US 20050220310A1

(19) United States
(12) Patent Application Publication
McGrath
(10) Pub. No.: US 2005/0220310 A1
(43) Pub. Date: Oct. 6, 2005

(54) TECHNIQUE AND DEVICE FOR THROUGH-THE-WALL AUDIO SURVEILLANCE

(76) Inventor: **William R. McGrath**, Monrovia, CA (US)

Correspondence Address:
CHRISTIE, PARKER & HALE, LLP
PO BOX 7068
PASADENA, CA 91109-7068 (US)

(21) Appl. No.: 11/095,122

(22) Filed: Mar. 30, 2005

Related U.S. Application Data

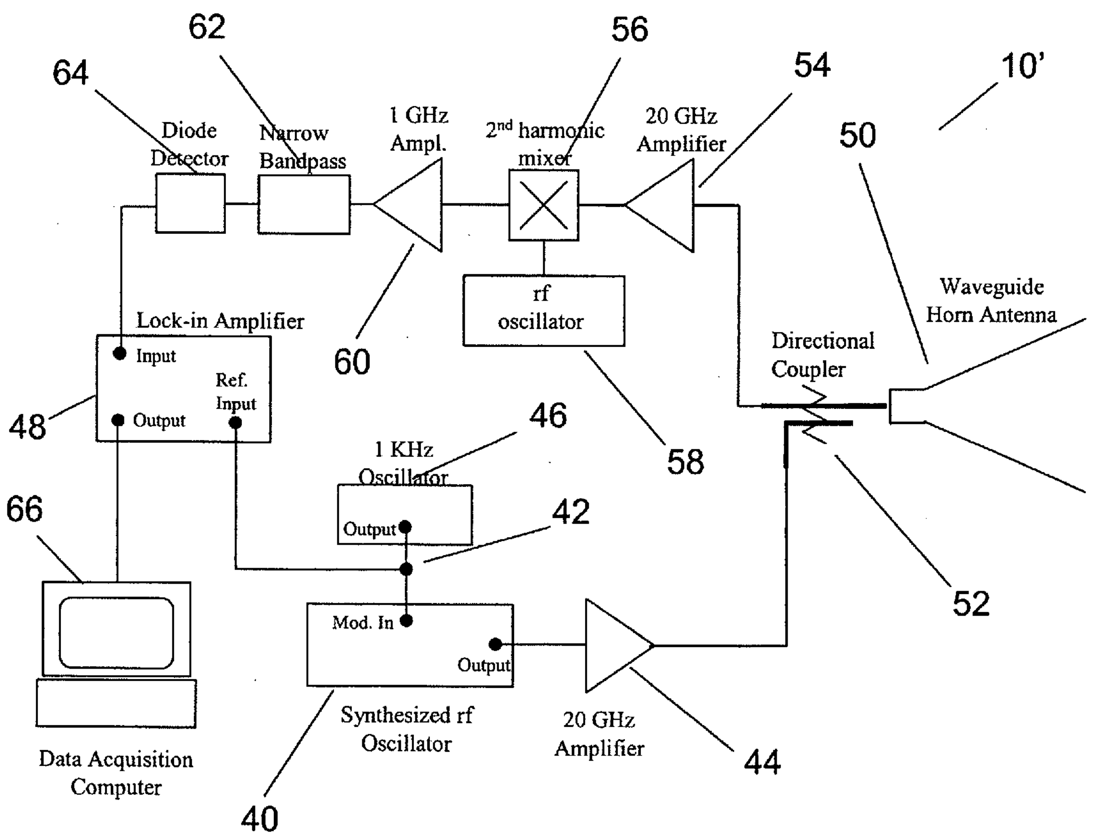
(60) Provisional application No. 60/557,542, filed on Mar. 30, 2004.

Publication Classification

(51) Int. Cl.[7] H04R 29/00
(52) U.S. Cl. 381/56

(57) ABSTRACT

Systems and methods are disclosed for detecting audible sound and/or the vibration of objects. Embodiments of the present invention are able to detect sound and other vibrations through barriers. One embodiment of the invention includes an RF transmitter configured to generate an RF signal having a frequency of at least 100 MHz and an unmodulated amplitude, an RF receiver configured to receive a reflected RF signal comprising an RF carrier having the same frequency as the generated RF signal that is amplitude modulated by an information signal and a signal processor configured to extract audio frequency information from the amplitude of the reflected RF signal.



