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(54) **Artificial magnetic mirror cell and applications thereof**

(57) An artificial magnetic mirror (AMM) cell includes a conductive element and an impedance element. The conductive element forms a lumped resistor-inductor-capacitor (RLC) circuit. The impedance element is coupled to the conductive element. The impedance of the impedance element and the impedance of the RLC circuit es-

tablish an electromagnetic property for the AMM cell within a given frequency range that contributes to the AMC. The AMM cell along with other AMM cells collectively produce an artificial magnetic conductor (AMC) having a geometric shape for an electromagnetic signal in the given frequency range.

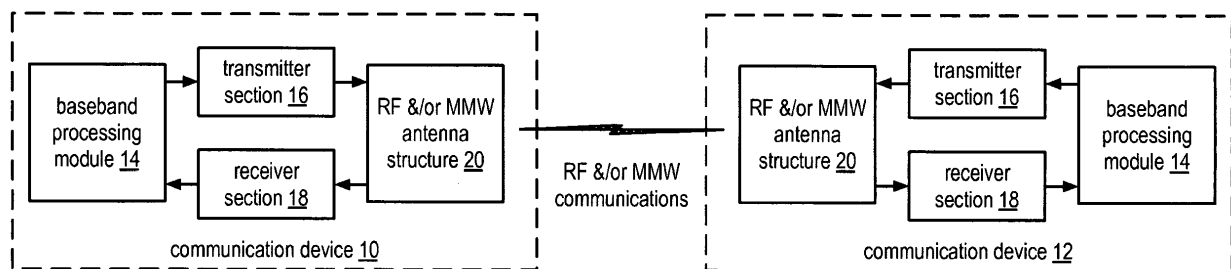


FIG. 1

Description**CROSS REFERENCE TO RELATED PATENTS**

[0001] This patent application is claiming priority under 35 USC§ 119(e) to a provisionally filed patent application entitled PROGRAMMABLE SUBSTRATE AND PROJECTED ARTIFICIAL MAGNETIC CONDUCTOR, having a provisional filing date of 03/22/2012, and a provisional serial number of 61/614,066 (Attorney Docket # BP24568), which is incorporated by reference herein.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT-NOT APPLICABLE**INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ON A COMPACT DISC -NOT APPLICABLE****BACKGROUND OF THE INVENTION****TECHNICAL FIELD OF THE INVENTION**

[0002] This invention relates generally to electromagnetism and more particularly to electromagnetic circuitry.

DESCRIPTION OF RELATED ART

[0003] Artificial magnetic conductors (AMC) are known to suppress surface wave currents over a set of frequencies at the surface of the AMC. As such, an AMC may be used as a ground plane for an antenna or as a frequency selective surface band gap.

[0004] An AMC may be implemented by metal squares of a given size and at a given spacing on a layer of a substrate. A ground plane is on another layer of the substrate. Each of the metal squares is coupled to the ground plane such that, a combination of the metal squares, the connections, the ground plane, and the substrate, produces a resistor-inductor-capacitor (RLC) circuit that produces the AMC on the same layer as the metal squares within a set of frequencies.

BRIEF SUMMARY OF THE INVENTION

[0005] According to an aspect, a projected artificial magnetic mirror (PAMM) comprises:

a plurality of artificial magnetic mirror (AMM) cells that collectively produce an artificial magnetic conductor (AMC) having a geometric shape a distance from a surface of the PAMM for an electromagnetic signal in a given frequency range, wherein an AMM cell of the plurality of AMM cells includes:

a conductive element forming a lumped resistor-inductor-capacitor (RLC) circuit; and

an impedance element coupled to the conductive element, wherein an impedance of the impedance element and an impedance of the RLC circuit establish an electromagnetic property for the AMM cell within the given frequency range that contributes to the AMC.

[0006] Advantageously, the conductive element comprises:

a coil on a surface of a substrate, wherein a first end of the coil is coupled to a ground and a second end of the coil is coupled the impedance element, wherein a shape of the coil effects the electromagnetic property of the AMM cell.

[0007] Advantageously, the PAMM further comprises one of:

the conductive element coupled in series with the impedance element; and

the conductive element coupled in parallel with the impedance element.

[0008] Advantageously, the impedance element comprises:

a variable impedance circuit.

[0009] Advantageously, the variable impedance circuit comprises:

a negative resistor.

[0010] Advantageously, the variable impedance circuit comprises:

a varactor.

[0011] Advantageously, the variable impedance circuit comprises:

passive components, wherein at least one of the passive components is adjustable.

[0012] According to an aspect, an artificial magnetic mirror (AMM) cell comprises:

a conductive element forming a lumped resistor-inductor-capacitor (RLC) circuit; and

an impedance element coupled to the conductive element, wherein an impedance of the impedance element and an impedance of the RLC circuit establish an electromagnetic property for the AMM cell within a given frequency range.

[0013] Advantageously, the conductive element comprises:

a coil on a surface of a substrate, wherein a first end of the coil is coupled to a ground and a second end of the coil is coupled the impedance element, wherein a shape of the coil effects the electromagnetic property of the AMM cell.

[0014] Advantageously, the AMM cell further comprises one of:

the conductive element coupled in series with the impedance element; and
the conductive element coupled in parallel with the impedance element.

[0015] Advantageously, the impedance element comprises:

a variable impedance circuit.

[0016] Advantageously, the variable impedance circuit comprises:

a negative resistor.

[0017] Advantageously, the variable impedance circuit comprises:

a varactor.

[0018] Advantageously, the variable impedance circuit comprises:

passive components, wherein at least one of the passive components is adjustable.

[0019] According to an aspect, an artificial magnetic mirror (AMM) cell comprises:

a coil on a first layer of substrate;

a variable impedance circuit coupled to coil, wherein the variable impedance circuit establishes an impedance in accordance with a control signal; and

a ground plane on a second layer of the substrate, wherein an electromagnetic property of the AMM cell within a given frequency range are based on characteristics of the coil and the impedance of the variable impedance circuit.

[0020] Advantageously, the coil comprises:

a concentric spiral.

[0021] Advantageously, the coil comprises:

an eccentric spiral.

[0022] Advantageously, the variable impedance circuit comprises one of:

a negative resistor;

a varactor; and

passive components, wherein at least one of the passive components is adjustable.

[0023] Advantageously, the AMM cell further comprises:

a first end of the coil coupled to the ground plane;

a second end of the coil coupled to a first end of the variable impedance circuit; and

a second end of the variable impedance circuit coupled to the ground plane.

[0024] Advantageously, the AMM cell further comprises:

the variable impedance circuit on the second surface in an opening of the ground plane.

