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RF-based detection device for material identification using a smart frequency selection method

Abstract

A system for material detection and identification including: an RF transmitter configured for transmitting into an environment an RF signal at a first resonance frequency for a target material, wherein the first resonance frequency is obtained from a material database associating each of a plurality of materials with one or more corresponding resonance frequencies; an RF receiver configured for receiving a resultant response signal from the environment; and a processor configured for: analyzing the resultant response signal for resonance characteristics that indicate a presence of the target material, wherein analyzing includes, if the resonance characteristics are detected and no other material in the material database shares similar resonance characteristics for the first resonance frequency, reporting to a user that the target material has been identified.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of U.S. Provisional Application No. 63/667,582, filed Jul. 3, 2024, which is incorporated herein by reference.

FIELD OF THE DISCLOSURE
(1) The present disclosure is generally related to RF-based material identification.
BACKGROUND
(2) Material detection and identification often involves large and/or highly specialized technology. Security technology especially often requires large apparatuses such as metal detectors and X-ray machines that can only detect certain materials and/or devices.
(3) Present technologies for material identification are often unable to provide a comprehensive analysis due to the limitations in detecting and measuring resonance responses from multiple materials simultaneously in a given sample.
(4) Further, the differentiation between materials with similar or identical resonance frequencies remains problematic in sensing techniques, limiting the accuracy and specificity of material identification.
SUMMARY
(5) According to one aspect, a method for material detection and identification includes transmitting into an environment an RF signal at a first resonance frequency for a target material, wherein the first resonance frequency is obtained from a material database associating each of a plurality of materials with one or more corresponding resonance frequencies. The method also includes receiving a resultant response signal from the environment. The method further includes analyzing the resultant response signal for resonance characteristics that indicate a presence of the target material, where analyzing includes, if the resonance characteristics are detected and no other material in the material database shares similar resonance characteristics for the first resonance frequency, reporting to a user that the target material has been identified; and if the resonance characteristics are detected and one or more other materials in the material database share similar resonance characteristics for the first resonance frequency, reporting to the user that at least one of the target material and the one or more other materials have been identified.
(6) In some embodiments, the method further includes repeating transmitting, receiving, analyzing using a second resonance frequency for a material associated with the material of interest either to confirm that the target material is present or to distinguish between the target material and the one or more other materials.

(7) In some embodiments, the method further includes, if the resonance characteristics are not detected in the resultant response signal for either the first resonance frequency or the second resonance frequency, using environmental factors to identify the target material.
(8) In some embodiments, the material database indicates a priority of detecting at least a subset of the plurality of materials for one or more applications, and wherein transmitting includes transmitting into the environment the RF signal at the first resonance frequency for each material in order of the priority for a specific application.
(9) In some embodiments, the at least the subset of the plurality of materials is selected by the user.
(10) In some embodiments, the method further includes using machine learning to recognize patterns between one or more materials and one or more resonance characteristics for different frequencies.
(11) In some embodiments, the first resonance frequency is related to a number of protons in atoms composing the target material.
(12) In some embodiments, analyzing further includes: generating a report including: the target material; any other materials having a similar proton count; additional scans conducted; and a rationale for ruling out specific materials based on unique characteristics.
(13) In some embodiments, analyzing further includes generating a list of frequencies and associated resonance characteristics.
(14) In some embodiments, transmitting includes transmitting at least one resonance frequency multiple times for particular material to improve a confidence level of detection for the at least one resonance frequency.
(15) According to another aspect, a system for material detection and identification includes an RF transmitter configured for transmitting into an environment an RF signal at a first resonance frequency for a target material, wherein the first resonance frequency is obtained from a material database associating each of a plurality of materials with one or more corresponding resonance frequencies. The system also includes an RF receiver configured for receiving a resultant response signal from the environment and a processor configured for: analyzing the resultant response signal for resonance characteristics that indicate a presence of the target material, wherein analyzing includes: if the resonance characteristics are detected and no other material in the material database shares similar resonance characteristics for the first resonance frequency, reporting to a user that the target material has been identified; and if the resonance characteristics are detected and one or more other materials in the material database share similar resonance characteristics for the first resonance frequency, reporting to the user that at least one of the target material and the one or more other materials have been identified.
(16) In some embodiments, the processor is further configured for repeating transmitting, receiving, analyzing using a second resonance frequency for a material associated with the material of interest either to confirm that the target material is present or to distinguish between the target material and the one or more other materials.
(17) In some embodiments, the processor is further configured for, if the resonance characteristics are not detected in the resultant response signal for either the first resonance frequency or the second resonance frequency, using environmental factors to identify the target material.
(18) In some embodiments, the material database indicates a priority of detecting at least a subset of the plurality of materials for one or more applications, and wherein transmitting includes transmitting into the environment the RF signal at the first resonance frequency for each material in order of the priority for a specific application.
(19) In some embodiments, the at least the subset of the plurality of materials is selected by the user.
(20) In some embodiments, the system further includes a machine learning system configured to recognize patterns between one or more materials and one or more resonance characteristics for different frequencies.

(21) In some embodiments, the first resonance frequency is related to a number of protons in atoms composing the target material.
(22) In some embodiments, analyzing further includes: generating a report including: the target material; any other materials having a similar proton count; additional scans conducted; and a rationale for ruling out specific materials based on unique characteristics.
(23) In some embodiments, analyzing further includes: generating a list of frequencies and associated resonance characteristics.
(24) In some embodiments, transmitting includes transmitting at least one resonance frequency multiple times for particular material to improve a confidence level of detection for the at least one resonance frequency.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a schematic diagram of an RF detection system, according to an embodiment.
(2) FIG. **2** is a flowchart of a method performed by a Base Module, according to an embodiment.
(3) FIG. **3** is a flowchart of a method performed by a Detection Module, according to an embodiment.
(4) FIG. **4** is a flowchart of a method performed by a Determination Module, according to an embodiment.
(5) FIG. **5** is a flowchart of a method performed by a Material Database, according to an embodiment.
DETAILED DESCRIPTION
(6) Embodiments of the present disclosure will be described more fully hereinafter with reference to the accompanying drawings in which like numerals represent like elements throughout the several figures, and in which example embodiments are shown. Embodiments of the claims may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. The examples set forth herein are non-limiting examples and are merely examples among other possible examples.
(7) FIG. **1** illustrates an RF detection device **102**, which may be a specialized system designed to detect and identify specific materials based on their unique resonance frequencies when exposed to electromagnetic signals. The RF detection device **102** incorporates an RF detection system similar to that disclosed in U.S. patent Ser. No. 11/493,494B2, employing RF signals for the detection and identification of materials based on their resonance characteristics. The RF detection device **102** may operate by transmitting RF signals into the environment and analyzing the received signals for resonance characteristics that indicate the presence of a target material. The RF detection device **102** may be designed to detect a target material based on its resonance properties with specific RF frequencies. It utilizes the principle that materials resonate at particular frequencies when exposed to external RF signals, allowing for their identification and potential quantification. The RF detection device **102** may comprise a transmitter unit **106**, a receiver unit **124**, a control panel **146**, a transmitter antenna **120**, a receiver antenna **126**, a directional shield **142**, and a power supply **144**. Upon activation, the control panel **146** initializes the system, powering up the transmitter unit **106**, the receiver unit **124**, and associated electronics. The control panel **146** may instruct the transmitter unit **106** to generate RF signals at specified frequencies, such as 180 Hz, 1800 Hz, etc., and amplitudes, such as 320V, 160V, etc., known to resonate with a target material. The transmitter unit **106** emits these RF signals through the transmit antenna **120** into the testing environment. The receiver unit **124** captures the RF signals using the receiver antenna **126**. It then processes the received signals to identify resonance frequencies that indicate the presence of the target material.
(8) Further, embodiments may include a support frame **104**, which may be a structural component

designed to provide stability and support to various subsystems and components of the RF detection device **102**. The support frame **104** may provide proper alignment and positioning of the components, such as the transmitter unit **106**, the receiver unit **124**, antennas **120** **126**, and control panel **146**. The support frame **104** may provide mounting points and secure attachment locations for subsystems such as the transmitter unit **106**, the receiver unit **124**, antennas **120** **126**, and control panel **146**. By maintaining precise alignment and stability, the support frame **104** may minimize vibrations and unwanted movements that could interfere with the accuracy of RF signal transmission and reception. In some embodiments, the support frame **104** may be constructed from durable materials such as metal alloys or rigid polymers.