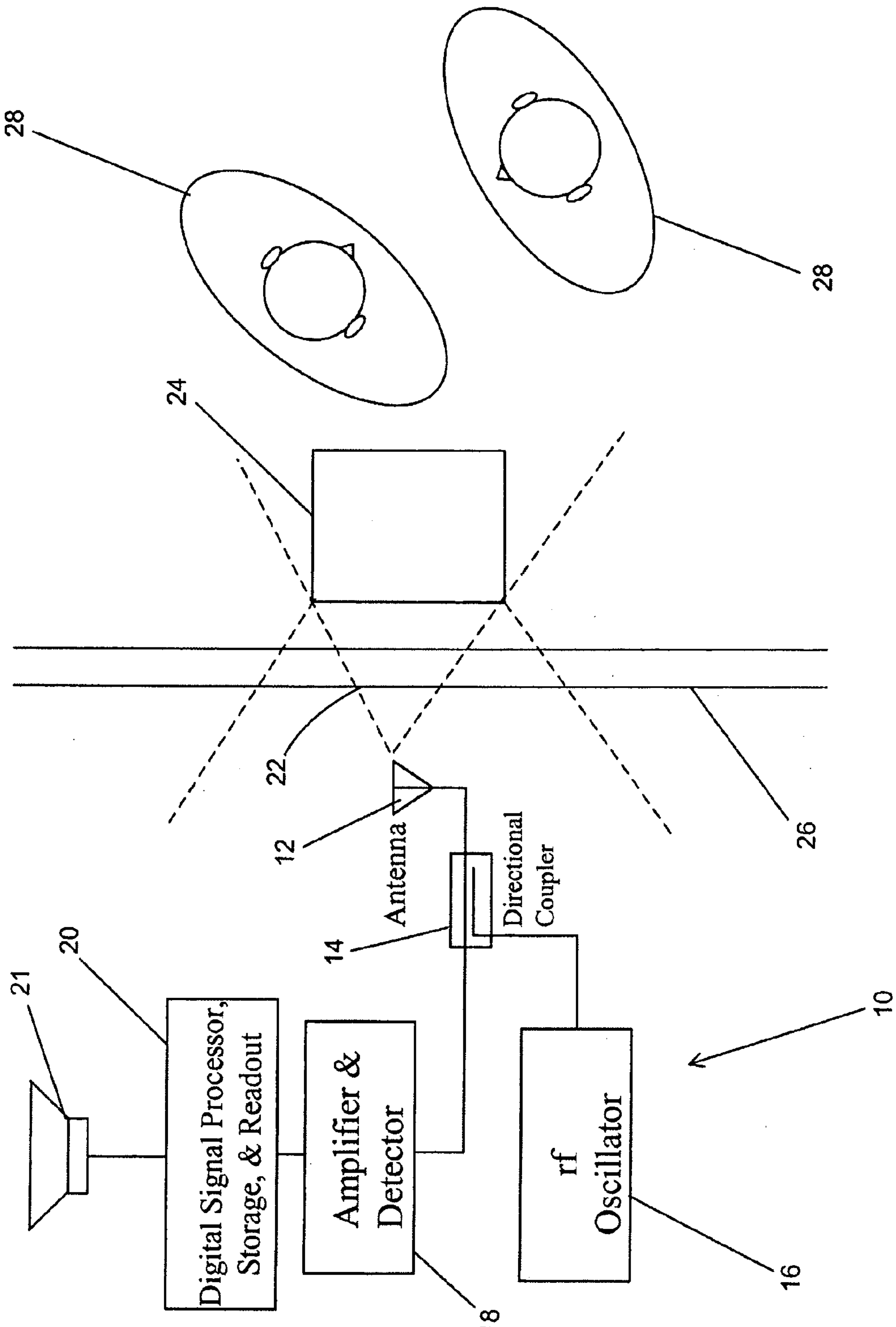

28
28
24
22
12
Antenna
Directional Coupler
14
26
20
21
Digital Signal Processor, Storage, & Readout
Amplifier & Detector
rf Oscillator
10
18
16

