried. Object **420** includes electrical non-linear characteristics that causes currents at the difference frequency to be induced in object **420**.

Electromagnetic signals may be emitted from these currents in the form of response signal **422**. Object **420** generates response signal **422** with a frequency that is the difference between frequency f1, generated by collimated millimeter wave source **404** and frequency f2, generated by collimated millimeter wave source **402**. This frequency is also referred to as a difference frequency.

Response signal **422** is detected by receiver **406** which sends the information in return signal **422** to processor **408** for processing. Processor **408** may store information received in return signal **422** in storage device **410**. Additionally, processor **408** may display this information in display **411** in detection system **400**.

In detection system **400**, beam **412** is a directed beam that may be used to search an area in the ground that has a radius or diameter for beam **412**. As a result, when a signal, such as response signal **422** is received by receiver **406**, a user of detection system **400** is able to identify object **420**.

The collimated millimeter wave sources used in the radio frequency identification units in FIG. **4** may be implemented using any available collimated millimeter wave source. More information on these types of wave sources and their configurations may be found in U.S. Pat. No. 6,864,825 B2 and U.S. Pat. No. 7,142,147 B2.

Turning now to FIG. **5**, a diagram illustrating an example of data that may be obtained using a detection system, such as

detection system **200** in FIG. **2** is depicted in accordance with an advantageous embodiment of the present invention. In this illustrative example, a detection system, such as detection system **200** in FIG. **2** is configured to transmit electromagnetic signals at 185 MHz and 215 MHz. The response signal received is at 30 MHz. Display **500** is generated using the response signals received. Such an image, as an example in display **500**, would be generated as detection system **200** moved across the ground. Display **500** is an illustrative example of a characteristic image (a vertical cross-section in the ground) that can be generated using the different processes in the advantageous embodiments.

Within display **500**, gas pipe **502** and gas pipe **504** are present. Gas pipe **502** and gas pipe **504** are illustrated in display **500** as a result of signals at Δf is received from corroded metal gas pipes in the ground. Further, the depth of these pipes below the ground also can be identified based on the time it took for the electromagnetic pulses to travel round-trip to the object and back to the receiver antenna. In addition, display **500** also contains shallower objects, such as sewer pipes **506** and **508** in these examples. Other examples of objects that can be detected are an electronic instrument control system, a computer, or communications equipment located below or under the ground. These objects may be located in a tunnel or a bunker in these examples.

With reference now to FIG. **6**, a flowchart of a process for detecting an object with electrical non-linear characteristics is depicted in accordance with an advantageous embodiment of the present invention. The process illustrated in FIG. **6** may be implemented in a detection system, such as detection system **200** in FIG. **2** or detection system **400** in FIG. **4**.

The process begins by transmitting electromagnetic signals into the ground in which these signals have a first frequency f1 and a second frequency f2 (operation **600**). In these examples, the electromagnetic signals are a continuous stream of electromagnetic pulses originating from two transmitters with carrier frequencies f1 and f2. Thereafter, the process monitors for an electromagnetic response signal having a difference frequency equal to a difference between the first frequency and the second frequency (operation **602**). A determination is made as the whether a response signal having the difference frequency is detected (operation **604**).

If a response signal with the difference frequency is detected, the signal is processed to identify a set of objects (operation **606**). The set of objects may be one or more objects depending on the number of objects in the ground having electrical non-linear characteristics that generate a response signal at a difference frequency. The process terminated thereafter.

With reference again to operation **604**, if the response signal is not detected, the process returns to operation **600** as described above.

Turning now to FIG. **7**, a process for transmitting electromagnetic signals is depicted in accordance with an advantageous embodiment to the present invention. The process illustrated in FIG. **7** may be implemented in a system, such as detection system **200** in FIG. **2**. In particular, the different instructions here may be implemented in a processor, such as processor **214** in FIG. **2**.

The process begins by selecting a first frequency f1 and a second frequency f2 (operation **700**). These two frequencies are selected in a manner to elicit a response from an object buried in the ground in which an electrical non-linearity is present in the object. The selection of the frequencies for the transmitters vary depending on the application or the implementation.