(9) Further, embodiments may include a transmitter unit **106**, which may include an electronic circuit **108**, powered by a battery, such as a 12-volt, 1.2 amp battery, with a regulated output of nine volts. The circuit **108** may use a 555 timer as a tunable oscillator to generate a pulse rate. The output of the oscillator is fed in parallel to an NPN transistor **112** and a silicon-controlled rectifier (SCR) **114**. The transistor may be used as a common emitter amplifier stage driving a transformer **116**. The transformer **116** may be used to step up the voltage as needed. The balanced output of the transformer **116** feeds a bridge rectifier **118**. The rectified direct current flows through a 100 K, three-watt resistor to terminal B of the transmitter antenna **120**. A plurality of resistors and capacitors may fill in the circuit **108**. In some embodiments, the transmitter antenna **120** may be formed from a coil of about 25 meters of 14-strand wire tightly wound around a one-centimeter PVC core. The transmitter antenna **120** may be, in one exemplary embodiment, in a 1″×3″ configuration at the bottom end of the support frame **104**. In some embodiments, the transmitter antenna **120** may be shielded approximately 315 degrees with the directional shield **142**, formed from aluminum and copper, leaving a two-inch opening. Terminal A of the transmitter antenna **120** is switched to ground through the SCR **114**. The SCR **114** is “fired” by the output of the 555 timer. This particular configuration generates a narrow pulsed waveform to the transmitter antenna **120** at a pulse rate as set by the 555 timer. Power is delivered through the 3 W resistor. Frequencies down to 4 Hz are achieved by an RC network containing a 100 K pot, a switch, and one of two capacitive paths. The circuit **108** may provide simple RC-controlled timing and deliver pulses to the primary of a step-up transformer **116**, the output of which is full-wave rectified and fed to the transmitter antenna **120**. The pulse rate is adjustable from the low Hz range to the low kHz range. The sharp pulses at low repetition frequencies yield a wide spectrum of closely spaced lines. The pulse rate is adjusted depending on the material to be detected. In some embodiments, one or more portions of the transmitter unit **106** may be implemented in an analog circuit configuration, a digital circuit configuration, or some combination thereof. In one example, the analog configuration may comprise one or more analog circuit components, such as, but not limited to, operational amplifiers, op-amps, resistors, inductors, and capacitors. In another example, the digital configuration may comprise one or more digital circuit components, such as, but not limited to, microprocessors, logic gates, and transistor-based switches. In some instances, a given logic gate may comprise one or more electronically controlled switches, such as transistors, and the output of a first logic gate may control one or more logic gates disposed “downstream” from the first logic gate.

(10) Further, embodiments may include a circuit **108**, which may be an assembly of electronic components that generate, modulate, and transmit radio frequency, RF signals. The circuit **108** may include oscillators, amplifiers, modulators, and other components that work together to produce a specific RF signal, which can then be transmitted through the transmitter antenna **120**. The circuit **108** may include an oscillator, which generates a stable RF signal at a specified frequency. This frequency is selected based on the resonance characteristics of the target material. For example, the system may operate at 180 Hz or 1800 Hz, depending on the specific requirements of the detection task. Once generated, the RF signal is fed into an amplifier. The amplifier boosts the signal strength to a level suitable for transmission over the required distance. This ensures that the signal can propagate through various media and reach the receiver unit effectively. Modulation circuits are

used to encode information into the RF signal. This may involve varying the amplitude, frequency, or phase of the signal to carry specific data related to the detection process. Modulation ensures that the transmitted signal can be uniquely identified and distinguished from other signals in the environment. The circuit **108** may include power control components that regulate the voltage and current supplied to the oscillator and amplifier. This ensures consistent signal output and helps in managing the power consumption of the device. In some embodiments, the transmitter may operate at voltages such as 160V and 320V, with adjustments made to optimize detection performance. The amplified and modulated RF signal is then routed to the transmitter antenna **120**. The transmitter antenna **120** converts the electrical signal into an electromagnetic wave that can propagate through the air or other media. In some embodiments, the circuit **108** may be integrated with the device's control systems, allowing for automated adjustments based on pre-set parameters or operator inputs.

(11) Further, embodiments may include a tunable oscillator **110**, which may be a type of electronic component that generates a periodic waveform with a frequency that can be adjusted or tuned over a specific range. The tunable oscillator **110** within the transmitter unit **106** may be utilized to generate the RF signal that will be transmitted by the RF detection device **102**. The tunable oscillator **110** in the transmitter unit **106** may be employed to produce an RF signal whose frequency can be precisely controlled. By adjusting the control inputs, the frequency of the output signal can be varied, allowing the system to adapt to different detection requirements and environmental conditions. This tuning mechanism may ensure that the oscillator produces a signal at the correct frequency needed for effective resonance with the target materials. By tuning the oscillator to specific frequencies, the system may detect various materials based on their unique resonant properties. The tunable oscillator **110** may work in conjunction with the control panel **146**, which sends control signals to adjust the oscillator's frequency as needed. The tunable oscillator **110** may act as the core signal generation component in the transmitter unit **106**. When the control panel **146** determines the required frequency for detection, it sends control signals to the tunable oscillator **110**. The oscillator then adjusts its frequency accordingly, generating an RF signal that matches the desired parameters. The tunable oscillator **110** may be connected to other components within the transmitter unit **106**, such as the SCR **114** and the transformer **116**. The SCR **114** manages the power supply to the oscillator, ensuring it receives the correct voltage. The transformer **116** steps up the voltage to the appropriate level required by the oscillator.

(12) Further, embodiments may include an NPN transistor **112**, which may be a type of bipolar junction transistor, BJT, that consists of three layers of semiconductor material: a layer of p-type material, the base layer, sandwiched between two layers of n-type material, the emitter and the collector. When a small current flows into the base, it allows a larger current to flow from the collector to the emitter, effectively acting as a current amplifier or switch in electronic circuits. The NPN transistor **112** in the transmitter unit **106** amplifies the RF signal generated by the oscillator. The NPN transistor **112** may operate in its active region, where a small input current applied to the base controls a larger current flowing from the collector to the emitter. This amplification process ensures that the RF signal reaches a sufficient power level for effective transmission. In some embodiments, the NPN transistor **112** may also function as a switch, controlling the flow of current within the circuit **108**. When the base-emitter junction is forward-biased, a small voltage is applied, and the NPN transistor **112** allows current to flow from the collector to the emitter. This switching action is used to modulate the RF signal, encoding information onto the carrier wave as required for the detection process. Proper biasing of the NPN transistor **112** is essential for stable operation. In some embodiments, resistors may be used to establish the correct biasing conditions to ensure that the NPN transistor **112** operates in its linear region for amplification or in saturation/cutoff regions for switching. The biasing circuit ensures that the NPN transistor **112** responds predictably to input signals, maintaining signal integrity. In some embodiments, the NPN transistor **112** may be involved in modulating the RF signal. By varying the input current to the base, the amplitude,

frequency, or phase of the RF signal can be modulated. This modulation is critical for encoding the detection data onto the transmitted signal, allowing for accurate chemical identification and analysis. In some embodiments, the NPN transistor **112** may be integrated into the broader transmitter circuit **108**, working in conjunction with other components such as capacitors, inductors, and resistors. This integration ensures that the amplification and switching actions of the NPN transistor **112** are synchronized with the overall signal generation and transmission process. The circuit **108** design may leverage the NPN transistor's **112** properties to achieve the desired RF output characteristics.

(13) Further, embodiments may include an SCR **114** or silicon controlled rectifier, which may be a type of semiconductor device that functions as a switch and rectifier, allowing current to flow only when a control voltage is applied to its gate terminal. The silicon controlled rectifier, SCR, **114**, is utilized within the transmitter unit **106** to manage and control the power delivery to the RF signal generation components. The SCR **114** in the transmitter unit **106** may be employed to control the flow of power to the RF oscillator circuit. By applying a gate signal to the SCR **114**, it switches from a non-conductive state to a conductive state, allowing current to pass through and power the oscillator. This control mechanism ensures that the oscillator only receives power when required, thereby conserving energy and preventing unnecessary power dissipation. The SCR **114** may act as a switching element in the transmitter unit **106**. When the control panel **146** determines that the RF signal needs to be generated, a gate voltage is applied to the SCR **114**. This triggers the SCR **114** to conduct, completing the circuit and enabling current to flow to the RF oscillator. The SCR **114** may ensure that sufficient current is supplied to the oscillator to produce a strong RF signal without being damaged by the high power levels. The gate terminal of the SCR **114** may be connected to the control panel **146**, which manages the timing and application of the gate signal. This integration ensures that the SCR **114** is activated precisely when the RF signal needs to be transmitted, in sync with the overall operation of the detection system. The control panel **146** sends the appropriate signal to the SCR **114**, ensuring accurate timing and efficient power usage. The SCR **114** may also serve as a protective component in the transmitter unit **106**. By controlling the power flow, it prevents overloading and potential damage to the RF oscillator and other sensitive components. If the system detects any abnormal conditions, the control panel **146** can withhold the gate signal, keeping the SCR **114** in a non-conductive state and thereby cutting off power to protect the circuit.