FIG. 1A

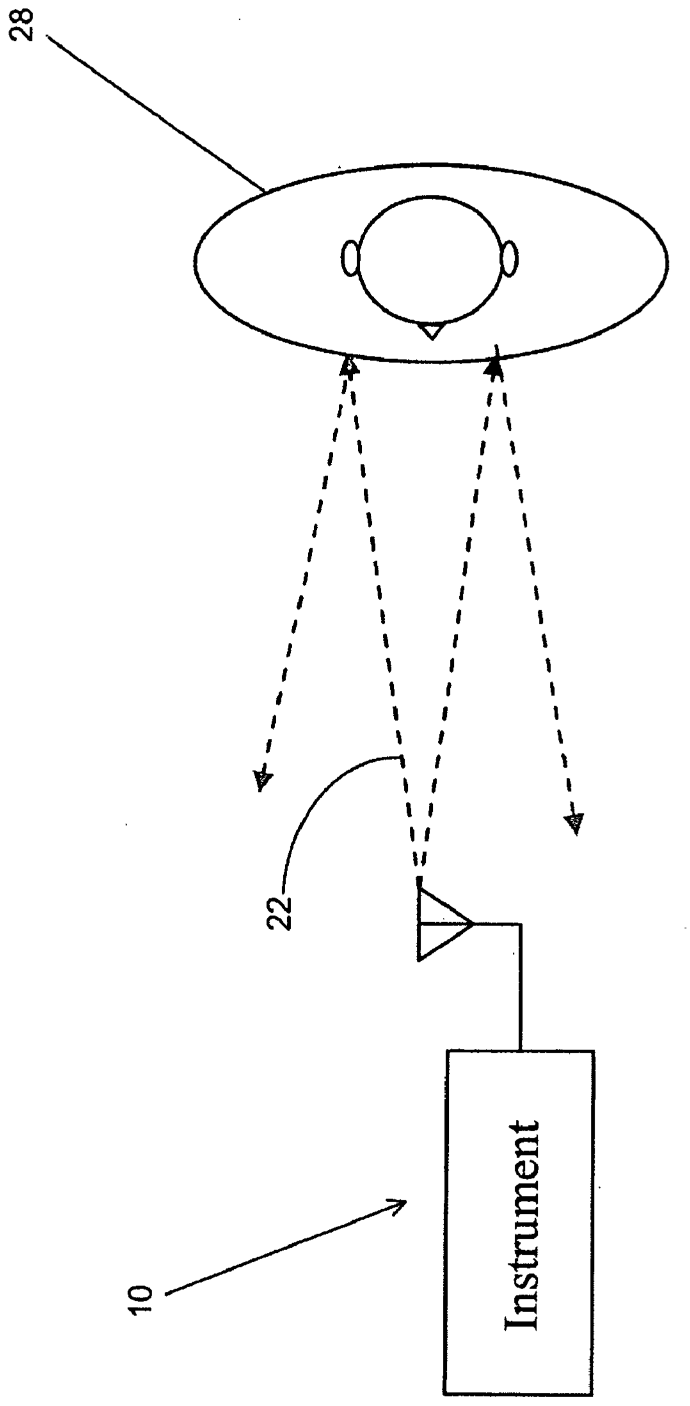


FIG. 1B

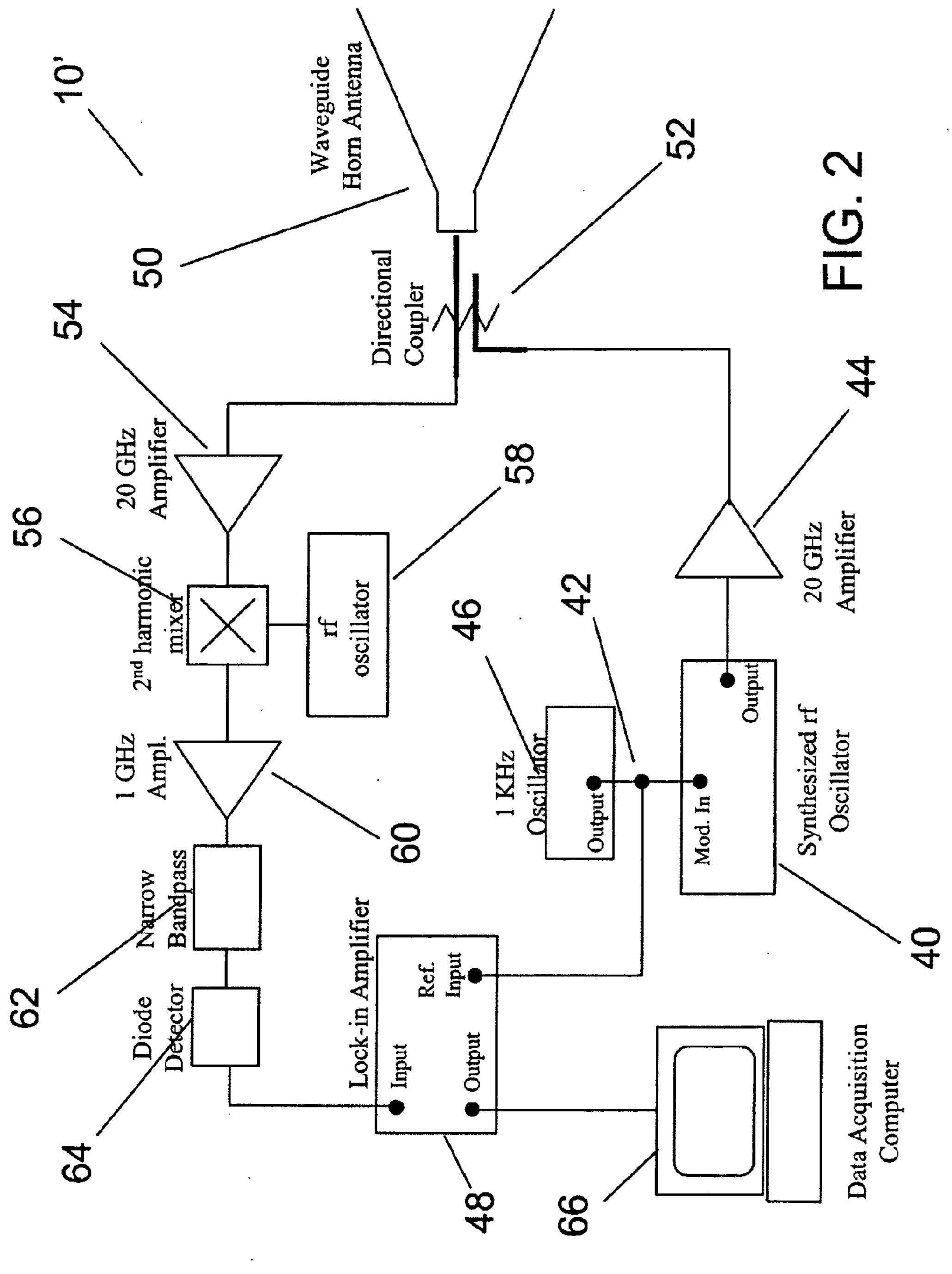

10'
Waveguide Horn Antenna
50
52
Directional Coupler
54
20 GHz Amplifier
56
2nd harmonic mixer
58
rf oscillator
1 GHz Ampl.
60
Narrow Bandpass
62
Diode Detector
64
Lock-in Amplifier
Input
Output
Ref. Input
48
66
Data Acquisition Computer
46
1 KHz Oscillator
Output
42
Mod. In
Output
Synthesized rf Oscillator
40
44
20 GHz Amplifier