30 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0025]

Figure 1 is a schematic block diagram of an embodiment of communication devices in accordance with the present invention;

Figure 2 is a schematic block diagram of an embodiment of an antenna structure in accordance with the present invention;

Figure 3 is a diagram of an embodiment of a tunable projected artificial magnetic mirror (PAMM) in accordance with the present invention;

Figure 4 is a schematic block diagram of an embodiment of an artificial magnetic mirror (AMM) cell in accordance with the present invention;

Figure 5 is a circuit schematic block diagram of an embodiment of an artificial magnetic mirror (AMM) cell in accordance with the present invention;

Figure 6 is a circuit schematic block diagram of another embodiment of an artificial magnetic mirror (AMM) cell in accordance with the present invention;

Figure 7 is a circuit schematic block diagram of an embodiment of an impedance element of an AMM cell in accordance with the present invention;

Figure 8 is a circuit schematic block diagram of another embodiment of an impedance element of an AMM cell in accordance with the present invention;

Figure 9 is a diagram of an example radiation pattern of an AMM cell having a concentric spiral coil in accordance with the present invention;

Figure 10 is a diagram of an example radiation pattern of an AMM cell having an eccentric spiral coil in accordance with the present invention;

Figure 11 is a circuit schematic block diagram of an embodiment of an AMM cell having a spiral coil in accordance with the present invention;

Figure 12 is a diagram of an example a projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 13 is a diagram of another example a projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 14 is a diagram of an example of adjusting orientation of a projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 15 is a diagram of an example of a plane wave resulting from a parabolic shaped projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 16 is a diagram of another example of a plane wave resulting from a parabolic shaped projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 17 is a diagram of another example of a plane wave resulting from a parabolic shaped projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 18 is a diagram of an example of a textured surface shaped projected artificial magnetic conductor (AMC) in accordance with the present invention;

Figure 19 is a schematic block diagram of another embodiment of an antenna structure in accordance with the present invention;

Figure 20 is a schematic block diagram of an embodiment of a tunable antenna structure in accordance with the present invention;

Figure 21 is a logic diagram of an embodiment of a method for tuning an antenna structure in accordance with the present invention;

Figure 22 is a schematic block diagram of an example of tuning a distance of an AMC for an antenna structure in accordance with the present invention; and

Figure 23 is a schematic block diagram of another example of tuning a distance of an AMC for an antenna structure in accordance with the present invention.

15 DETAILED DESCRIPTION OF THE INVENTION

[0026] Figure 1 is a schematic block diagram of an embodiment of communication devices 10, 12 communicating via radio frequency (RF) and/or millimeter wave (MMW) communication mediums. Each of the communication devices 10 12 includes a baseband processing module 14, a transmitter section 16, a receiver section 18, and an RF &/or MMW antenna structure 20. The RF &/or MMW antenna structure 20 will be described in greater detail with reference to one or more of Figures 2-23. Note that a communication device 10, 12 may be a cellular telephone, a wireless local area network (WLAN) client, a WLAN access point, a computer, a video game console and/or player unit, etc.

[0027] In an example of operation, one of the communication devices 10 12 has data (e.g., voice, text, audio, video, graphics, etc.) to transmit to the other communication device. In this instance, the baseband processing module 14 receives the data (e.g., outbound data) and converts it into one or more outbound symbol streams in accordance with one or more wireless communication standards (e.g., GSM, CDMA, WCDMA, HSUPA, HSDPA, WiMAX, EDGE, GPRS, IEEE 802.11, Bluetooth, ZigBee, universal mobile telecommunications system (UMTS), long term evolution (LTE), IEEE 802.16, evolution data optimized (EV-DO), etc.). Such a conversion includes one or more of: scrambling, puncturing, encoding, interleaving, constellation mapping, modulation, frequency spreading, frequency hopping, beamforming, space-time-block encoding, space-frequency-block encoding, frequency to time domain conversion, and/or digital baseband to intermediate frequency conversion. Note that the baseband processing module converts the outbound data into a single outbound symbol stream for Single Input Single Output (SISO) communications and/or for Multiple Input Single Output (MISO) communications and converts the outbound data into multiple outbound symbol streams for Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) communications.

[0028] The transmitter section 16 converts the one or more outbound symbol streams into one or more outbound RF signals that has a carrier frequency within a

given frequency band (e.g., 2.4 GHz, 5 GHz, 57- 66 GHz, etc.) . In an embodiment, this may be done by mixing the one or more outbound symbol streams with a local oscillation to produce one or more up- converted signals. One or more power amplifiers and/or power amplifier drivers amplifies the one or more up- converted signals, which may be RF bandpass filtered, to produce the one or more outbound RF signals. In another embodiment, the transmitter section 16 includes an oscillator that produces an oscillation. The outbound symbol stream (s) provides phase information (e.g., $\pm \Delta\theta$ [phase shift] and/or $\theta(t)$ [phase modulation]) that adjusts the phase of the oscillation to produce a phase adjusted RF signal (s), which is transmitted as the outbound RF signal (s) . In another embodiment, the outbound symbol stream (s) includes amplitude information (e.g., $A(t)$ [amplitude modulation]), which is used to adjust the amplitude of the phase adjusted RF signal (s) to produce the outbound RF signal (s) .

[0029] In yet another embodiment, the transmitter section 14 includes an oscillator that produces an oscillation (s). The outbound symbol stream(s) provides frequency information (e.g., $\pm \Delta f$ [frequency shift] and/or $f(t)$ [frequency modulation]) that adjusts the frequency of the oscillation to produce a frequency adjusted RF signal(s), which is transmitted as the outbound RF signal(s). In another embodiment, the outbound symbol stream(s) includes amplitude information, which is used to adjust the amplitude of the frequency adjusted RF signal(s) to produce the outbound RF signal(s). In a further embodiment, the transmitter section includes an oscillator that produces an oscillation(s). The outbound symbol stream(s) provides amplitude information (e.g., $\pm \Delta A$ [amplitude shift] and/or $A(t)$ [amplitude modulation]) that adjusts the amplitude of the oscillation(s) to produce the outbound RF signal(s).

[0030] The RF &/or MMW antenna structure 20 receives the one or more outbound RF signals and transmits it. The RF &/or MMW antenna structure 20 of the other communication devices receives the one or more RF signals and provides it to the receiver section 18.

[0031] The receiver section 18 amplifies the one or more inbound RF signals to produce one or more amplified inbound RF signals. The receiver section 18 may then mix in-phase (I) and quadrature (Q) components of the amplified inbound RF signal(s) with in-phase and quadrature components of a local oscillation(s) to produce one or more sets of a mixed I signal and a mixed Q signal. Each of the mixed I and Q signals are combined to produce one or more inbound symbol streams. In this embodiment, each of the one or more inbound symbol streams may include phase information (e.g., $\pm \Delta\theta$ [phase shift] and/or $\theta(t)$ [phase modulation]) and/or frequency information (e.g., $\pm \Delta f$ [frequency shift] and/or $f(t)$ [frequency modulation]). In another embodiment and/or in furtherance of the preceding embodiment, the inbound RF signal(s) includes amplitude information (e.g., $\pm \Delta A$ [amplitude shift] and/or $A(t)$ [amplitude modulation]).

To recover the amplitude information, the receiver section includes an amplitude detector such as an envelope detector, a low pass filter, etc.

[0032] The baseband processing module 14 converts the one or more inbound symbol streams into inbound data (e.g., voice, text, audio, video, graphics, etc.) in accordance with one or more wireless communication standards (e.g., GSM, CDMA, WCDMA, HSPA, HSDPA, WiMAX, EDGE, GPRS, IEEE 802.11, Bluetooth, ZigBee, universal mobile telecommunications system (UMTS), long term evolution (LTE), IEEE 802.16, evolution data optimized (EV-DO), etc.). Such a conversion may include one or more of: digital intermediate frequency to baseband conversion, time to frequency domain conversion, space-time-block decoding, space-frequency-block decoding, demodulation, frequency spread decoding, frequency hopping decoding, beamforming decoding, constellation demapping, deinterleaving, decoding, depuncturing, and/or descrambling. Note that the baseband processing module converts a single inbound symbol stream into the inbound data for Single Input Single Output (SISO) communications and/or for Multiple Input Single Output (MISO) communications and converts the multiple inbound symbol streams into the inbound data for Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) communications.