(14) Further, embodiments may include a transformer **116**, which is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. The transformer **116** is utilized within the transmitter unit **106** to manage and control the voltage levels required for the RF signal generation and transmission. The transformer **116** in the transmitter unit **106** may be employed to step up or down the voltage as needed to ensure the proper operation of the RF oscillator circuit. By adjusting the voltage levels, the transformer **116** ensures that the components within the transmitter unit **106** receive the appropriate voltage for efficient functioning. The transformer **116** may act as a voltage regulation element in the transmitter unit **106**. When the control panel **146** determines that the RF signal needs to be generated, the transformer **116** adjusts the input voltage to the desired level. This adjustment involves converting the primary winding voltage to a higher or lower voltage in the secondary winding, depending on the requirements of the RF oscillator. The transformer ensures that the oscillator receives a stable and appropriate voltage, which is critical for producing a consistent and strong RF signal. The primary winding of the transformer **116** may be connected to the power supply **144**, while the secondary winding is connected to the RF oscillator circuit. This integration ensures that the transformer **116** can effectively manage the voltage levels needed for RF signal generation. The control panel **146** monitors and regulates the input voltage to the transformer **116**, ensuring accurate and efficient voltage conversion and delivery to the RF oscillator.

(15) Further, embodiments may include a bridge rectifier **118**, which is an electrical device designed to convert alternating current, AC, to direct current, DC, using a combination of four

diodes arranged in a bridge configuration. The bridge rectifier **118** is utilized within the transmitter unit **106** to ensure that the RF signal generation components receive a steady and reliable DC power supply. The bridge rectifier **118** in the transmitter unit **106** may be employed to convert the incoming AC voltage from the power supply into a DC voltage. By using all portions of the AC waveform, the bridge rectifier **118** provides full-wave rectification, resulting in a more efficient conversion process and producing a smoother and more stable DC output. The bridge rectifier **118** may act as a key power conversion element in the transmitter unit **106**. When the control panel **146** determines that the RF signal needs to be generated, the AC voltage supplied to the transmitter unit is passed through the bridge rectifier **118**. The rectifier converts the AC voltage into a DC voltage by directing the positive and negative halves of the AC waveform through the appropriate diodes. This process results in a continuous DC voltage output that is used to power the RF oscillator and other critical components. The input terminals of the bridge rectifier **118** may be connected to the AC power supply, while the output terminals provide the rectified DC voltage to the RF oscillator circuit. This integration ensures that the bridge rectifier **118** can effectively convert and deliver the required DC power for RF signal generation. The control panel **146** monitors the output of the bridge rectifier, ensuring that the DC voltage is stable and within the desired range for optimal performance.

(16) Further, embodiments may include a transmitter antenna **120**, which may be a device that radiates radio frequency, RF, signals generated by the transmitter unit **106** towards a target material. The transmitter antenna **120** may be designed to efficiently transmit the generated RF signals into the surrounding environment and ensure the signals reach the intended target with minimal loss. The transmitter antenna **120** may be responsible for the emission of RF signals necessary for detecting materials at a distance. In some embodiments, the transmitter antenna **120** may operate within a specific frequency range suitable for detecting the atomic structures and characteristics of the target materials. The frequency range may be determined by the system's requirements and the properties of the materials being detected. In some embodiments, the gain of the antenna may be a measure of its ability to direct the RF energy towards the target. Higher gain antennas focus the energy more effectively, resulting in stronger signal transmission over longer distances. The antenna gain may be optimized for the operational frequency range. In some embodiments, the radiation pattern of the transmitter antenna **120** describes the distribution of radiated energy in space. For effective material detection, the antenna may have a directional radiation pattern, concentrating the RF energy in a specific direction to enhance detection accuracy. In some embodiments, impedance matching between the transmitter antenna **120** and the transmitter unit **106** may maximize power transfer and minimize signal reflection. Proper impedance matching may ensure efficient operation and reduce losses in the transmission path. In some embodiments, the physical design of the transmitter antenna **120** may include configurations such as dipole, patch, or horn antennas, depending on factors such as frequency range, gain, and environmental conditions. In some embodiments, the transmitter antenna **120** may be integrated with the transmitter unit **106** and other system components through connectors and mounting structures to ensure stable and reliable operation, with considerations for minimizing interference and signal loss.

(17) Further, embodiments may include a battery **122**, which may be a type of energy storage device that provides a stable and portable power source for the transmitter unit **106**. The battery **122** within the transmitter unit **106** may be utilized to supply the necessary electrical energy to the various components involved in generating and transmitting the RF signal. The battery **122** may be designed to store electrical energy and supply it to the respective components as required. The battery **122** may be rechargeable or replaceable cells capable of providing DC voltage. They are selected based on factors such as voltage output and capacity, which may be measured in ampere-hours, Ah, and size to meet the power requirements of each component effectively. In the transmitter unit **106**, battery **122** may serve as a portable power source, enabling the generation and transmission of RF signals without requiring a direct connection to an external power supply. The

battery **122** powers essential components such as the oscillator circuit **108**, SCR **114**, and transformer **116**, ensuring continuous operation in various environmental conditions. In some embodiments, the battery **122** used may include lithium-ion, nickel-metal hydride, or other types suitable for portable electronic devices.

(18) Further, embodiments may include a receiver unit **124**, which may include the electronic circuit **128**. Voltage from the receiver antenna **126** passes through a 10 K gain pot to an NPN transistor **130** used as a common emitter. The output is capacitively coupled to a PNP Darlington transistor **132**. A plurality of resistors and capacitors fills in the circuit **128**. The output is fed through an RPN **134** to a 555 timer that is used as a voltage-controlled oscillator. A received signal of a given amplitude generates an audible tone at a given frequency. In some embodiments, the output is fed to a tone generator, such as a speaker, via a standard 386 audio amp. Sounds can be categorized as “grunts,” “whines,” and a particular form of whine with a higher harmonic notably present. In some embodiments, another indicator of a received signal is used, such as light, vibration, digital display, or analog display, in alternative to or in combination with the sound signal. A battery may be used to power the receiver circuit **128**. The receiver circuit **128** may utilize a coherent, direct-conversion mixer, homodyne, with RF gain, yielding a baseband signal centered about DC. After a baseband gain stage, the baseband signal is fed to another timing circuit that functions as a voltage-controlled audio-frequency oscillator. The output of this oscillator is amplified and fed to a speaker. In some embodiments, one or more portions of the receiver unit **124** may be implemented in an analog circuit configuration, a digital circuit configuration, or some combination thereof. In one example, the analog configuration may comprise one or more analog circuit components, such as, but not limited to, operational amplifiers, op-amps, resistors, inductors, and capacitors. In another example, the digital configuration may comprise one or more digital circuit components, such as, but not limited to, microprocessors, logic gates, and transistor-based switches. In some instances, a given logic gate may comprise one or more electronically controlled switches, such as transistors, and the output of a first logic gate may control one or more logic gates disposed “downstream” from the first logic gate.

(19) Further, embodiments may include a receiver antenna **126**, which may be a device that captures the radio frequency, RF, signals responded from a target material. The receiver antenna **126** may be designed to efficiently receive the responded RF signals and transmit them to the receiver unit **124** for further processing and analysis. The receiver antenna **126** may be responsible for capturing the RF signals that have interacted with the target material. In some embodiments, the receiver antenna **126** may be designed to operate within the same frequency range as the transmitter antenna **120** to ensure compatibility and optimal performance for detecting the atomic structures and characteristics of the target materials. In some embodiments, the sensitivity may be a measurement of the receiver antenna's **126** ability to detect weak signals. A highly sensitive receiver antenna **126** may detect low power responded signals, enhancing the system's detection capabilities. In some embodiments, the noise figure of the receiver antenna **126** may indicate the level of noise it introduces into the received signal. A lower noise figure may be desirable as it ensures that the captured signals are as clean and strong as possible for accurate processing. In some embodiments, proper impedance matching between the receiver antenna **126** and the receiver unit **124** may maximize the power transfer from the receiver antenna **126** to the processing unit to ensure efficient and accurate signal reception. In some embodiments, the directional properties of the receiver antenna **126** may determine its ability to capture signals from specific directions to distinguish signals responded from the target material versus other sources of interference. In some embodiments, the gain of the receiver antenna **126** may enhance its ability to receive signals from distant targets. Higher gain antennas can improve the system's ability to detect materials at greater distances. In some embodiments, the physical design of the receiver antenna **126** may include various configurations such as dipole, patch, or parabolic antennas and may be based on factors such as frequency range, gain, and the specific detection requirements. In some embodiments, the

receiver antenna **126** may be integrated with the receiver unit **124** and other system components through connectors and mounting structures to ensure stable and reliable operation, with considerations for minimizing interference and signal loss. In some embodiments, the receiver antenna **126** and the transmitter antenna **120** may be a single antenna used by the RF detection device **102**.