FIG. 2

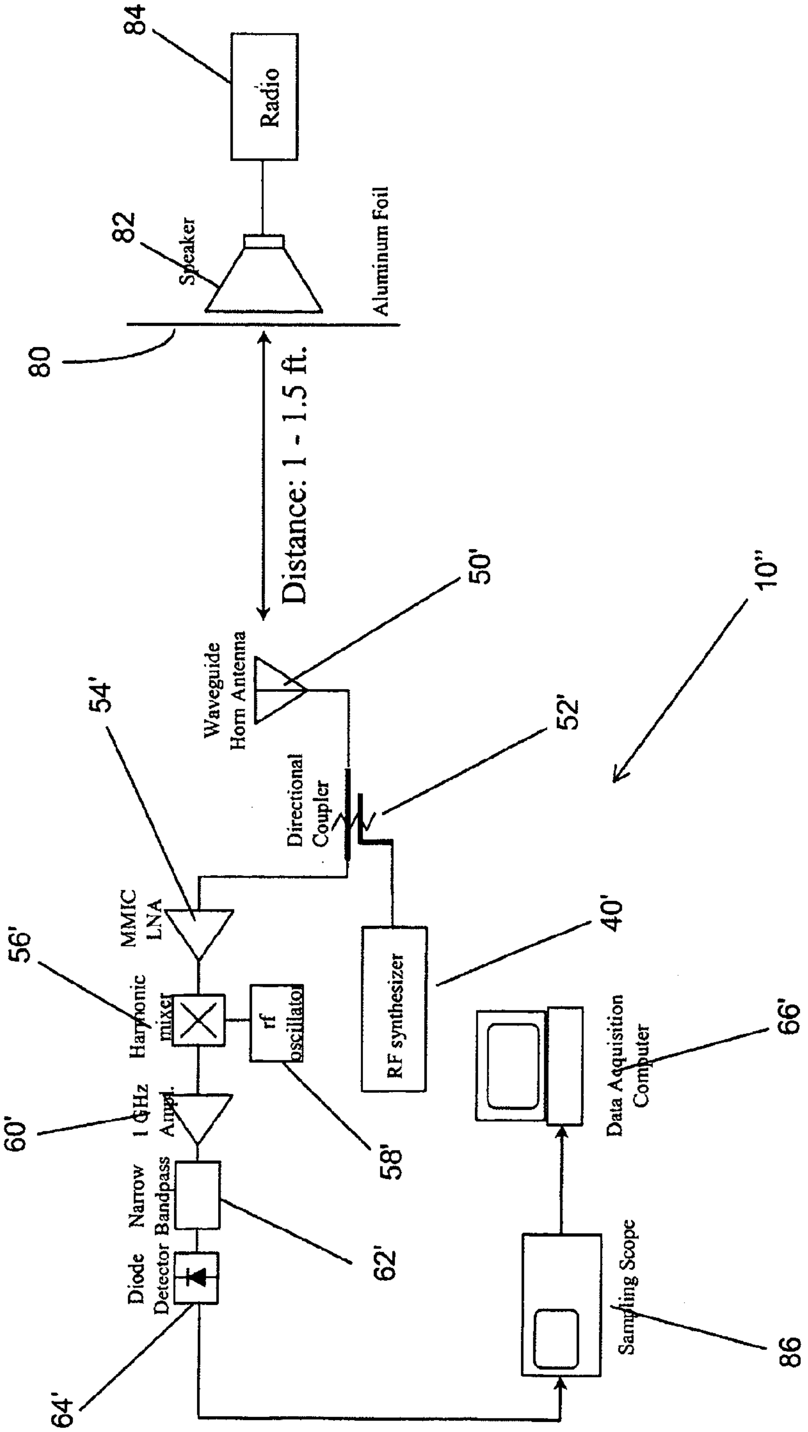

84
Radio
82
Speaker
Aluminum Foil
80
Distance: 1 - 1.5 ft.
50'
10''
Waveguide Horn Antenna
54'
52'
Directional Coupler
MMIC LNA
56'
Harmonic mixer
rf oscillator
40'
RF synthesizer
66'
Data Aqquisition Computer
60'
1 GHz Ampl.
58'
Narrow Bandpass
62'
Diode Detector
64'
Sampling Scope
86

FIG. 3

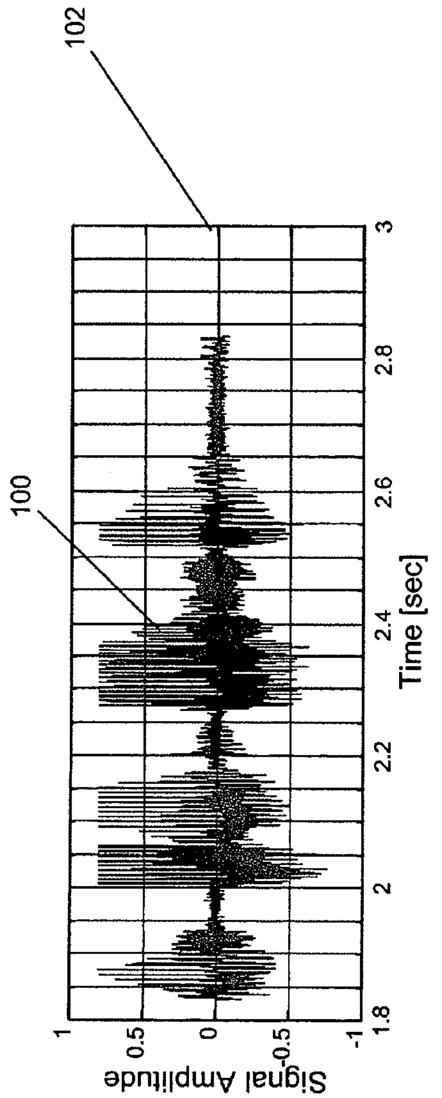

102
100
Signal Amplitude
1
0.5
0
-0.5
-1
1.8
2
2.2
2.4
2.6
2.8
3
Time [sec]

FIG. 4A

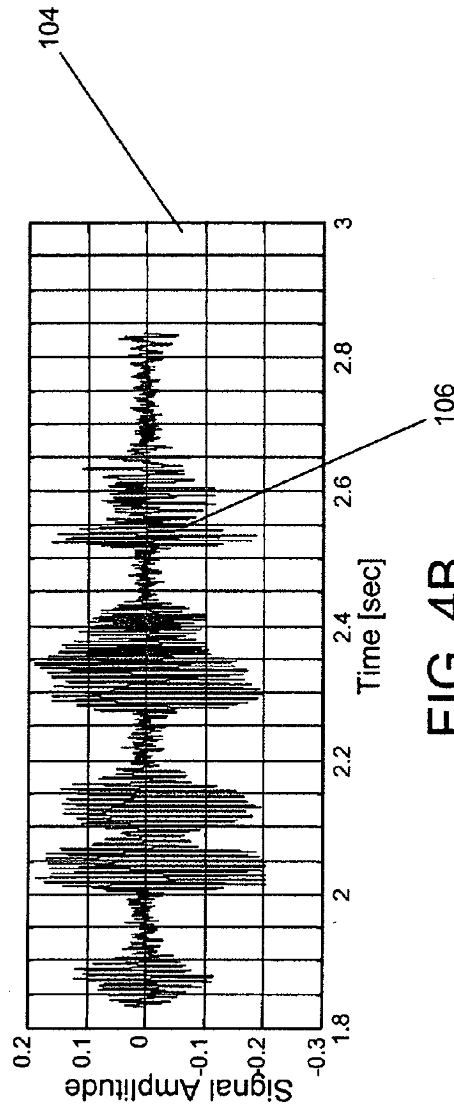

104
106
Signal Amplitude
0.2
0.1
0
-0.1
-0.2
-0.3
1.8
2
2.2
2.4
2.6
2.8
3
Time [sec]