[0033] Figure 2 is a schematic block diagram of an embodiment of an antenna structure 20 that may be implemented on a substrate. The substrate may be a die of an integrated circuit (IC), an IC package substrate, a printed circuit board (PCB), or other structure that includes a plurality of dielectric layers, metal traces, circuits, etc. that can be implemented on one or more metal layers supported by the dielectric layers. The antenna structure 20 includes an antenna 30 (e.g., a monopole, a dipole, etc.) on one layer 24 of the substrate 22, a tunable projected artificial magnetic mirror (PAMM) 26 on another layer 24, a ground plane 28 on another layer 24, and a control module 32. The tunable PAMM 26 includes a plurality of artificial magnetic mirror (AMM) cells (not shown).

[0034] In an example of operation, the control module 32 generates control information 34 and provides it to one or more of the AMM cells of the PAMM 26. The control information 34 includes one or more control signals for tuning an electromagnetic property, or properties, (e.g., radiation pattern, polarization, gain, scatter signal phase, scatter signal magnitude, gain, etc.) of one or more of the AMM cells within a given frequency band for an electromagnetic signal. For example, the electromagnetic signal may be a radar signal in a 2 GHz frequency band, in a 60 GHz frequency band, etc. As another example, the electromagnetic signal may be a communication signal in a 900 MHz frequency band, a 1.8 MHz frequency band, a 2 GHz frequency band, a 2.4 GHz frequency band, a 5 GHz frequency band, a 29 GHz frequency band, a 60 GHz frequency band, or some other frequency band.

[0035] The tuning of one or more of the AMM cells tunes a geometric shape of an artificial magnetic con-

ductor (AMC) and/or distance of the AMC from the surface of the tunable PAMM for the electromagnetic signal. In general, the AMM cells collectively produce the AMC. By tuning electromagnetic properties of one or more of the AMM cells, the geometric shape, orientation, and/or distance of the AMC may be adjusted. For example, the geometric shape of the AMC may be one of a sphere, a partial sphere, a cylinder, a partial cylinder, a plane, a textured surface, a concaved surface, or a convex surface.

[0036] The control module 32 may determine the control information 34 in a variety of ways. For example, the control module 32 tests various electromagnetic property configurations of the AMM cells for a given signal to determine which configuration(s) provide a desired antenna response (e.g., gain, radiation pattern, polarization, etc.). As another example, the control module 32 determines the type of signal to be transmitted or received and, using a look up table, determines the control information. As yet another example, the control module 32 functions in a dynamic manner to generate the control information to adjust the AMC to adapt to changing conditions of the electromagnetic signal, the environment, etc.

[0037] Figure 3 is a diagram of an embodiment of a tunable projected artificial magnetic mirror (PAMM) 26 that includes a plurality, or array, of artificial magnetic mirror (AMM) cells 40. In one embodiment, each of the AMM cells 40 includes a conductive element (e.g., a metal trace on layer of the substrate) that is substantially of the same shape, substantially of the same pattern, and substantially of the same size as in the other cells. The shape may be circular, square, rectangular, hexagon, octagon, elliptical, etc. and the pattern may be a spiral coil, a pattern with interconnecting branches, an n^{th} order Peano curve, an n^{th} order Hilbert curve, etc. In another embodiment, the conductive elements may be of different shapes, sizes, and/or patterns.

[0038] Within an AMM cell, the conductive element may be coupled to the ground plane 28 by one or more connectors (e.g., vias). Alternatively, the conductive element of an AMM cell may be capacitively coupled to the metal backing (e.g., no vias). While not shown in this figure, a conductive element of an AMM cell is coupled to an impedance element of the AMM cell, which will be further discussed with reference to one or more subsequent figures.

[0039] The plurality of conductive elements of the AMM cells is arranged in an array (e.g., 3x5 as shown). The array may be of a different size and shape. For example, the array may be a square of n -by- n conductive elements, where n is 2 or more. As another example, the array may be a series of concentric rings of increasing size and number of conductive elements. As yet another example, the array may be of a triangular shape, hexagonal shape, octagonal shape, etc.

[0040] Figure 4 is a schematic block diagram of an embodiment of an artificial magnetic mirror (AMM) cell 50 of the plurality of AMM cells 40. The AMM cell 50 includes

a conductive element 52 and an impedance element 54, which may be fixed or variable. The conductive element is constructed of an electrically conductive material (e.g., a metal such as copper, gold, aluminum, etc.) and is of a shape (e.g., a spiral coil, a pattern with interconnecting branches, an n^{th} order Peano curve, an n^{th} order Hilbert curve, etc.) to form a lumped resistor-inductor-capacitor (RLC) circuit.

[0041] The impedance element 54 is coupled to the conductive element 52. An impedance of the impedance element 54 and an impedance of the RLC circuit establish an electromagnetic property (e.g., radiation pattern, polarization, gain, scatter signal phase, scatter signal magnitude, gain, etc.) for the AMM cell within the given frequency range, which contributes to the size, shape, orientation, and/or distance of the AMC.

[0042] Figure 5 is a circuit schematic block diagram of an embodiment of an artificial magnetic mirror (AMM) cell where the conductive element 52 is represented as a lumped RLC circuit 56. In this example, the impedance element 54 is a variable impedance circuit that is coupled in series with the RLC circuit 56. Note that in an alternate embodiment, the impedance element 54 may be a fixed impedance circuit.

[0043] Figure 6 is a circuit schematic block diagram of an embodiment of an artificial magnetic mirror (AMM) cell where the conductive element 52 is represented as a lumped RLC circuit 56. In this example, the impedance element 54 is a variable impedance circuit that is coupled in parallel with the RLC circuit 56. Note that in an alternate, the impedance element 54 may be a fixed impedance circuit.

[0044] Figure 7 is a circuit schematic block diagram of an embodiment of a variable impedance element 54 of an AMM cell implemented as a negative resistor. The negative resistor includes an operational amplifier, a pair of resistors, and a passive component impedance circuit (Z), which may include a resistor, a capacitor, and/or an inductor.

[0045] Figure 8 is a circuit schematic block diagram of another embodiment of a variable impedance element 54 of an AMM cell as a varactor. The varactor includes a transistor and a capacitor. The gate of the transistor is driven by a gate voltage (V_{gate}) and the connection of the transistor and capacitor is driven by a tuning voltage (V_{tune}). As an alternative embodiment of the variable impedance element 54, it may be implemented using passive components (e.g., resistors, capacitors, and/or inductors), where at least one of the passive components is adjustable.

[0046] Figure 9 is a diagram of an example radiation pattern of an AMM cell having a conductive element in the shape of concentric spiral coil (e.g., symmetrical about a center point). In the presence of an external electromagnetic field (e.g., a transmitted RF and/or MMW signal, reflected radar signal), the coil functions as an antenna with a radiation pattern that is normal to its x-y plane. As such, when a concentric coil is incorporated

into a projected artificial magnetic mirror (PAMM), it reflects electromagnetic energy in accordance with its radiation pattern. For example, when an electromagnetic signal is received at an angle of incidence, the concentric coil, as part of the PAMM, will reflect the signal at the corresponding angle of reflection (i.e., the angle of reflection equals the angle of incidence).