(20) Further, embodiments may include a circuit **128** within the receiver unit **124**, which may be an assembly of electrical components designed to process the received RF signal. The circuit **128** may accurately interpret the RF signals responded or emitted from the target materials and convert them into data that can be analyzed by the RF detection device **102**. The circuit **128** in the receiver unit **124** may be employed to handle signal amplification, filtering, demodulation, and signal processing. When an RF signal is received via the receiver antenna **126**, it is typically weak and may contain noise or interference. The first stage of the circuit **128** may involve an amplifier that boosts the signal strength to a level suitable for further processing. This amplification ensures that even weak signals can be analyzed effectively. Next, the circuit **128** may include filtering components that serve to remove unwanted frequencies and noise from the received signal. Filters ensure that only the relevant frequency components of the RF signal are passed through, enhancing the signal-to-noise ratio and improving the clarity of the data. The circuit **128** may also incorporate a demodulator, which extracts the original information-bearing signal from the modulated RF carrier wave. This step interprets the data encoded in the RF signal, allowing the system to identify specific characteristics or signatures of the target materials. In some embodiments, the circuit **128** may include various signal processing components, such as analog-to-digital converters ADCs, which convert the analog RF signal into digital data. This digital data may then be processed by the control panel **146** or other computational units within the system for detailed analysis. The signal processing may involve algorithms to detect specific patterns, frequencies, or anomalies that indicate the presence of target materials. The components within the circuit **128** interact seamlessly to ensure accurate and efficient signal processing. For example, the amplified signal from the amplifier is passed to the filter, which cleans up the signal before it reaches the demodulator. The demodulated signal is then digitized by the ADC and sent to the control panel **146** for analysis.

(21) Further, embodiments may include an NPN transistor **130**, which may be a three-terminal semiconductor device used for amplification and switching of electrical signals. The NPN transistor **130** may consist of three layers of semiconductor material: a thin middle layer, or base, between two heavily doped layers, or emitter and collector. The NPN transistor operates by controlling the flow of current from the collector to the emitter, regulated by the voltage applied to the base terminal. The NPN transistor **130** integrated into the receiver unit **124** may be designed to process incoming RF signals and may operate in a configuration where the base-emitter junction is forward-biased by a small control voltage provided by the preceding stages of the circuit. The collector of the NPN transistor **130** may be connected to the circuit's supply voltage through a load resistor. When a small current flows into the base terminal, it allows a larger current to flow from the collector to the emitter. This amplification process increases the strength of the received signal, enabling subsequent stages of the circuit to process it more effectively. In the receiver unit **124**, the NPN transistor **130** may be employed within amplifier stages where signal gain is crucial. By controlling the base current, the circuit can modulate the transistor's conductivity and thereby regulate the amplification factor. This capability enhances weak RF signals received by the receiver antenna **126** and prepares them for further processing. In some embodiments, the NPN transistor **130** may be utilized in conjunction with capacitors and resistors to form amplifier circuits tailored to the specific requirements of the RF detection device **102**. Capacitors may be used to couple AC signals while blocking DC components, ensuring that only the RF signal is amplified. Resistors set the biasing and operating points of the transistor, optimizing its performance within the circuit.

(22) Further, embodiments may include a PNP Darlington transistor **132**, which may be a semiconductor device consisting of two PNP transistors connected in a configuration that provides

high current gain. The PNP Darlington transistor **132** integrates two stages of amplification in a single package, where the output of the first transistor acts as the input to the second, significantly boosting the overall gain of the circuit. The PNP Darlington transistor **132** amplifies weak RF signals received by the receiver antenna **126**. The incoming RF signal is fed into the base of the first PNP transistor within the Darlington pair. The PNP Darlington transistor **132**, due to its high current gain, allows a much larger current to flow from its collector to the emitter compared to the base current. The output from the collector of the first transistor serves as the input to the base of the second PNP transistor in the Darlington pair. The second PNP transistor further amplifies the signal received from the first stage, again with significant current gain.

(23) Further, embodiments may include an RPN **134** or resistor potentiometer network, which may be an electrical circuit composed of resistors and potentiometers interconnected in a specific configuration to achieve desired electrical characteristics, such as voltage division, signal attenuation, or adjustment of resistance values. Potentiometers, also known as variable resistors, allow for manual adjustment of resistance within the circuit, while resistors set fixed values to control current flow and voltage levels. The RPN **134** in the receiver unit **124** may be configured to adjust signal levels received from the receiver antenna **126** and prepare them for further processing. This network consists of resistors and potentiometers connected to achieve precise voltage division and attenuation. By adjusting the potentiometers, operators can fine-tune the signal strength and impedance matching, optimizing signal quality for subsequent stages of signal processing. The RPN **134** ensures that incoming RF signals from the receiver antenna **126** are properly attenuated and scaled to match the input requirements of downstream electronics. This calibration process maintains signal integrity and fidelity throughout the reception and decoding process. In some embodiments, the potentiometers within the RPN **134** may allow for manual adjustment of signal parameters such as amplitude and impedance, enabling operators to optimize signal reception based on environmental conditions and operational requirements.

(24) Further, embodiments may include a tone generator **136**, which may be a type of electronic device that produces audio signals or tones to alert the user of specific conditions. The tone generator **136** within the receiver unit **124** is utilized to generate audible alerts when the detection system identifies the presence of target materials. The tone generator **136** in the receiver unit **124** may be employed to create specific tones that serve as audible indicators for the user. By generating these tones, the tone generator **136** provides immediate feedback to the operator, signaling the detection of target materials in real time. The tone generator **136** may ensure that the operator is promptly informed of detections without needing to constantly monitor visual displays. The tone generator **136** produces distinct sounds that correspond to different detection events, making it easier for the operator to understand the system's status and respond accordingly. The tone generator **136** may act as a critical alerting component within the receiver unit **124**. When the control panel **146** determines that the RF signal corresponds to a detected target material, it sends a signal to the tone generator **136**. This triggers the tone generator **136** to produce a sound, alerting the operator to the detection event.

(25) Further, embodiments may include an audio amplifier **138**, which may be a type of electronic device designed to increase the amplitude of audio signals. The audio amplifier **138** within the receiver unit **124** may be utilized to boost the audio signals generated by the tone generator **136**, ensuring that the output sound is sufficiently loud and clear for the operator to hear. The audio amplifier **138** in the receiver unit **124** may be employed to enhance the volume and clarity of the audio tones produced by the tone generator **136**. By amplifying these audio signals, the audio amplifier **138** ensures that the operator receives audible alerts even in noisy environments, thus improving the overall effectiveness of the detection system. The audio amplifier **138** may act as an intermediary component between the tone generator **136** and the output device, such as a speaker. When the tone generator **136** produces an audio signal, this signal is sent to the audio amplifier **138**. The amplifier then boosts the signal's power, making it strong enough to drive the speaker and