FIG. 4B

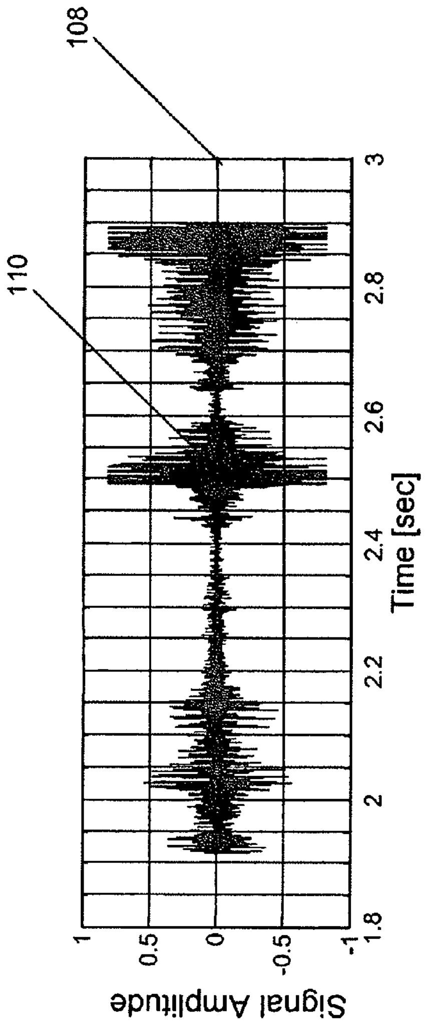

108
110
Signal Amplitude
1
0.5
0
-0.5
-1
1.8
2
2.2
2.4
2.6
2.8
3
Time [sec]

FIG. 4C

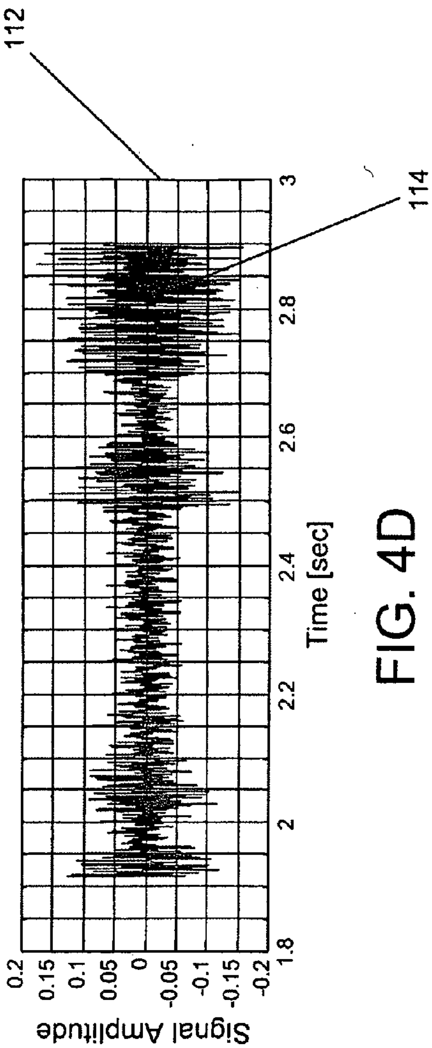

112
114
Signal Amplitude
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
1.8
2
2.2
2.4
2.6
2.8
3
Time [sec]