[0047] Figure 10 is a diagram of an example radiation pattern of an AMM cell having a conductive element having an eccentric spiral coil (e.g., asymmetrical about a center point). In the presence of an external electromagnetic field (e.g., a transmitted RF and/or MMW signal, or reflected radar signal), the eccentric spiral coil functions as an antenna with a radiation pattern that is offset from normal to its x-y plane. The angle of offset (e.g., θ) is based on the amount of asymmetry of the spiral coil. In general, the greater the asymmetry of the spiral coil, the greater its angle of offset will be.

[0048] When an eccentric spiral coil is incorporated into a projected artificial magnetic mirror (PAMM), it reflects electromagnetic energy in accordance with its radiation pattern. For example, when an electromagnetic signal is received at an angle of incidence, the eccentric spiral coil, as part of the PAMM, will reflect the signal at the corresponding angle of reflection plus the angle of offset (i.e., the angle of reflection equals the angle of incidence plus the angle of offset, which will asymptote parallel to the x-y plane). The properties of the coils (concentric and/or eccentric) in a PAMM can be further adjusted by adjusting the impedance of the impedance element attached thereto within an AMM cell of the PAMM.

[0049] Figure 11 is a circuit schematic block diagram of an embodiment of an AMM cell 50 that includes a spiral coil conductive element 52 (e.g., concentric or eccentric) on a surface of a substrate 22, an impedance element 54, and a ground plane 28. The impedance element 54 may be implemented on the same substrate layer as the conductive element, on the same layer as the ground plane 28 within an opening of the ground plane, or on a different layer of the substrate.

[0050] As shown, a first end of the spiral coil conductive element 52 is coupled to the ground plane 28 and a second end of the spiral coil conductive element 52 is coupled to the impedance element 54. The coupling between the spiral coil conductive element 52, the ground plane 28, and the impedance element 54 may be one or more metal traces, vias, wires, etc.

[0051] Figure 12 is a diagram of an example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 a distance (d) above its surface. The shape of the projected AMC 60 is based on the characteristics of the artificial magnetic mirror (AMM) cells of the PAMM 26, wherein the characteristics are adjustable via the control information 34. In this example, the projected AMC 60 is a plane. Alternatively, the shape of the AMC could be a sphere, a partial sphere, a cylinder, a partial cylinder, a plane, a textured surface, a concaved surface, or a convex sur-

face. Note that the AMC 60 is a surface with an electromagnetic state in which the tangential magnetic field is zero. Further note that the AMC surface has a frequency band over which surface waves and current cannot propagate, making the AMC a mirror of signals within the frequency band.

[0052] In this example, an electromagnetic signal 62 is reflected off of the AMC 60 producing a scatter field 64. If the electromagnetic properties of the AMM cells of the PAMM 26 are changed, the scatter field 64 is changed. The resulting change in the scatter field 64 corresponds to effectively changing the shape of the AMC 60.

[0053] Figure 13 is a diagram of another example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 a distance (d) above its surface. The shape of the projected AMC 60 is based on the characteristics of the artificial magnetic mirror (AMM) cells of the PAMM 26, wherein the characteristics are adjustable via the control information 34. In this example, the projected AMC 60 is a parabolic shape of $y = ax^2$. The control module 32 generates the control information 34 to tune the "a" term of the parabolic shape, thereby changing the parabolic shape of the AMC 60.

[0054] Figure 14 is a diagram of an example of a projected artificial magnetic mirror (PAMM) 26 generating an initial projected artificial magnetic conductor (AMC) 60 a distance (d) above its surface. The shape of the initial projected AMC 60 is parabolic shape. The control module 32 may adjust the orientation of the initial projected AMC 60 by adjusting the characteristics of the artificial magnetic mirror (AMM) cells of the PAMM 26. For example, the initial projected AMC 60 may be achieved by tuning the AMC cells to have a radiation pattern as shown in Figure 9 and the orientation of the projected AMC 60 may be changed by tuning at least some of the AMC cells to have a radiation pattern as shown in Figure 10.

[0055] Figure 15 is a diagram of an example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 having a parabolic shape. For a given electromagnetic signal, the parabolic AMC 60 causes a plane wave to occur at some distance from the focal point of the parabolic AMC 60. Note that a plane wave is a plane in which the rays (e.g., scatter field) of the electromagnetic signal are in phase. Further note that the control module 32 may generate the control information 34 to tune the plurality of AMM cell such that a plane wave is formed with respect to the dish shaped AMC at a desired position with respect to the dish shaped AMC.

[0056] Figure 16 is a diagram of another example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 having a parabolic shape at a shifted orientation than that of Figure 15. For a given electromagnetic signal, the parabolic AMC 60 causes a plane wave to occur at some

distance from the focal point of the parabolic AMC 60 and at an angle from the plane wave of Figure 15. Note that the control module 32 may generate the control information 34 to tune the plurality of AMM cell such that orientation of the plane wave with respect to the dish shape is changed to effectuate signal scanning. For example, the dish shaped AMC may be effectively rotated to emulate rotation a dish antenna for a radar system.

[0057] Figure 17 is a diagram of another example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 having a sphere-based shape (e.g., a sphere, a partial sphere, a cylinder, a partial cylinder, etc.). For a given electromagnetic signal, the parabolic AMC 60 causes an arced plane wave to occur at some distance from the AMC 60. Such an AMC 60 may be useful for an omnidirectional antenna or surface-to-surface omnidirectional antenna.

[0058] Figure 18 is a diagram of an example of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 having a textured surface. The textured surface may have one or more peaks and valleys.

[0059] Figure 19 is a schematic block diagram of another embodiment of a projected artificial magnetic mirror (PAMM) 26 generating a projected artificial magnetic conductor (AMC) 60 a distance (d) above its surface. The shape of the projected AMC 60 is based on the characteristics of the artificial magnetic mirror (AMM) cells of the PAMM 26, wherein the characteristics are adjustable via the control information 34. In this example, the projected AMC 60 is a plane. Alternatively, the shape of the AMC could be a sphere, a partial sphere, a cylinder, a partial cylinder, a plane, a textured surface, a concaved surface, or a convex surface.

[0060] In this example, an antenna 70 (e.g., dipole, monopole, helical, etc.) is positioned at a desired location with respect to the AMC 60. If the AMC 60 has a geometric shape of a plane, then the desired location of the antenna 70 may be in line with the plane. If the AMC 60 has a parabolic geometric shape, then the desired location of the antenna 70 may be at a focal point of the parabolic shape. If the AMC 60 has a spherical-based geometric shape, then the desired location of the antenna 70 may be at a point from a surface of the spherical-based shape.

[0061] Figure 20 is a schematic block diagram of an embodiment of a tunable antenna structure that includes a projected artificial magnetic mirror (PAMM) 26, an antenna 70, and a control module 32. In this example, the PAMM 26 is generating an initial projected artificial magnetic conductor (AMC) 60 having a parabolic shape of $y = ax^2$. The control module 32 generates the control information 34 to tune the "a" term of the parabolic shape, thereby changing the parabolic shape of the AMC 60.

[0062] The parabolic shaped AMC 60 provides an effective dish for the antenna 70. In this example, the antenna 70 is positioned at a focal point of the parabolic shaped AMC 60. In this manner, a dish antenna is

achieved using essentially flat circuitry.