produce an audible sound. The audio amplifier **138** is connected to other components within the receiver unit **124**, including the tone generator **136** and the speaker. It receives the low-power audio signals from the tone generator **136** and amplifies them to a level suitable for driving the speaker.
(26) Further, embodiments may include a battery **140**, which may be a type of energy storage device that provides a stable and portable power source for the receiver unit **124**. The battery **140** within the receiver unit **124** may be utilized to supply the necessary electrical energy to the various components involved in generating and transmitting the RF signal. The battery **140** may be designed to store electrical energy and supply it to the respective components as required. The battery **140** may be rechargeable or replaceable cells capable of providing DC voltage. They are selected based on factors such as voltage output and capacity, which may be measured in ampere-hours, Ah, and size to meet the power requirements of each component effectively. In the receiver unit **124**, batteries provide the necessary electrical energy to receive and process RF signals detected by the receiver antenna **126**. The battery **140** may power components such as amplifiers, filters, and signal processing circuitry, enabling the device to analyze incoming RF signals and extract relevant information. In some embodiments, the battery **140** used may include lithium-ion, nickel-metal hydride, or other types suitable for portable electronic devices.
(27) Further, embodiments may include a directional shield **142**, which may be a physical barrier or enclosure designed to direct or block electromagnetic radiation in a specific direction. The directional shield **142** may be constructed from conductive materials such as metal to attenuate or reflect RF signals, thereby controlling the propagation of electromagnetic waves. The directional shield **142** may be positioned around the RF oscillator and antenna **120 126** components and may act as a physical barrier that prevents RF signals from propagating in undesired directions, thereby enhancing the precision and accuracy of signal transmission and reception. During operation, when the transmitter unit **106** generates an RF signal, the directional shield **142** helps to focus and channel this signal towards the intended detection area. By reducing signal dispersion and reflection, the directional shield **142** improves the efficiency of signal transmission and enhances the system's overall sensitivity to detecting RF responses from underground objects or materials.
(28) Further, embodiments may include a power supply **144**, such as batteries serving as the power source for specific components within the RF detection device **102**, including the control panel **146**. These batteries are designed to store electrical energy and supply it to the respective components as required. The batteries in the control panel **146** may be rechargeable or replaceable cells capable of providing DC voltage. They are selected based on factors such as voltage output and capacity, which may be measured in ampere-hours, Ah, and size to meet the power requirements of each component effectively. In some embodiments, the control panel **146** relies on batteries to maintain functionality for user interface operations, data processing, and communication with other parts of the RF detection device **102**. The batteries in the control panel **146** ensure that they remain operational during field use, supporting tasks such as signal monitoring, parameter adjustment, and data transmission. In some embodiments, the batteries used in these components may include lithium-ion, nickel-metal hydride, or other types suitable for portable electronic devices. They are integrated into the design to provide sufficient power capacity and longevity, allowing the RF detection device **102** to operate autonomously for extended periods between recharges or battery replacements.
(29) Further, embodiments may include a control panel **146**, which may be a centralized interface comprising electronic controls and displays. The control panel **146** may serve as the user-accessible interface for configuring, monitoring, and managing the RF detection device's **102** operational parameters and data output. In some embodiments, the control panel **146** may be designed to provide operators with intuitive access to control and monitor various aspects of the RF detection device **102**. The control panel **146** may allow for the configuration of settings such as signal frequency, transmission power, receiver sensitivity, and signal processing algorithms. In some embodiments, operators may use the control panel **146** to initiate and terminate detection

operations, adjust calibration settings, and troubleshoot operational issues. In some embodiments, the control panel **146** may include a graphical display screen or LED indicators to present real-time status information and measurement results. In some embodiments, input controls such as buttons, knobs, or touch-sensitive panels may enable operators to interact with the device, input commands, and navigate through menu options. The control panel **146** may interface directly with the internal electronics of the RF detection device **102**, including the transmitter unit **106**, receiver unit **124**, antennas **120 126**, and signal processing circuitry. Through electronic connections and communication protocols, the control panel **146** may send commands to adjust operational parameters and receive feedback and status updates from the device. In some embodiments, the control panel **146** may be mounted on the support frame **104** and may provide an operator with control of the RF detection device **102**, including adjusting various settings and signaling the operator of a detected material. In some embodiments, a rechargeable battery may power the RF detection device **102**, including the transmitter unit **106**, the receiver unit **124**, and the control panel **146**. In some embodiments, multiple batteries may be used. In some embodiments, a tone generator, such as a speaker, may be mounted to the support frame **104** to provide audible signals to the operator for detecting target materials.

(30) Further, embodiments may include a memory **148**, which may include suitable logic, circuitry, and/or interfaces that may be configured to store a machine code and/or a computer program with at least one code section executable by a processor. Examples of implementation of the memory **148** may include, but are not limited to, Random Access Memory (RAM), Read Only Memory (ROM), Hard Disk Drive (HDD), and/or a Secure Digital (SD) card.

(31) Further, embodiments may include a base module **150**, which may sweep through a list of frequencies in order to find which frequencies generate a response in a sample material. For each frequency, the base module **150** may initiate the detection module **152** to determine if the frequency elicits a response from the material based on its resonant characteristics. The base module **150** may then generate a table of which frequencies elicited a response in the sample material. The base module **150** may then initiate the determination module **154** to compare the table to the material database **156** in order to identify which material or materials are present in the sample. If more than one possible identification is returned, the base module **150** may narrow down the options using conditional logic and/or data from additional sensors **158**.

(32) Further, embodiments may include a detection module **152**, which may be responsible for configuring and generating the RF signal through the transmitter unit **106**. The detection module **152** may interact with the control panel **146** to set parameters such as frequency and amplitude. Once the RF signal is generated and transmitted via the transmitter antenna **120**, the detection module **152** may monitor the receiver unit **124** for RF signal reception. Upon receiving the RF signal via the receiver antenna **126**, the detection module **152** processes the signal to extract relevant data about the presence of target materials. This processed data is then sent to the base module **150** for further analysis and decision-making. The detection module **152** operates iteratively as long as the system remains activated, continuously polling and analyzing data to detect and identify target materials based on the received RF signals.

(33) Further, embodiments may include a determination module **154**, which may identify the material or materials present in a sample. The determination module **154** may receive a table of frequencies and responses from the base module **150**, which correspond to the frequencies at which resonance with a material was detected. The determination module **154** may then compare that table to the material database **156** to identify materials present in the sample.

(34) Further, embodiments may include a material database **156**, which may contain a list of materials and their associated resonance frequencies. These resonance frequencies are the frequencies of electromagnetic waves emitted from the transmitter antenna **120** that produce a response from the material that can be received by the receiver unit **124**.

(35) Further, embodiments may include one or more additional sensors **158**, which may provide

additional identifying information about the sample. For example, a visible light camera may detect the color of the sample, an infrared camera may detect temperature or other infrared properties, a chemical detector may detect any volatile materials, etc. These additional sensors **158** can provide additional data to identify the material or materials in the sample when multiple materials have a similar or the same resonance frequency. In another embodiment, a material detection system uses a hybrid antenna that can operate both in RF-based and magnetic-based detection modes. This system is capable of switching between detecting materials based on their interaction with the RF field or the magnetic field, depending on the material being analyzed. In RF mode, the antenna transmits RF waves, and the system analyzes how the material reflects or absorbs these waves, providing information based on the dielectric constant or conductive properties of the material. In magnetic mode, the antenna focuses on the interaction between the material and the magnetic field component of the electromagnetic wave, allowing detection of materials with high magnetic permeability or strong magnetic responses. For example, the system could be used to detect metallic substances or magnetic compounds, such as those found in explosive materials, by optimizing the detection process based on which field interaction yields the clearest signature.

(36) In yet another embodiment, a near-field material detection system uses a magnetic-based loop antenna that focuses on magnetic field interaction within close proximity to the target material. This system uses magnetic resonance principles, detecting changes in the magnetic field due to interactions with materials possessing magnetic susceptibility, such as ferromagnetic metals. The loop antenna generates a localized oscillating magnetic field, and when materials are introduced into the detection zone, they alter the field by inducing eddy currents or magnetic resonance effects. These changes are then measured to determine the material's properties. This method is particularly useful in applications such as industrial quality control or close-range security screening, where detecting the magnetic characteristics of a material offers clear advantages.

(37) In still another embodiment, far-field magnetic resonance techniques are employed for material detection at greater distances. This system operates by transmitting an electromagnetic wave where the magnetic field component is emphasized, focusing on its interaction with materials that have resonant magnetic properties. By tuning the system to specific resonant frequencies, materials that exhibit strong magnetic responses, such as certain alloys or ferromagnetic materials, can be detected over a larger range. The detection system then analyzes the phase or amplitude of the reflected wave to infer material characteristics. This embodiment is particularly suitable for remote sensing applications, such as geological surveys, where materials can be identified based on their magnetic resonance even when located at a distance from the detection apparatus.

(38) In other embodiments, an array of antennas is used to simultaneously detect materials based on both RF and magnetic field interactions. The antenna array consists of dipole antennas optimized for detecting the electric component of the RF wave and loop antennas that focus on the magnetic field interaction. These two types of signals are combined to create a composite material signature, allowing for detailed analysis of both the dielectric and magnetic properties of the material. By processing both electric and magnetic field data, the system can more accurately identify materials that exhibit a combination of electrical conductivity and magnetic permeability, such as advanced composites or stealth materials. This dual-mode system can be particularly useful in defense or aerospace applications.