Typically, in these examples, frequencies between 1 MHz and 1000 MHz are selected. In these particular examples, the transmit frequencies for the first and second frequencies are 94 MHz and 106 MHz. The difference frequency is 12 MHz. This difference frequency is the frequency at which a response signal is expected if a metallic object with a non-linear feature is present.

As a result, the frequency selected may vary depending on the penetration depth desired for the transmission and response to the transmission of these electromagnetic signals.

Afterwards, the first and second frequencies are set for the transmitters (operation **702**). Electromagnetic signals are then transmitted into the ground (operation **704**) with the process terminating thereafter. The transmission of these electromagnetic signals may take various forms. For example, they may be in the form of pulses that are repeated. Alternatively, the signals may be transmitted as continuous wave radio frequency signals. The transmission of these signals in operation **704** continue until the process terminates in these examples.

The process illustrated in FIG. **7** may be repeated as often as needed. Further, each time the process is repeated, the first frequency and the second frequency may be changed such that the difference frequency, which is a frequency equal to the difference between the first frequency f1 and the second frequency f2, also changes. This changing of the difference frequency may be used each time the process is repeated to attempt to identify objects under the ground that may have different electrical non-linear characteristics that respond at different frequencies. The process in FIG. **7** may be repeated such that a range of difference frequencies may be detected. If the detection system has fixed frequencies for the transmitters, steps **700** and **702** are omitted and the process only involves transmitting the electromagnetic signals into the ground.

Turning now to FIG. **8**, a flowchart of a process for detecting a response signal is depicted in accordance with an advantageous embodiment to the present invention. The process illustrated in FIG. **8** may be implemented in a detection system, such as detection system **200** in FIG. **2**.

The process monitors for a response on a difference frequency equal to a difference between the first frequency and the second frequency (operation **800**). This monitoring is performed using a receiver, such as receiver **210** in FIG. **2**. A determination is made as to whether a response signal with the difference frequency is detected (operation **802**).

If a response signal is not detected, the process returns to operation **800** to continue to monitor for a difference frequency. As the process loops between operations **800** and **802**, the electromagnetic signals continue to be pulsed or emitted as a beam from the detection system.

Alternatively, the vehicle may be stationery or the detection unit may be placed on the ground or a platform for use. If the frequencies set for the transmitter cycle such that the difference frequency changes, operation **800** monitors for the different difference frequencies. In this manner, a range of difference frequencies may be monitored to detect objects that may have different electrical non-linear characteristics.

When a response signal having the difference frequency is detected in operation **802**, the data from the response signals is processed (operation **804**). This processing may include, for example, identifying the location or depth at which the object is located in the ground. Additionally, the data in the response signals may be processed to generate an image of the object.

Next, the processed data is displayed (operation **806**) with the process terminating thereafter. This process may be repeated to obtain images of an object in addition to merely locating an object. An example of an image is depicted in display **600** in FIG. **6**. In the depicted examples, this process may be performed while the detection unit is moving in a vehicle, such as aircraft **106** or truck **110** in FIG. **1**.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatus, methods, and computer program products. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified function or functions. In some alternative implementations, the function or functions noted in the block may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved.

Thus, the different advantageous embodiments of the present invention provide a method and apparatus for detecting objects located underground. In one advantageous embodiment, a detection system detects objects having electrical non-linear characteristics located underground. The detection system comprises a transmitter unit, a receiver, and a processor. The transmitter transmits a plurality of pulsed radio frequency signal having a first frequency and a second frequency into a ground.

The receiver monitors for a response signal having a frequency equal to a difference between the first frequency and a second frequency, wherein the response radio frequency signal is generated by an object having non-linear conductive characteristics in response to receiving the plurality of electromagnetic signals. The processor is connected to the transmitter unit and the receiver, wherein the processor controls a selection of the first frequency and the second frequency, wherein the object is detected when the response signal is detected by the receiver. By sweeping through the frequency ranges, additional information about an object buried in the ground may be obtained.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A detection system for detecting objects having electrical non-linear characteristics located underground, the detection system comprising:

a transmitter unit for transmitting into a ground a first pulsed radio frequency signal at a first frequency generated by a first transmitter and a second pulsed radio frequency signal at a second frequency generated by a second transmitter; and

a receiver for monitoring for a response radio frequency signal having a third frequency equal to a difference between the first frequency and the second frequency,

wherein the response radio frequency signal is generated by an object having non-linear conductive characteristics in response to receiving the first pulsed radio frequency signal at the first frequency and the second pulsed radio frequency signal at the second frequency; and

a processor for controlling an operation of the transmitter unit and the receiver, wherein the processor is connected to the transmitter unit and the receiver, and wherein the object is detected when the response radio frequency signal is detected by the receiver.

2. The detection system of claim **1**, wherein the processor controls the transmitter unit to change the first frequency and the second frequency such that the frequency of the response radio frequency signal changes through a range of frequencies.

3. The detection system of claim **1**, wherein the processor executes a program to interpret the response radio frequency signal.

4. An apparatus comprising:

a transmitter unit for transmitting, into a ground, a first electromagnetic signal having a first frequency and a second electromagnetic signal having a second frequency; and

a receiver for monitoring for a third electromagnetic signal having a third frequency equal to a difference between the first frequency and the second frequency in which the frequency is generated by an object having an electrical non-linear conductive characteristic in response to being exposed to the first electromagnetic signal having the first frequency and the second electromagnetic signal having the second frequency, wherein the object is detected when the third electromagnetic signal having the third frequency is detected by the receiver.

5. The apparatus of claim **4**, wherein the plurality of electromagnetic signals are pulsed radio frequency signals.

6. The apparatus of claim **4**, wherein the plurality of electromagnetic signals are continuous wave radio frequency signals.

7. The apparatus of claim **4** further comprising:

a processor controlling a selection of the first frequency and the second frequency, wherein the processor is connected to the transmitter unit and the receiver.

8. The apparatus of claim **4**, wherein the processor executes instructions to analyze electromagnetic signals received by the receiver to provide an interpretation of the electromagnetic signals.

9. The apparatus of claim **4** wherein the transmitter unit comprises a first transmitter and a second transmitter and wherein the first transmitter generates electromagnetic signals in the plurality of electromagnetic signals having the first frequency and the second transmitter generates electromagnetic signals in the plurality of electromagnetic signals having the second frequency.

10. The apparatus of claim **4**, wherein the difference frequency is predetermined.

11. The apparatus of claim **4**, wherein the first frequency and the second frequency change to change the difference frequency, wherein the difference frequency changes through a range of frequencies.

12. The apparatus of claim **4**, wherein the first frequency and the second frequency are selected to penetrate the ground to a selected depth in the ground.

13. The apparatus of claim **4**, wherein the electrical non-linear characteristic is a metal with corrosion in portions of the metal.

14. A method for detecting an object with electrical non-linear characteristics, the method comprising:

transmitting into a ground, a first electromagnetic signal having a first frequency and a second electromagnetic signal having a second frequency;

monitoring for a third electromagnetic signal having a third frequency equal to a difference between the first frequency and the second frequency, wherein the third electromagnetic signal is generated by an object in ground having an electrical non-linear characteristic in response to being exposed to the plurality of electromagnetic signals; and

detecting the object having the electrical non-linear characteristic when the third electromagnetic signal is detected.

15. The method of claim **14**, wherein the transmitting step comprises:

transmitting a plurality of pulsed radio frequency signals having the first frequency and the second frequency.

16. The method of claim **14**, wherein the transmitting step comprises:

transmitting a plurality of continuous wave radio frequency signals having the first frequency and the second frequency.

17. The method of claim **14** further comprising:

interpreting the electromagnetic signal received by the receiver.

18. The method of claim **14**, wherein the transmitting step comprises:

transmitting a plurality of electromagnetic signals having the first frequency and the second frequency into the ground in which the first frequency and the second frequency change to change the frequency through a range of frequencies.

19. The method of claim **14**, wherein the electrical non-linear characteristic is a metal with corrosion in portions of the metal.

20. The method of claim **14**, wherein the object is one of a tunnel, a bunker, an electronic instrument control system, a computer, or communication equipment.

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