[0063] Figure 21 is a logic diagram of an embodiment of a method for tuning an antenna structure that begins with the control module 32 providing control information 34 to one or more of the AMM cells of the PAMM 26, such that the PAMM 26 produces a projected AMC 60 having a partial sphere shaped dish (e.g., as shown in Figure 17). With an antenna positioned a desired location with respect to the partial sphere shaped AMC 60, the antenna structure is an omnidirectional antenna. In this manner, signals from any direction will be received with approximately the same signal strength (assuming the same transmit power and the transmitting sources (or radar reflecting sources) are about the same distance from the antenna).

[0064] The method continues by determining whether an electromagnetic signal is detected, where the electromagnetic signal may be a wireless communication device transmission or a reflected radar signal. If a signal is not detected, the method waits until one is detected. Once a signal is detected, the method continues with the control module generating control information to tune one or more AMM cells of the PAMM to produce a cylinder shaped AMC. In this instance, a cylinder shaped dish antenna is achieved, which functions well for radar systems to track motion of an object.

[0065] The method continues by determining whether the system has locked on to the electromagnetic signal (e.g., easily tracking it or it is relatively stationary). If not, the method repeats as shown. If yes, the method continues with the control module generating control information to tune one or more AMM cells of the PAMM to produce a parabolic shaped AMC. In this instance, a parabolic shaped dish antenna is achieved, which functions well for satellite communications, point-to-point microwave links, etc.

[0066] Figure 22 is a schematic block diagram of an example of an antenna structure 20 that may be implemented on a substrate. The antenna structure 20 includes an antenna 30 (e.g., a monopole, a dipole, helical, etc.) on one layer 24 of the substrate 22, a tunable projected artificial magnetic mirror (PAMM) 26 on another layer 24, a ground plane 28 on another layer 24, and a control module 32. The tunable PAMM 26 includes a plurality of artificial magnetic mirror (AMM) cells.

[0067] In an example of operation, the control module 32 generates control information 34 and provides it to one or more of the AMM cells of the PAMM 26. The control information 34 includes one or more control signals for tuning an electromagnetic property, or properties, (e.g., radiation pattern, polarization, gain, scatter signal phase, scatter signal magnitude, gain, etc.) of one or more of the AMM cells within a given frequency band for an electromagnetic signal. For example, the electromagnetic signal may be a radar signal in a 2 GHz frequency band, in a 60 GHz frequency band, etc. As another example, the electromagnetic signal may be a communication signal in a 900 MHz frequency band, a 1.8 MHz frequency

band, a 2 GHz frequency band, a 2.4 GHz frequency band, 5 GHz frequency band, a 29 GHz frequency band, a 60 GHz frequency band, or some other frequency band.

[0068] The tuning of one or more of the AMM cells tunes the distance of the artificial magnetic conductor (AMC) from the surface of the tunable PAMM for the electromagnetic signal. In general, at different frequencies, the AMC will have different distances from the surface of the PAMM 26. Accordingly, by tuning one or more AMM cells of the PAMM, the distance of the AMC can be adjusted to a desired distance (e.g., the thickness of the corresponding substrate layer, or layers).

[0069] Figure 23 is a schematic block diagram of another example of tuning a distance of an AMC for an antenna structure that is a continuation of Figure 22. In this diagram, an untuned distance for a given electromagnetic signal is a distance above the layer on which the antenna 30 lies. Knowing, or determining, the frequency of the signal, the control module 32 can generate control information 34 to adjust the distance of the AMC to a desired distance (e.g., at the surface of the layer on which the antenna 30 lies).

[0070] As may be used herein, the terms "substantially" and "approximately" provides an industry-accepted tolerance for its corresponding term and/or relativity between items. Such an industry-accepted tolerance ranges from less than one percent to fifty percent and corresponds to, but is not limited to, component values, integrated circuit process variations, temperature variations, rise and fall times, and/or thermal noise. Such relativity between items ranges from a difference of a few percent to magnitude differences. As may also be used herein, the term(s) "operably coupled to", "coupled to", and/or "coupling" includes direct coupling between items and/or indirect coupling between items via an intervening item (e.g., an item includes, but is not limited to, a component, an element, a circuit, and/or a module) where, for indirect coupling, the intervening item does not modify the information of a signal but may adjust its current level, voltage level, and/or power level. As may further be used herein, inferred coupling (i.e., where one element is coupled to another element by inference) includes direct and indirect coupling between two items in the same manner as "coupled to". As may even further be used herein, the term "operable to" or "operably coupled to" indicates that an item includes one or more of power connections, input(s), output(s), etc., to perform, when activated, one or more its corresponding functions and may further include inferred coupling to one or more other items. As may still further be used herein, the term "associated with", includes direct and/or indirect coupling of separate items and/or one item being embedded within another item. As may be used herein, the term "compares favorably", indicates that a comparison between two or more items, signals, etc., provides a desired relationship. For example, when the desired relationship is that signal 1 has a greater magnitude than signal 2, a favorable comparison may be achieved when the magnitude of signal 1 is great-

er than that of signal 2 or when the magnitude of signal 2 is less than that of signal 1.

[0071] As may also be used herein, the terms "processing module", "processing circuit", and/or "processing unit" may be a single processing device or a plurality of processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on hard coding of the circuitry and/or operational instructions. The processing module, module, processing circuit, and/or processing unit may be, or further include, memory and/or an integrated memory element, which may be a single memory device, a plurality of memory devices, and/or embedded circuitry of another processing module, module, processing circuit, and/or processing unit. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. Note that if the processing module, module, processing circuit, and/or processing unit includes more than one processing device, the processing devices may be centrally located (e.g., directly coupled together via a wired and/or wireless bus structure) or may be distributedly located (e.g., cloud computing via indirect coupling via a local area network and/or a wide area network). Further note that if the processing module, module, processing circuit, and/or processing unit implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory and/or memory element storing the corresponding operational instructions may be embedded within, or external to, the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry. Still further note that, the memory element may store, and the processing module, module, processing circuit, and/or processing unit executes, hard coded and/or operational instructions corresponding to at least some of the steps and/or functions illustrated in one or more of the Figures. Such a memory device or memory element can be included in an article of manufacture.

[0072] The present invention has been described above with the aid of method steps illustrating the performance of specified functions and relationships thereof. The boundaries and sequence of these functional building blocks and method steps have been arbitrarily defined herein for convenience of description. Alternate boundaries and sequences can be defined so long as the specified functions and relationships are appropriately performed. Any such alternate boundaries or sequences are thus within the scope and spirit of the claimed invention. Further, the boundaries of these functional building blocks have been arbitrarily defined for convenience of description. Alternate boundaries could be de-

defined as long as the certain significant functions are appropriately performed. Similarly, flow diagram blocks may also have been arbitrarily defined herein to illustrate certain significant functionality. To the extent used, the flow diagram block boundaries and sequence could have been defined otherwise and still perform the certain significant functionality. Such alternate definitions of both functional building blocks and flow diagram blocks and sequences are thus within the scope and spirit of the claimed invention. One of average skill in the art will also recognize that the functional building blocks, and other illustrative blocks, modules and components herein, can be implemented as illustrated or by discrete components, application specific integrated circuits, processors executing appropriate software and the like or any combination thereof.