(39) In still other embodiments, a magnetic-based antenna system is designed for material detection in environments where RF signals would typically be degraded, such as underground or underwater. This system uses a loop antenna to generate a magnetic field that interacts with materials possessing strong magnetic properties, even in situations where RF signals are heavily attenuated. The antenna detects variations in the magnetic field caused by materials with high permeability, such as iron or nickel-based substances. This method allows for the detection of magnetic materials in conditions where RF detection would be unreliable, such as in deep-sea exploration or subterranean mining operations, where conventional RF signals would fail to

penetrate effectively.
(40) In further embodiments, a phased array system is designed specifically to manipulate the magnetic component of the electromagnetic wave for high-resolution material detection. A phased array of loop antennas is used to steer and focus the magnetic field, creating a directed magnetic beam that can scan across a target area. The system detects materials based on how they alter the magnetic field, allowing for precise location and identification of magnetic objects. By adjusting the phase and amplitude of each antenna element, the system provides a fine degree of control, enabling highly localized material detection. This approach is useful in situations requiring detailed spatial resolution, such as identifying hidden metallic objects in security screening or detailed inspections in industrial settings.
(41) In additional embodiments, a portable or wearable material detection system is implemented using a small, magnetic-based loop antenna for detecting magnetic materials in close proximity. This compact system allows security personnel or industrial workers to move through different environments while continuously monitoring for materials that exhibit magnetic properties. The loop antenna generates a localized magnetic field and detects perturbations caused by nearby magnetic materials, such as concealed weapons or magnetic tags. The system then alerts the user when such materials are detected, making it ideal for field operations where mobility and ease of use are critical.
(42) In yet another embodiment, the material detection system is entirely RF-based, using a highly optimized RF antenna to detect materials based solely on their interaction with the RF field. The RF antenna transmits electromagnetic waves at specific frequencies, and the system analyzes how these waves are reflected, absorbed, or scattered by the material. By focusing on the dielectric constant or conductive properties of the target material, the system can accurately identify substances such as explosives, chemicals, or other dielectric materials. This approach is particularly effective in environments where magnetic field-based detection is unnecessary or less effective. The RF-based system can be adapted for wide-ranging applications, from industrial material testing to security scanning, where detecting the electrical characteristics of the material is sufficient for identification.
(43) In one configuration, the system further includes a machine learning system **162** configured to recognize patterns between the material and the resonance characteristics that indicate the presence of the material.
(44) FIG. **2** displays the base module **150**. The base module **150** may be initiated at step **200** when the RF detection device **102** starts up. The base module **150** may also be initiated when a sample is detected or when a user presses a button to begin sample identification. The base module **150** may select at step **202** a first frequency to transmit. This may be selected from a range of frequencies, such as 10-1000 Hz. The range of frequencies may correspond to the range in which the resonant frequencies of the most common materials are found. The frequencies may be selected in any order, but optimally, the frequencies most likely to resonate with materials of interest may be selected first. For example, if Hydrochloric Acid (HCl) is a material of interest, then its resonant frequency, which may be 180 Hz, may be selected first. The base module **150** may refer to the material database **156** in order to determine which order to select the frequencies in. Each entry in the material database **156** may have a priority tier associated with a frequency and with an application of the RF detection device **102**. For example, for a medical application, materials that indicate cancer, such as Prostate-Specific Antigen and Cancer Antigen **125**, may be 1st priority, with unlikely but still dangerous materials such as Uranium being a lower priority. For another example, in a security application, hazardous materials such as Uranium and Nitroglycerin may be 1st priority, whereas while H2O2 can be used to create explosives, it also has legitimate uses as an antiseptic, so it is a lower priority. The base module **150** may skip over selecting frequencies for which there is no known material that resonates with that frequency. A material database including priority tiers is shown in FIG. **5**.

(45) The base module **150** may initiate at step **204**, and the detection module **152**. The base module **150** may then send the selected frequency to the detection module **152**. The detection module **152** may generate an RF signal at the selected frequency through the transmitter unit **106**. The detection module **152** may interact with the control panel **146** to set parameters such as frequency and amplitude. Once the RF signal is generated and transmitted via the transmitter antenna **120**, the detection module **152** may monitor the receiver unit **124** for RF signal reception. Upon receiving the RF signal via the receiver antenna **126**, the detection module **152** processes the signal to extract relevant data about the presence of target materials. This processed data is then sent to the base module **150** for further analysis and decision-making. The base module **150** may receive at step **206** detection data from the detection module **152**. Detection data may be a simple binary indication if the transmission frequency produced a resonance response from the sample. For example, the data may indicate there was a resonance response at 180 Hz but no resonance response at 181 Hz. In some embodiments, detection data may include the detected response signal. If the data from the detection module **152** is complex, then the base module **150** may also undertake data processing steps such as cleaning, formatting, reduction, and analysis. The base module **150** may determine at step **208** if another frequency has not yet been selected. In some embodiments, certain frequencies may be selected multiple times to improve the confidence level of the detection data for those frequencies. The base module **150** may include a smart frequency selection algorithm, which may select the next frequency based on an optimized selection pattern. For example, if a material was detected at a certain frequency, the selection algorithm may cause the base module **150** to select the next frequency where that same material would be detected to quickly confirm the presence of the material. Likewise, if a material was not detected at its expected frequency, other resonant frequencies for that material may not be selected at all. The smart frequency selection method for identifying materials using RF signals may be described as follows: When a scan is initiated, the system may first determine the frequency to be used based on the material of interest. The frequency calculation may be directly tied to the number of protons in the material's atoms. The user selects a material from a comprehensive materials database **156**, which contains information about the number of protons for each element. Using this data, the system may calculate the appropriate RF frequency that corresponds to the material's unique proton count. Once the frequency is calculated, the transmitter unit **106** sends out an RF signal at this specific frequency. The receiver unit **124** then listens for a return signal at the same frequency, indicating the presence of the material. Upon detecting the frequency, the system consults the material database **156** to check if there are other materials with the same proton count. If no other materials share the same proton count, the system reports that the selected material has been found. If multiple materials share the same proton count, the system generates a list of these materials and identifies unique qualities or sub-components that can help differentiate them. For instance, if the material of interest contains arsenic, the system will search for arsenic's specific frequency. If this frequency is detected, the system confirms the presence of the material. If not, it continues to analyze other unique characteristics. Other qualities might include environmental factors or associated materials that naturally occur near the material of interest. For example, if searching for a specific cancer cell, the system might also look for precancerous cells in proximity, enhancing the accuracy of detection. After the algorithm completes its analysis, the system generates a comprehensive report detailing the findings. This report includes the identified material, the list of potential materials with similar proton counts, the additional scans conducted, and the rationale for ruling in or out specific materials based on unique characteristics. This method ensures a thorough and precise identification process, leveraging the unique properties of RF signals and advanced database-driven algorithms to differentiate and confirm the presence of specific materials. If another frequency has not yet been selected, the base module **150** may select at step **210**, the next frequency, and return to step **204**. If each frequency in the frequency range has been selected, the base module **150** may initiate at step **212** the determination module **154** and send in the detection

data for each selected frequency. This may be a list of which selected frequencies produced any response at all or a data table of selected frequencies and their associated received resonance response or lack thereof. The determination module **154** may compare the received detection data to the material database **156** to identify materials present in the sample. The base module **150** may receive at step **214** material identification or identifications from the determination module **154**. For example, the determination module **154** may identify HCl in the sample. The base module **150** may determine at step **216** if there are any identifications from the determination module **154** that are ambiguous. This may occur when the determination module **154** does not have enough information to determine the material exactly but instead can narrow it to a few options. For example, HCl and hydrogen peroxide (H2O2) have the same number of total protons, 18. This may cause them to resonate at the same transmitted frequency. In which case, the determination module **154** may not be able to determine the identity of the material, only these options. If there are no ambiguous identifications, the base module **150** may skip to step **222**. If any identifications are ambiguous, the base module **150** may collect at step **218** data from one or more additional sensors **158**. The one or more additional sensors **158** may provide additional identifying information about the sample. For example, a visible light camera may detect the color of the sample, an infrared camera may detect temperature or other infrared properties, a chemical detector may detect any volatile materials, etc. These additional sensors **158** can provide additional data to identify the material or materials in the sample when multiple materials have a similar or the same resonance frequency. The base module **150** may identify at step **220** the ambiguous materials using the data from the additional sensors **158**. For example, if it is unclear if a sample contains HCl or H2O2, a color sensitive camera may be able to detect the slight yellow color of HCL or the slight blue color of H2O2. For another example, a chemical detection sensor may be able to detect the presence of hydrogen chloride gas, which would serve to identify the material as HCl. The base module **150** may display and/or send at step **222** the material identification or identifications to the user. The RF detection device **102** may have a visual display **160** that the user can read, or the identification data may need to be sent to a terminal or a user device such as a smartphone. The base module **150** may end at step **224**.