FIG. 4D

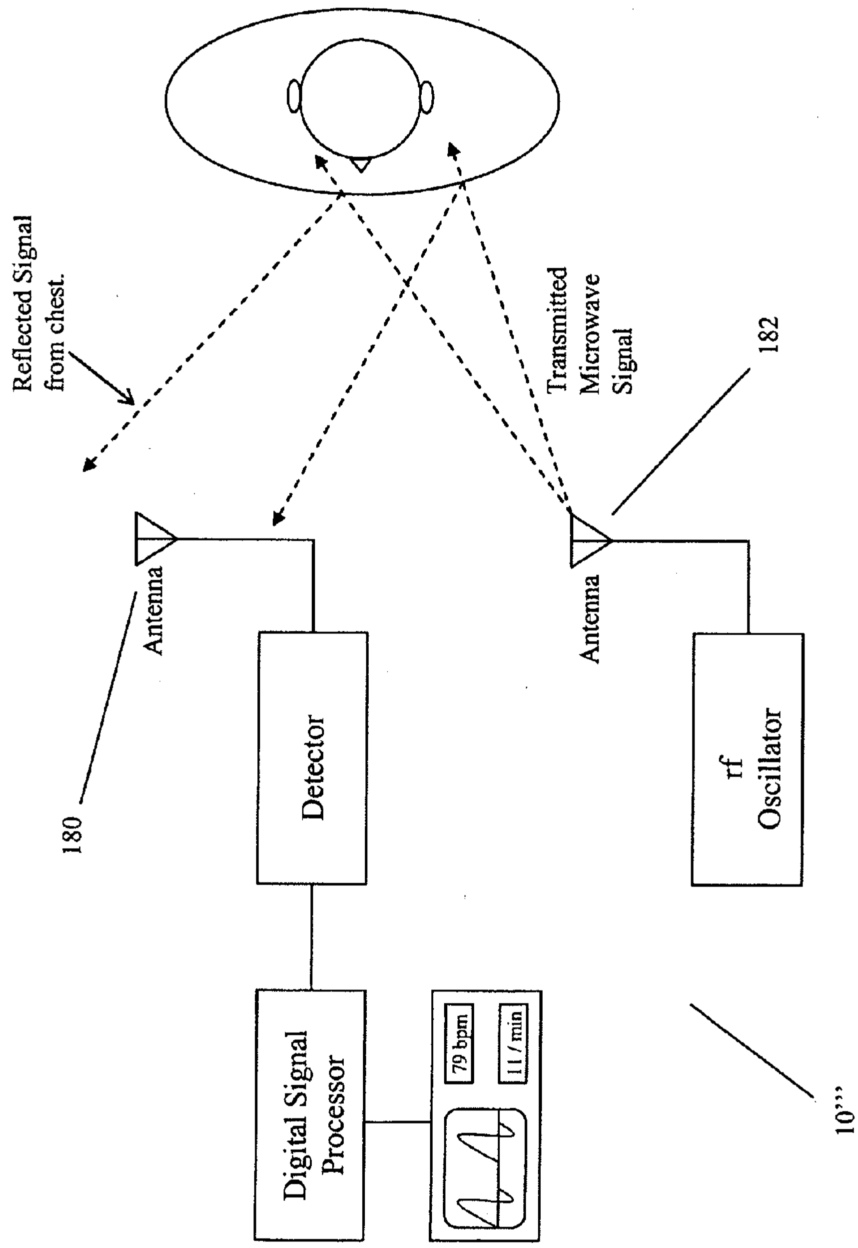

Reflected Signal
from chest.
Transmitted
Microwave
Signal
182
Antenna
Antenna
180
Detector
rf
Oscillator
Digital Signal
Processor
79 bpm
11 / min
10'''

FIG. 5

TECHNIQUE AND DEVICE FOR THROUGH-THE-WALL AUDIO SURVEILLANCE

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority based on U.S. Provisional Application No. 60/557,542 filed Mar. 30, 2004.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] The U.S. Government has certain rights in this invention pursuant to NAS7-1407 provided by the National Aeronautics and Space Administration, Office of Space Science.

BACKGROUND

[0003] The present invention generally relates to the detection of audible sound and more specifically relates to the detection of sound through an interposed barrier.

[0004] Audio surveillance is an important part of law enforcement activity. The ability to overhear conversations can provide vital information relating to the commission of a crime. One method of detecting sound is to place a microphone proximate the source of the sound. Sound is essentially a pressure wave and the microphone detects sound by detecting fluctuations in pressure associated with the pressure wave.

[0005] Attempts to detect sound using a microphone can be frustrated by interposing a barrier between the source of the sound and the microphone. In instances where the barrier absorbs the energy of the sound pressure waves, then a microphone can experience difficulty in detecting the sound. In addition, a space can be "sound-proofed" to frustrate audio surveillance. Sound-proofing describes constructing barriers that effectively prevent pressure waves associated with sound from escaping a space.

SUMMARY OF THE INVENTION

[0006] Embodiments of the present invention can detect vibrations of objects including slight vibrations caused by sound pressure waves. In one aspect of the present invention an object is illuminated with a monochromatic RF beam that does not include any amplitude modulation. Observations of amplitude modulations in reflections of the RF beam can provide information concerning vibrations or movements of the object. Audio information can be extracted from the amplitude modulated information and used to reproduce any sound pressure waves incident on the object.

[0007] One embodiment of the invention includes an RF transmitter configured to generate an RF signal having a frequency of at least **100** MHz and an unmodulated amplitude, an RF receiver configured to receive a reflected RF signal comprising an RF carrier having the same frequency as the generated RF signal that is amplitude modulated by an information signal and a signal processor configured to extract audio frequency information from the amplitude of the reflected RF signal.

[0008] In another embodiment of the invention, the RF transmitter includes an RF synthesizer coupled to an antenna.

[0009] In a further embodiment of the invention, the antenna is a planar antenna. In yet another embodiment of the invention, the antenna is a waveguide horn antenna.

[0010] In a still further embodiment, the RF receiver includes an antenna, a low noise amplifier coupled to the antenna, a harmonic mixer connected to an output of the low noise amplifier and to an RF oscillator, a second amplifier connected to an output of the harmonic mixer, a narrow bandpass filter connected to an output of the second amplifier and a diode detector connected to an output of the narrow bandpass filter.

[0011] In yet another embodiment of the invention again, the antenna is a planar antenna. In a still further embodiment of the invention again, the antenna is a waveguide horn antenna.

[0012] In yet another additional embodiment, the low noise amplifier is implemented using MMIC.

[0013] In a still further additional embodiment the signal processor includes an audio speaker. In still yet another embodiment, the RF signal can have a frequency in the range of 100 MHz to 200 GHz. Moreover, the RF signal can have a frequency in the range of 1 GHz to 100 GHz. In addition, the RF signal can have a frequency in the range of 10 GHz to 100 GHz.

[0014] An embodiment of the method of the invention includes illuminating an object with a generated RF signal having a frequency of at least 100 MHz and having an unmodulated amplitude, extracting amplitude modulated information from reflections of the generated RF signal, isolating the portions of the extracted information corresponding to audio frequencies and generating audio using the isolated portions of the extracted information.

[0015] In another embodiment of the method of the invention, the RF signal has a frequency in the range of 100 MHz to 200 GHz. Moreover, the RF signal can have a frequency in the range of 1 GHz to 100 GHz. In addition, the RF signal can have a frequency in the range of 10 GHz to 100 GHz.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] **FIG. 1A** is a schematic diagram of a sound detection system in accordance with an embodiment of the present invention illuminating an object with an RF beam through a barrier;

[0017] **FIG. 1B** is a schematic diagram of a sound detection system in accordance with an embodiment of the present invention illuminating the chest of a subject with an RF beam;

[0018] **FIG. 2** is a schematic circuit diagram of a system in accordance with an embodiment of the present invention;

[0019] **FIG. 3** is a schematic diagram of an experimental configuration;

[0020] **FIGS. 4A and 4B** are graphs showing comparisons between audio signal amplitudes and the amplitude modulation of an RF signal detected in accordance with an embodiment of the method of the present invention, where the RF signal is reflected from an aluminum foil upon which the audio signal pressure waves are incident;

[0021] **FIGS. 4C and 4D** are graphs showing comparisons of audio signal amplitudes and the amplitude modulation of an RF signal obtained in a similar manner to the graphs shown in **FIGS. 4A and 4B** with the exception that a plywood barrier is interposed between the sound detection system and the aluminum foil; and

[0022] **FIG. 5** is a schematic diagram of an embodiment of a sound detection system in accordance with the present invention that includes an RF source separate from an RF detector.