[0073] The present invention may have also been described, at least in part, in terms of one or more embodiments. An embodiment of the present invention is used herein to illustrate the present invention, an aspect thereof, a feature thereof, a concept thereof, and/or an example thereof. A physical embodiment of an apparatus, an article of manufacture, a machine, and/or of a process that embodies the present invention may include one or more of the aspects, features, concepts, examples, etc. described with reference to one or more of the embodiments discussed herein. Further, from figure to figure, the embodiments may incorporate the same or similarly named functions, steps, modules, etc. that may use the same or different reference numbers and, as such, the functions, steps, modules, etc. may be the same or similar functions, steps, modules, etc. or different ones.

[0074] While the transistors in the above described figure(s) is/are shown as field effect transistors (FETs), as one of ordinary skill in the art will appreciate, the transistors may be implemented using any type of transistor structure including, but not limited to, bipolar, metal oxide semiconductor field effect transistors (MOSFET), N-well transistors, P-well transistors, enhancement mode, depletion mode, and zero voltage threshold (VT) transistors.

[0075] Unless specifically stated to the contra, signals to, from, and/or between elements in a figure of any of the figures presented herein may be analog or digital, continuous time or discrete time, and single-ended or differential. For instance, if a signal path is shown as a single-ended path, it also represents a differential signal path. Similarly, if a signal path is shown as a differential path, it also represents a single-ended signal path. While one or more particular architectures are described herein, other architectures can likewise be implemented that use one or more data buses not expressly shown, direct connectivity between elements, and/or indirect coupling between other elements as recognized by one of average skill in the art.

[0076] The term "module" is used in the description of the various embodiments of the present invention. A module includes a processing module, a functional block,

hardware, and/or software stored on memory for performing one or more functions as may be described herein. Note that, if the module is implemented via hardware, the hardware may operate independently and/or in conjunction software and/or firmware. As used herein, a module may contain one or more sub-modules, each of which may be one or more modules.

[0077] While particular combinations of various functions and features of the present invention have been expressly described herein, other combinations of these features and functions are likewise possible. The present invention is not limited by the particular examples disclosed herein and expressly incorporates these other combinations.

Claims

1. An artificial magnetic mirror (AMM) cell comprises:
 - a conductive element forming a lumped resistor-inductor-capacitor (RLC) circuit; and
 - an impedance element coupled to the conductive element, wherein an impedance of the impedance element and an impedance of the RLC circuit establish an electromagnetic property for the AMM cell within a given frequency range.
2. The AMM cell of claim 1, wherein the conductive element comprises:
 - a coil on a surface of a substrate.
3. The AMM cell of claim 2, wherein a first end of the coil is coupled to a ground and a second end of the coil is coupled the impedance element, wherein a shape of the coil effects the electromagnetic property of the AMM cell.
4. The AMM cell of any of claims 1 to 3 further comprising:
 - the conductive element coupled in series with the impedance element.
5. The AMM cell of any of claims 1 to 3 further comprising:
 - the conductive element coupled in parallel with the impedance element.
6. The AMM cell of any of claims 1 to 5, wherein the impedance element comprises:
 - a variable impedance circuit.
7. The AMM cell of claim 6, wherein the variable impedance circuit comprises:

a negative resistor.

8. The AMM cell of claim 6 or 7, wherein the variable impedance circuit comprises:

5

a varactor.

9. The AMM cell of any of claims 6 to 8, wherein the variable impedance circuit comprises:

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passive components, wherein at least one of the passive components is adjustable.

10. A projected artificial magnetic mirror (PAMM), comprising at least one AMM cell according to any of claims 1 to 9. 15

11. The projected artificial magnetic mirror (PAMM) of claim 10, comprising a plurality of AMM cells according to any of claims 1 to 9. 20

12. The projected artificial magnetic mirror (PAMM) of claim 11, wherein the plurality of artificial magnetic mirror (AMM) cells collectively produce an artificial magnetic conductor (AMC) having a geometric shape a distance from a surface of the PAMM for an electromagnetic signal in a given frequency range. 25

13. The projected artificial magnetic mirror (PAMM) of claim 12, wherein the impedance of the impedance element and the impedance of the RLC circuit establish an electromagnetic property within the given frequency range that contributes to the AMC. 30

14. An artificial magnetic mirror (AMM) cell comprises: 35

a coil on a first layer of substrate;
a variable impedance circuit coupled to coil,
wherein the variable impedance circuit establishes an impedance in accordance with a control signal; and 40
a ground plane on a second layer of the substrate, wherein an electromagnetic property of the AMM cell within a given frequency range are based on characteristics of the coil and the impedance of the variable impedance circuit. 45

15. The AMM cell of claim 14, wherein the coil comprises:

50

a concentric spiral.