(46) FIG. **3** displays the detection module **152**. The detection module **152** may be initiated at step **300** by the base module **150**. In some embodiments, the detection module **152** may be initiated by the user or operator through the control panel **146**. The detection module **152** receives at step **302** the selected frequency from the base module **150** **154**. The detection module **152** may command at step **304** the transmitter unit **106** to configure the transmit signal. The transmitter unit **106** prepares the signal that will be transmitted at the selected frequency. In some embodiments, the parameters and components may be set up with the desired characteristics to generate the RF signal. The control panel **146** determines the specific parameters of the RF signal that need to be generated. Once the parameters are set, the control panel **146** sends a command to activate the oscillator circuit within the transmitter unit **106**. The oscillator circuit may be responsible for generating a stable RF signal at the desired frequency and may consist of components like capacitors, inductors, and amplifiers that work together to create the oscillating signal. The power delivery to the oscillator circuit may be managed by the SCR **114**. When the control panel **146** sends a gate signal to the SCR **114**, it switches from a non-conductive to a conductive state, allowing current from the power source, such as batteries, to flow to the oscillator circuit. After the oscillator circuit generates the RF signal, the transformer **116** adjusts the voltage level of the signal to match the requirements of the transmit antenna **120**. It may also provide impedance matching to ensure efficient signal transmission. The transformer **116** ensures that the RF signal is at the appropriate voltage and current levels for optimal transmission. For example, the control panel **146** may determine that an RF signal with a frequency of 50 Hz requires a specific power level. It sends a command to the transmitter unit **106** to configure this signal. The oscillator circuit is activated, generating an RF signal at 50 Hz. The SCR **114** is triggered, allowing power from the batteries to flow to the

oscillator circuit. The generated signal is then conditioned by the transformer **116**, ensuring it is at the correct voltage level for transmission. The detection module **152** may command at step **306** the transmitter unit **106** to generate the transmit signal via the transmit antenna **120**. The transmitter unit **106** generates the RF signal and transmits it through the transmit antenna **120** by converting electrical energy into radio waves that can be used for detecting specific materials. The transmit antenna **120** radiates the RF signal into the environment. The radio waves propagate through the medium, such as air or ground, and interact with the target materials. The interaction between the RF signal and the target materials will produce detectable changes in the signal, which can be received and analyzed by the receiver unit **124**. For example, the transmitter unit **106** generates a wave pulse at a specified frequency that is transmitted directionally into the ground. The generated frequency is closely approximate or exact to that of the target material, and that relationship creates a responsive RF wave and/or a magnetic line between the transmitter antenna **120** and the target. When the RF detection device **102** is aligned with a target material, for example, when the opening of the directional shield **142** is pointing toward the target material, the voltage produced by the receiver antenna **126** changes and thereby produces a detection output signal, such as an audio signal having a tone different than that of the baseline. A response wave is produced by the target material that amplifies, resonates, offsets, or otherwise modifies the magnetic field passing through the receiver antenna **126** to alter the voltage produced, thereby generating the output signal. The receiver antenna **126** is responding to a voltage increase from the transmitter antenna **120** swinging over the magnetic line to the material. The detection module **152** may command at step **308** the receiver unit **124** to receive RF signal via receiver antenna **126**. The receiver unit **124** captures the RF signal that has interacted with the environment and potential target materials using the receiver antenna **126**. The receiver antenna **126** captures the incoming RF signal, which has been transmitted by the transmitter unit **106** and has interacted with the environment and any target materials present. The receiver antenna **126** may be designed to effectively capture these radio waves and convert them back into electrical signals. Once the RF signal is received by the receiver antenna **126**, it may be fed into an RF amplifier, which boosts the signal strength without significantly altering its characteristics. In some embodiments, the use of the standard atomic structure of a material may be used to calculate the resonant frequency to which a particular material would generate or respond. Each element and material comprises a definable atomic structure composed of the total number of protons and neutrons of that target material. This unique nuclear composition of every material makes it uniquely identifiable and detectable. The manner in which this information is applied thus enables the detection of any target material. A target material can be detected and located based on a resonant, responsive RF wave and/or magnetic relationship between the target and a transmitter antenna **120** transmitting at a frequency specific and unique to the target material. The transmitter unit **106**, through the transmitter antenna **120**, induces a resonance due to responsive RF waves and/or magnetic and/or otherwise in a targeted material to resonate at a specific computed frequency. The receiver antenna **126** and receiver circuit **128** detect the resonance induced in the material and, in so doing, indicate the approximate line of bearing to the material. The primary method used by this detection system to detect specific materials is based on tuning the circuit **108** of the transmitter unit **106** to a specific value that is computed for the material of interest. The frequency can be based on any of the three defining characteristics of the material, the number of protons, the number of neutrons, or the atomic mass, such as the sum of protons and neutrons and combinations thereof. The frequency can be transmitted at varying voltages to compensate for other external effects or interference. In some embodiments, a table or database of characteristics of common materials may be used to calculate the resonant frequencies. To accomplish this tuning, the frequency of the signal from the transmitter antenna **120** is set to some harmonic of the elements of the material. The detection module **152** may command at step **310** the receiver unit **124** to process the RF signal. The receiver unit **124** processes the received RF signal to extract meaningful data that can be analyzed for the presence of specific materials, which

may involve further amplification, filtering, digitization, and initial data processing before the signal is sent to the control panel **146** for detailed analysis. In some embodiments, after the RF signal is received and initially amplified, it may require further amplification to ensure the signal is at an optimal level for processing. In some embodiments, an additional RF amplifier within the receiver unit **124** may boost the signal strength while maintaining its integrity. The amplified signal may be subjected to more advanced filtering by the filter circuit, which removes any residual noise and unwanted frequencies that might have passed through the initial filtering stage. In some embodiments, the filtering may involve bandpass filters that allow only the desired frequency range to pass through. The filtered analog signal may be converted into a digital format using an Analog-to-Digital Converter, ADC. The ADC samples the analog signal at a high rate and converts it into a series of digital values. The digitized signal may be processed using digital techniques. The digital signal may be fed into a Digital Signal Processor, DSP, within the receiver unit **124**. In some embodiments, the DSP may perform initial data processing tasks such as demodulation, noise reduction, and feature extraction. Demodulation involves extracting the original information-bearing signal from the carrier wave. Noise reduction techniques may further clean the signal, making it easier to analyze. Feature extraction may involve identifying key characteristics of the signal that are indicative of the presence of target materials. The detection module **152** may command at step **312** the receiver unit **124** to send the output to the base module **150**. The resultant data from the process is organized and packaged, which may involve structuring the data into packets, adding metadata such as timestamps and identifiers, and incorporating error-checking codes to ensure data integrity during transmission. The data may be a binary indication of whether or not a resonance response was detected by the receive antenna **126**. Alternatively, some or all of the received signal data may be sent to the base module **150**. The detection module **152** may return at step **314** to the base module **150**.
(47) FIG. **4** displays the determination module **154**. The determination module **154** may be initiated at step **400** by the base module **150**. The determination module **154** may receive at step **402** detection data from the base module **150**. This may be a list of which selected frequencies produced any response at all or a data table of selected frequencies and their associated received resonance response. The determination module **154** may compare at step **404** the detection data to the material database **156**. For example, if the detection data showed a response at 180 Hz, 340 Hz, and 1160 Hz, then the determination module **154** would search the material database **156** for any entries with those frequencies. The determination module **154** may identify at step **406** the possible materials in the sample. These would be any materials or elements that have resonant frequencies that correspond to the frequencies in the detection data. For example, given that there was a response at the frequencies at 92 Hz, 180 Hz, 340 Hz, and 1160 Hz, then the possible materials in the sample would be Uranium, H2O2, HCl, and Nitroglycerin (CH2NO3CHNO3CH2NO3) based on the data in the material database **156**. The determination module **154** may attempt at step **408** to resolve any ambiguous results. Since some materials may share similar features, such as total atomic weight or number of protons, they may have similar or the same resonant frequencies. In ambiguous cases, the determination module **154** may be able to identify which material is present based on the material's other resonance frequencies. For example, H2O2 and HCl have a resonance frequency of 180 Hz, which does appear in the detection data. However, 340 Hz also had a response, which corresponds to H2O2 and not HCl which means H2O2 is likely present. Further, there was no response at 360 Hz which indicates that HCl is not present in the sample. For another example, Uranium would resonate at 92 Hz because it has 92 protons. But Uranium has several isotopes, most notably Uranium-235 and Uranium-238. Detection of a resonant response at 92 Hz and 238 Hz, but no response at 235 Hz would indicate Uranium-238. Some ambiguities cannot be resolved by the determination module **154** and may be sent to the base module **150** as an ambiguous identification for further differentiation. The determination module **154** may send at step **410** all identified materials and/or elements to the base module **150**. The determination module

154 may return at step **412** to the base module **150**.