DETAILED DESCRIPTION OF THE INVENTION

[0023] Embodiments of the present invention use reflected electromagnetic signals to detect audible sound. Pressure waves incident on an object can cause the object to vibrate in a manner indicative of the pressure waves. Electromagnetic radiation reflected by a vibrating object can include an amplitude modulated component indicative of the object's vibrations. Several embodiments of the present invention illuminate objects with an RF signal that does not have a modulated amplitude and extract amplitude modulated information from reflections of the RF signal. In many embodiments, the amplitude modulated information includes information indicative of pressure waves incident on the object. Analysis of the signals indicative of pressure waves can then be performed to reproduce any audible sounds included in the pressure waves.

[0024] Turning now to the diagrams, **FIG. 1** illustrates a sound detection system **10** in accordance with the present invention that includes an antenna **12** coupled via a directional coupler **14** to an RF oscillator **16** and a RF detector **18**. In addition, the RF detector is connected to a digital signal processor **20** which is connected to a speaker **21**. The RF oscillator and the antenna can illuminate an object **24** with an electromagnetic beam **22**. The object typically reflects a portion of the incident electromagnetic signal and the antenna and the RF detector can be used to generate a signal indicative of the amplitude of the reflected signal. The amplitude of the reflected signal may be modulated if the object is vibrating. Information can then be extracted from the signal generated by the antenna and the RF detector by the digital signal processor.

[0025] In the illustrated embodiment, a barrier **26** separates the sound detection system **10** and the object **24**. In addition, two people **28** are conducting a conversation proximate the object. Pressure waves generated as the people speak are incident on the object causing it to vibrate. As indicated above, these vibrations can modulate the amplitude of the RF beam reflections from the object.

[0026] In one embodiment, the reflected signal is received by the antenna, amplified by a low noise amplifier and detected by a total-power direct detector with a bandwidth of at least several 10's of kilohertz to accommodate audio information. A real time digital signal processor can then be used to recover the audio information and convert the audio information to an analog signal for amplification and output to a loud speaker. In several embodiments, signal processing techniques similar to those used with laser sound detection systems can be employed.

[0027] In one embodiment, the sound detection system generates a monochromatic RF beam using a planner antenna having a frequency within the range of 100 MHz to 200 GHz. In other embodiments, the RF beam can have a frequency within the range 1 GHz to 100 GHz. In further embodiments, the RF beam can have a frequency within the range of 10 GHz to 200 GHz As will be discussed below, other antenna configurations can be used such as horn antennas. The frequency of the RF beam can be less than 100 MHz, however, antenna size may increase and the beam may have a width that encompass a very wide field.

[0028] An embodiment of a sound detection system in accordance with the present invention that can be used to detect sound by observing RF reflections from the chest of a human subject is shown in **FIG. 1A**. A sound detection system **10** is shown generating an RF beam **22** that is illuminating the chest of a human subject **28**. The subject's chest reflects the beam and the RF beam's reflections can be amplitude modulated by, amongst other things, a component indicative of any sound being generated by the subject.

[0029] A diagram of a sound detection system in accordance with the present invention is shown in **FIG. 2**. The sound detection system **10'** includes a synthesized RF oscillator **40** that is connected to a common node **42** and a first amplifier **44**. The common node **42** is connected to an oscillator **46** and a lock-in amplifier **48**. The output of the first amplifier **44** is connected to an antenna **50** via a directional coupler **52**. The directional coupler is also connected to a second amplifier **54**. The output of the second amplifier is connected to a mixer **56**. An RF oscillator **58** also provides an output to the mixer. The output of the mixer is connected to the input of a third amplifier **60**. The output of the third amplifier is connected to a bandpass filter **62** and the output of the bandpass filter is connected to a diode detector **64**. An output of the diode detector is connected to an input of the lock-in amplifier **48** and the output of the lock-in amplifier is then provided to a data acquisition computer **66**. In several embodiments, the data acquisition computer includes a speaker. Although the illustrated embodiment uses a lock-in amplifier, the lock-in amplifier may not be necessary as can be seen from the embodiments as discussed below.

[0030] In many embodiments, the RF components of sound detection systems in accordance with the present invention can be fabricated using MMIC technology. Such circuits could cover an area at least as small as several square inches. The RF circuitry can be combined with digital signal processing boards or field programmable gate arrays to perform signal processing functions. The antenna can be constructed using a planar integrated-circuit antenna, such as a microstrip patch array. In one embodiment, an antenna designed for use with a 30 GHz RF signal can be constructed using a patch-array antenna that is approximately 4 inches on a side. Such an antenna can produce a transmitted beam approximately 3 feet wide at a distance of 26 feet. A 3-foot wide beam is typically sufficient to localize a single person or a convenient adjacent reflecting surface. If localization is not an issue, then a similarly small antenna system can be useful up to tens of meters. For situations where the antenna size is not important, a larger array can be used. The effective range of a beam scales approximately with the antenna size and transmitted power. In addition, use of higher frequencies allows for reduced antenna size. Higher frequencies, typically, do not penetrate barriers as effectively as lower frequencies. Reflected signals can be very weak, but microwave amplifiers can be designed and built with a noise level of only 0.1 pW for a 20 MHz bandwidth. Thus a transmitted signal of 100 mW can be attenuated on the round trip path by up to 120 dB before the signal-to-noise ratio drops to 1. Using frequencies near 100 GHz, would provide a narrow-beam, ≈1° wide, for an antenna with only a 4-inch aperture.

[0031] An embodiment of a sound detection system in accordance with the present invention configured to detect vibrations of an aluminum foil is shown in **FIG. 3**. In the illustrated configurations, the sound detection system **10**" is positioned a distance of approximately 1 foot from an aluminum foil **80**. A speaker **82** is positioned on the other side of the foil and directs sound pressure waves at the foil. The speaker is capable of generating sound because it is connected to a radio **84**. The sound detection system **10**" can detect movement of the foil by directing an RF beam at the foil.