55

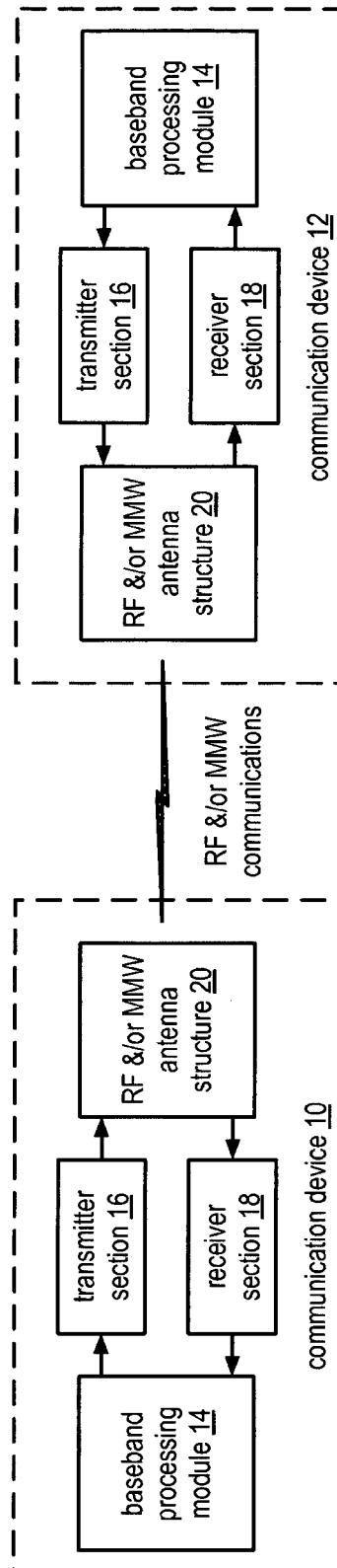


FIG. 1

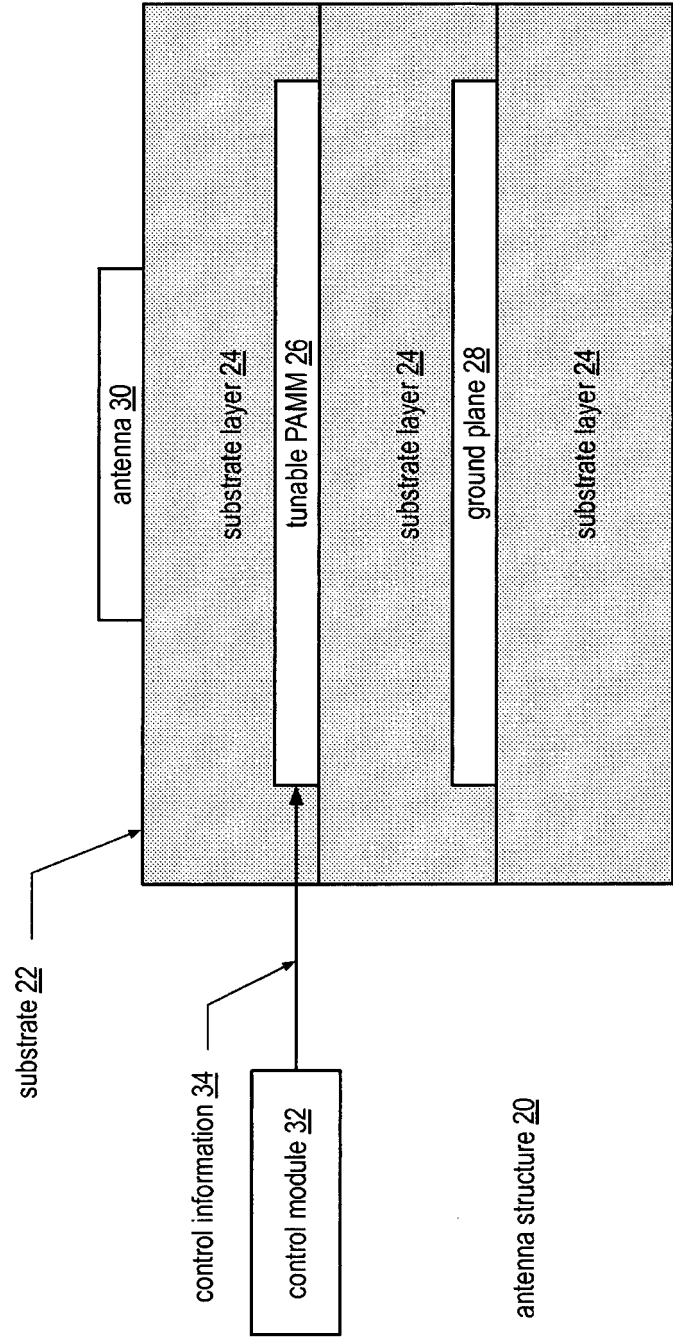


FIG. 2

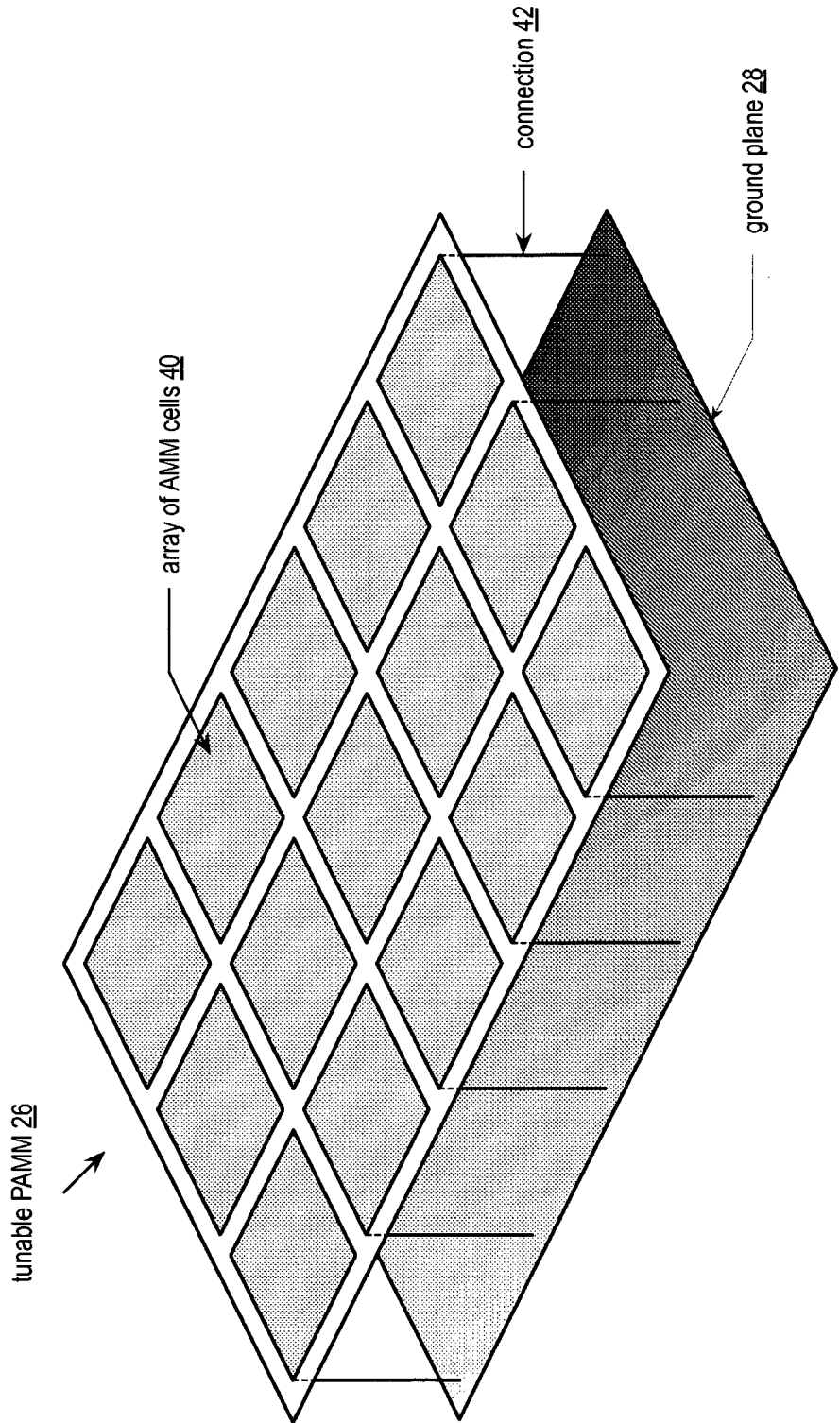


FIG. 3

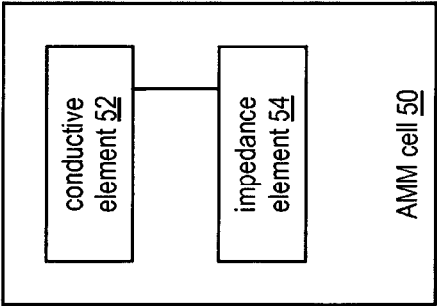


FIG. 4

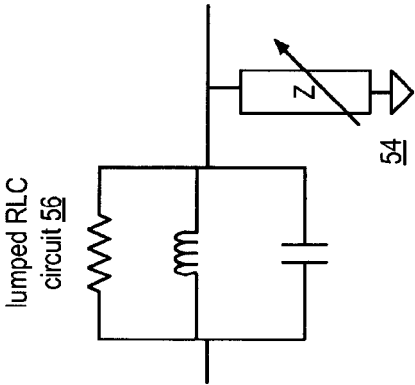


FIG. 5