(48) FIG. **4** displays the material database **156**. The material database **156** may contain a list of materials and their associated resonance frequencies. These resonance frequencies are the frequencies of electromagnetic waves emitted from the transmitter antenna **120** that produce a response from the material that can be received by the receiver unit **124**. The frequency at which an element resonates may be based on the number of protons, number of neutrons, and/or atomic mass (sum of protons and neutrons) for the element. For example, the selected frequencies for Arsenic (As) may be 33 Hz (based on number of protons), 42 Hz (based on number of neutrons), and 75 Hz (based on atomic mass). These frequencies can also be increased by one or more orders of magnitude (10×, 100×, etc.). Similarly, the frequencies for a material may be based on the sum total of the constituent parts. For example, a Hydrogen Peroxide (H2O2) molecule has a combined total of 18 protons (corresponding to a frequency of 18 or 180 Hz) and a mass of 34 (corresponding to a frequency of 34 or 340 Hz). Individual scans using two or more of these frequencies can be used to uniquely identify the element or material. Note that these frequencies are examples. The actual frequencies at which materials and elements resonate may be determined by physics models and/or experimentation. The material database may further contain priority tiers for specific applications. These priority tiers may determine in which order frequencies are selected for testing. For example, application A may be a medical application wherein Arsenic and H2O2 would be high priority due to the toxicity of Arsenic and H2O2. Uranium, while also deadly, is unlikely to be found in the human body and is, therefore, a lower priority. For another example, application B may be a security checkpoint wherein Uranium and Nitroglycerin (CH2NO3CHNO3CH2NO3) are high priority due to the damage they can cause to others. Arsenic, while still deadly, is unlikely to cause mass damage or death because it is noncombustible and not highly radioactive. The material database **156** may be specific to different applications by prioritizing specific materials. For example, in medical diagnostics for primary care, early detection of breast cancer through BRCA1/BRCA2 gene mutations can significantly improve treatment outcomes as these mutations are common indicators for breast cancer. Detecting EGFR mutations aids in the early diagnosis of lung cancer, the leading cause of cancer deaths. Elevated PSA levels are a common biomarker for prostate cancer, and KRAS mutations indicate colorectal cancer, a common and potentially preventable cancer. Early detection of melanoma can be life-saving, as it is the most serious type of skin cancer. Rare cancers, while important, are less common in primary care settings and may be less prioritized compared to more prevalent cancers. Integration of this system should ensure real-time data sharing between the detection device and electronic health records (EHR) systems to enhance diagnostic responsiveness and accuracy. Automated response protocols should be developed so that if cancer markers are detected, the system automatically notifies healthcare providers and prompts follow-up tests. Intuitive user interfaces should be designed to provide clear, actionable information to healthcare providers, including detection levels, potential diagnoses, and recommended actions. The device must operate in various clinical settings, from busy primary care offices to specialized diagnostic centers. A flexible system for setting and updating priority tiers in the material database should be developed based on emerging medical research and patient demographics. Comprehensive training for healthcare providers on system operation and data interpretation is essential, along with regular updates and support services to address any issues. Robust data security measures must be implemented to protect sensitive patient information, ensuring compliance with healthcare regulations. For security checkpoints at airports and borders, the priority materials include uranium, nitroglycerin, RDX, and TATP due to their use in radiological and explosive devices. Arsenic is less prioritized due to its non-combustible nature. In industrial safety and environmental monitoring, priority materials include benzene, chlorine, ammonia, and methane due to their hazardous properties, while hydrogen peroxide is less commonly found in industrial leaks. Customs and border protection prioritize detecting cocaine, heroin, methamphetamine, and various explosives, with hydrogen peroxide being less common in

large quantities crossing borders. For food safety and inspection, pesticides, heavy metals, and pathogens are prioritized over industrial contaminants. In pharmaceutical manufacturing, active pharmaceutical ingredients and contaminants like heavy metals and solvents are prioritized over biological contaminants. Military applications prioritize detecting explosives and chemical weapons over narcotics. Construction site safety focuses on asbestos and silica dust over general industrial chemicals. Research laboratories prioritize radioactive isotopes and toxic chemicals over biological samples. Environmental monitoring prioritizes pollutants like benzene, toluene, and xylene, as well as hazardous gases like methane, sulfur dioxide, and nitrogen dioxide, over heavy metals in soil. Integration considerations include ensuring real-time data sharing between the detection device and application-specific apparatus to enhance threat detection responsiveness and accuracy. Automated response protocols should be developed for each integrated device, such as locking down cargo containers and alerting authorities if hazardous materials are detected. Intuitive user interfaces should be designed to provide operators with clear, actionable information, including threat levels, material types, and recommended actions. Integrated devices must operate in various environmental conditions, from the high humidity of ports to the confined spaces of mail trucks or crowded airports. A flexible system for setting and updating priority tiers in the material database should be developed to adapt to different contexts and emerging threats. Comprehensive training for users on system operation and data interpretation is essential, along with regular updates and support services. Robust data security measures must be implemented to protect sensitive information, especially in security and border control applications. Integrating the RF-specific material detection device into these applications enhances the overall safety, efficiency, and accuracy of hazardous material detection across multiple industries. This approach allows for tailored detection strategies that prioritize the most relevant threats in each context, thereby improving response times and reducing risks.
(49) The functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

Claims

1. A method for material detection and identification, the method comprising: transmitting into an environment an RF signal at a first resonance frequency for a target material, wherein the first resonance frequency is obtained from a material database associating each of a plurality of materials with one or more corresponding resonance frequencies; receiving a resultant response signal from the environment; and analyzing the resultant response signal for resonance characteristics that indicate a presence of the target material, wherein analyzing includes: determining that one or more other materials in the material database share similar resonance characteristics for the first resonance frequency; and displaying a report on graphical display screen identifying: the target material; and the one or more other materials in the material database that share the similar resonance characteristics for the first resonance frequency.
2. The method of claim 1, further comprising: repeating transmitting, receiving, analyzing using a second resonance frequency for a material associated with the material of interest either to confirm that the target material is present or to distinguish between the target material and the one or more other materials.
3. The method of claim 2, further comprising, if the resonance characteristics are not detected in the resultant response signal for either the first resonance frequency or the second resonance frequency, using environmental factors to identify the target material.
4. The method of claim 1, wherein the material database indicates a priority of detecting at least a subset of the plurality of materials for one or more applications, and wherein transmitting includes

transmitting into the environment the RF signal at the first resonance frequency for each material in order of the priority for a specific application.

5. The method of claim 4, wherein the at least the subset of the plurality of materials is selected by the user.

6. The method of claim 1, further comprising using machine learning to recognize patterns between one or more materials and one or more resonance characteristics for different frequencies.

7. The method of claim 1, wherein the first resonance frequency is related to a number of protons in atoms composing the target material.

8. The method of claim 1, wherein the report further includes: additional scans conducted; and a rationale for ruling out specific materials based on unique characteristics.

9. The method of claim 1, wherein analyzing further includes: generating a list of frequencies and associated resonance characteristics.

10. The method of claim 1, wherein transmitting includes transmitting at least one resonance frequency multiple times for particular material to improve a confidence level of detection for the at least one resonance frequency.

11. A system for material detection and identification, the system comprising: an RF transmitter configured for transmitting into an environment an RF signal at a first resonance frequency for a target material, wherein the first resonance frequency is obtained from a material database associating each of a plurality of materials with one or more corresponding resonance frequencies; an RF receiver configured for receiving a resultant response signal from the environment; and a processor configured for: analyzing the resultant response signal for resonance characteristics that indicate a presence of the target material, wherein analyzing includes: determining that one or more other materials in the material database share similar resonance characteristics for the first resonance frequency; and displaying a report on graphical display screen identifying: the target material; and the one or more other materials in the material database that share the similar resonance characteristics for the first resonance frequency.

12. The system of claim 11, wherein the processor is further configured for repeating transmitting, receiving, analyzing using a second resonance frequency for a material associated with the material of interest either to confirm that the target material is present or to distinguish between the target material and the one or more other materials.

13. The system of claim 12, wherein the processor is further configured for, if the resonance characteristics are not detected in the resultant response signal for either the first resonance frequency or the second resonance frequency, using environmental factors to identify the target material.

14. The system of claim 11, wherein the material database indicates a priority of detecting at least a subset of the plurality of materials for one or more applications, and wherein transmitting includes transmitting into the environment the RF signal at the first resonance frequency for each material in order of the priority for a specific application.

15. The system of claim 14, wherein the at least the subset of the plurality of materials is selected by the user.

16. The system of claim 11, further comprising a machine learning system configured to recognize patterns between one or more materials and one or more resonance characteristics for different frequencies.

17. The system of claim 11, wherein the first resonance frequency is related to a number of protons in atoms composing the target material.

18. The system of claim 11, wherein the report further includes: additional scans conducted; and a rationale for ruling out specific materials based on unique characteristics.

19. The system of claim 11, wherein analyzing further includes: generating a list of frequencies and associated resonance characteristics.

20. The system of claim 11, wherein transmitting includes transmitting at least one resonance

frequency multiple times for particular material to improve a confidence level of detection for the at least one resonance frequency.