[0032] In the illustrated embodiment, the sound detection system **10**" includes an RF synthesizer **40**' connected to an antenna **50**' via a directional coupler **52**'. The directional coupler is also connected to a low noise amplifier **54**', which in this instance is implemented using MMIC technology. The output of the low noise amplifier is provided to a harmonic mixer **56**', which is connected to an RF oscillator **58**' and a second amplifier **60**'. An output from the second amplifier is provided to a narrow band filter **62**', which in turn provides an output to a diode detector **64**'. The diode detector is connected to a sampling scope **86**, which is connected to a data acquisition computer **66**'. In one embodiment, the RF beam generated by the sound detection system is a monochromatic, has a frequency of 18 GHz and a amplitude that is unmodulated. The sound detection system **10**" observes reflections of the RF beam from the aluminum foil using the antenna **50** and the signal is processed in accordance with the description above. In several embodiments, the power of the RF beam can be of the order of several milliwatts. The reflected signal can be fed to the low-noise 18 GHz amplifier **54**'. The signal can then be heterodyned down to 1 GHz and bandpass filtered to 2 MHz to reduce the overall system noise. The detected signal can then be displayed on the sampling scope **86** or simply digitized and stored on a computer. Simultaneously, the audio signal from the radio can also be digitized and stored for comparison with the microwave response.

[0033] A graph showing the amplitude of audio signal incident on the aluminum foil shown in **FIG. 3** is illustrated in **FIG. 4A**. The graph **100** charts **102** the signal amplitude as a function of time. The signal itself was generated by tuning the radio **84** shown in **FIG. 3** to a talk radio station.

[0034] A graph showing the output of the sound detection system illustrated in **FIG. 3**, when the audio signal shown in **FIG. 4A** is incident on the aluminum foil **80** shown in **FIG. 3**, is illustrated in **FIG. 4B**. The graph **104** charts **106** the output obtained by the sound detection system in accordance with the process described above against time.

[0035] As discussed above, embodiments of sound detection systems in accordance with the present invention can detect sounds through barriers. In one instance, a plywood barrier having a thickness of 0.75 inches was interposed between the sound detection device **10**" and the aluminum barrier **80** shown in **FIG. 3**. A graph **108** charting **110** the audio signal incident on the barrier is shown in **FIG. 4C**. A graph **112** charting **114** the output generated by the sound detection system in accordance with the processes of the present invention, when the RF beam generated by the sound detection system must pass through the plywood barrier described above, is shown in **FIG. 4D**. The microwave beam can penetrate the plywood barrier **80** and be modulated by the vibrations of the foil caused by the audio signal pressure waves.

[0036] An embodiment of a sound detection system in accordance with the present invention that includes separate antennas for illuminating a subject and for receiving reflections is illustrated in **FIG. 5**. The remote detection system **10**'" is similar to the embodiment illustrated in **FIG. 1**, except that a first antenna **180** is used to generate an electromagnetic signal beam and a second antenna **182** is used to detect the reflected electromagnetic signal beam.

[0037] While the above description contains many specific embodiments of the invention, these should not be construed as limitations on the scope of the invention, but rather as an example of one embodiment thereof. Many other variations are possible, including implementing sound detections systems in accordance with the present invention using planar antennas and MMIC manufacturing techniques. In addition, vibrations of objects associated with pressure wave other than sound pressure waves can be monitored. Accordingly, the scope of the invention should be determined not by the embodiments illustrated, but by the appended claims and their equivalents.

What is claimed is:

1. A device for detecting audible sound, comprising:

an RF transmitter configured to generate an RF signal having a frequency of at least 100 MHz and an unmodulated amplitude;

an RF receiver configured to receive a reflected RF signal comprising an RF carrier having the same frequency as the generated RF signal that is amplitude modulated by an information signal; and

a signal processor configured to extract audio frequency information from the amplitude of the reflected RF signal.

2. The device of claim 1, wherein the RF transmitter comprises an RF synthesizer coupled to an antenna.

3. The device of claim 2, wherein the antenna is a planar antenna.

4. The device of claim 2, wherein the antenna is a waveguide horn antenna.

5. The device of claim 1, wherein the RF receiver comprises:

an antenna;

a low noise amplifier coupled to the antenna;

a harmonic mixer connected to an output of the low noise amplifier and to an RF oscillator;

a second amplifier connected to an output of the harmonic mixer;

a narrow bandpass filter connected to an output of the second amplifier; and a diode detector connected to an output of the narrow bandpass filter.

6. The device of claim 5, wherein the antenna is a planar antenna.

7. The device of claim 5, wherein the antenna is a waveguide horn antenna.

8. The device of claim 5, wherein the low noise amplifier is implemented using MMIC.

9. The device of claim 1, wherein the signal processor includes an audio speaker.

10. The device of claim 1, wherein the RF signal has a frequency in the range of 100 MHz to 200 GHz.

11. The device of claim 1, wherein the RF signal has a frequency in the range of 1 GHz to 100 GHz.

12. The device of claim 1, wherein the RF signal has a frequency in the range of 10 GHz to 100 GHz.

13. A method of reproducing an audible sound, comprising:

illuminating an object with a generated RF signal having a frequency of at least 100 MHz and having an unmodulated amplitude;

extracting amplitude modulated information from reflections of the generated RF signal;

isolating the portions of the extracted information corresponding to audio frequencies; and

generating audio using the isolated portions of the extracted information.

14. The device of claim 13, wherein the RF signal has a frequency in the range of 100 MHz to 200 GHz.

15. The device of claim 13, wherein the RF signal has a frequency in the range of 1 GHz to 100 GHz.

16. The device of claim 13, wherein the RF signal has a frequency in the range of 10 GHz to 100 GHz.

17. A system for determining the frequency with which an object vibrates, comprising:

means for generating an RF signal having a frequency of at least 100 MHz;

means for receiving reflections of the RF signal reflected by the object; and

means for demodulating the received RF signal to extract a signal indicative of the frequency with which the object is vibrating.

18. The system of claim 17, further comprising means for generating an audio signal indicative of the audio frequency components of the extracted signal.

* * * * *