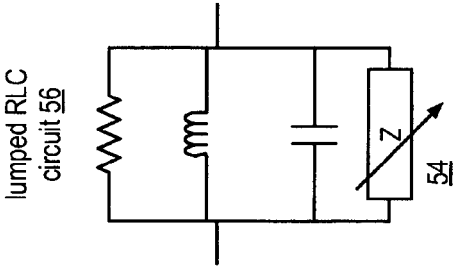


FIG. 6

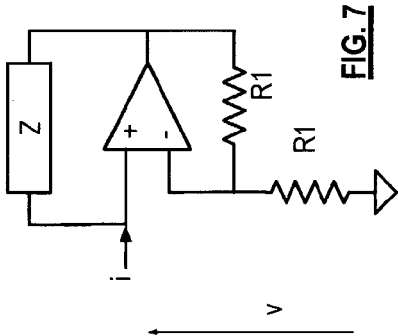


FIG. 7

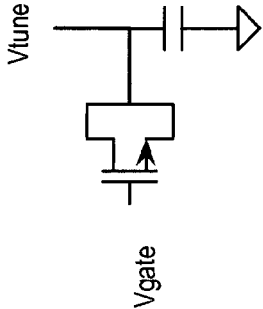


FIG. 8

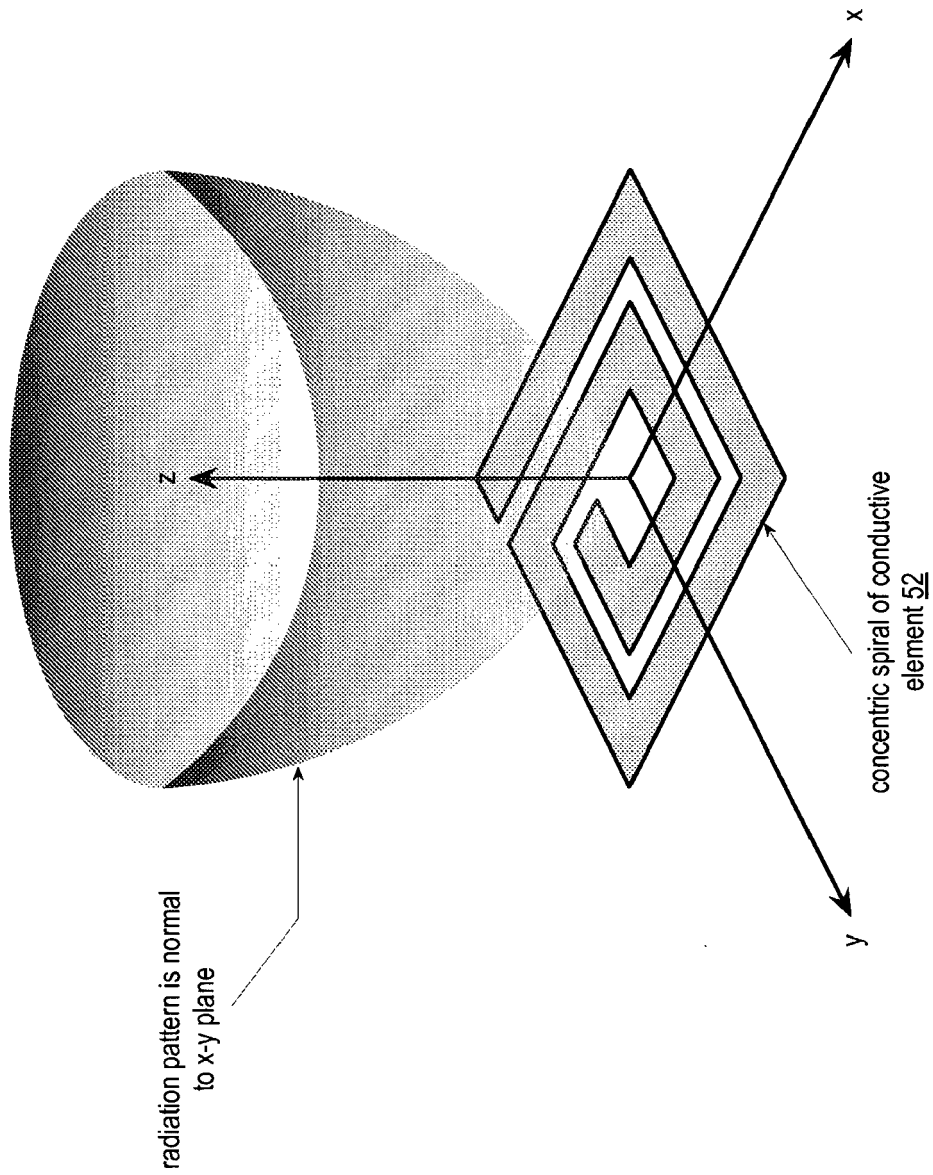


FIG. 9

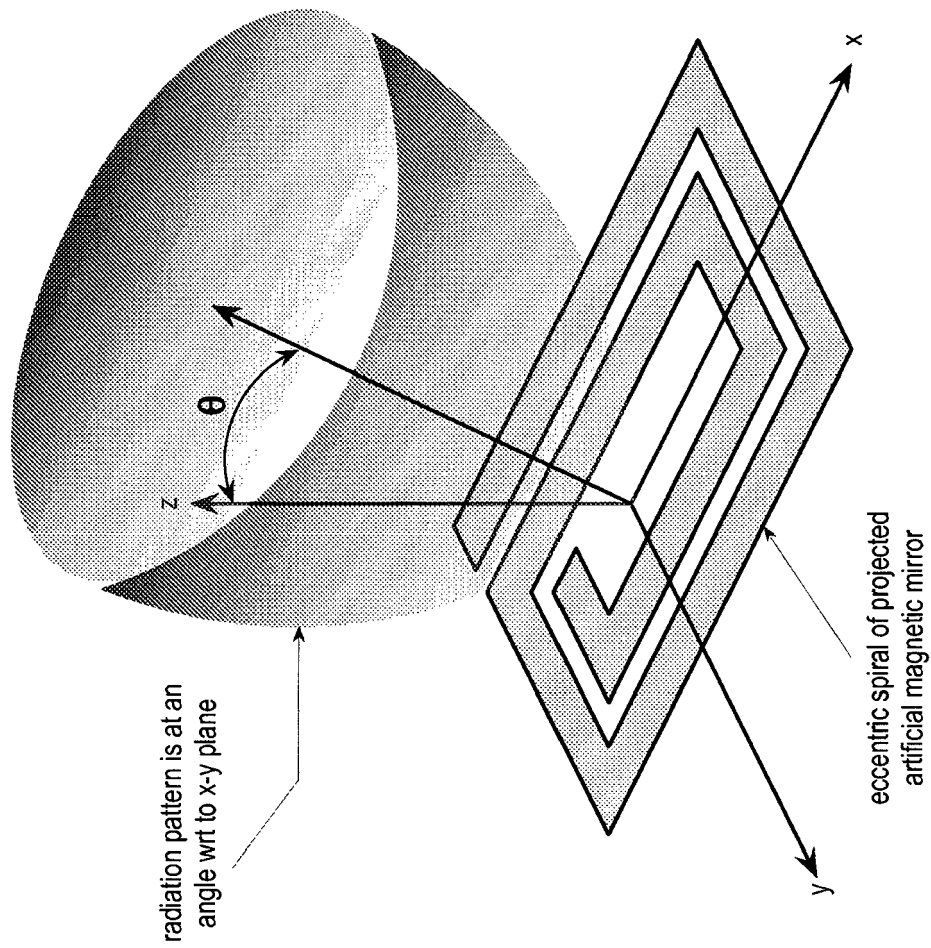


FIG. 10

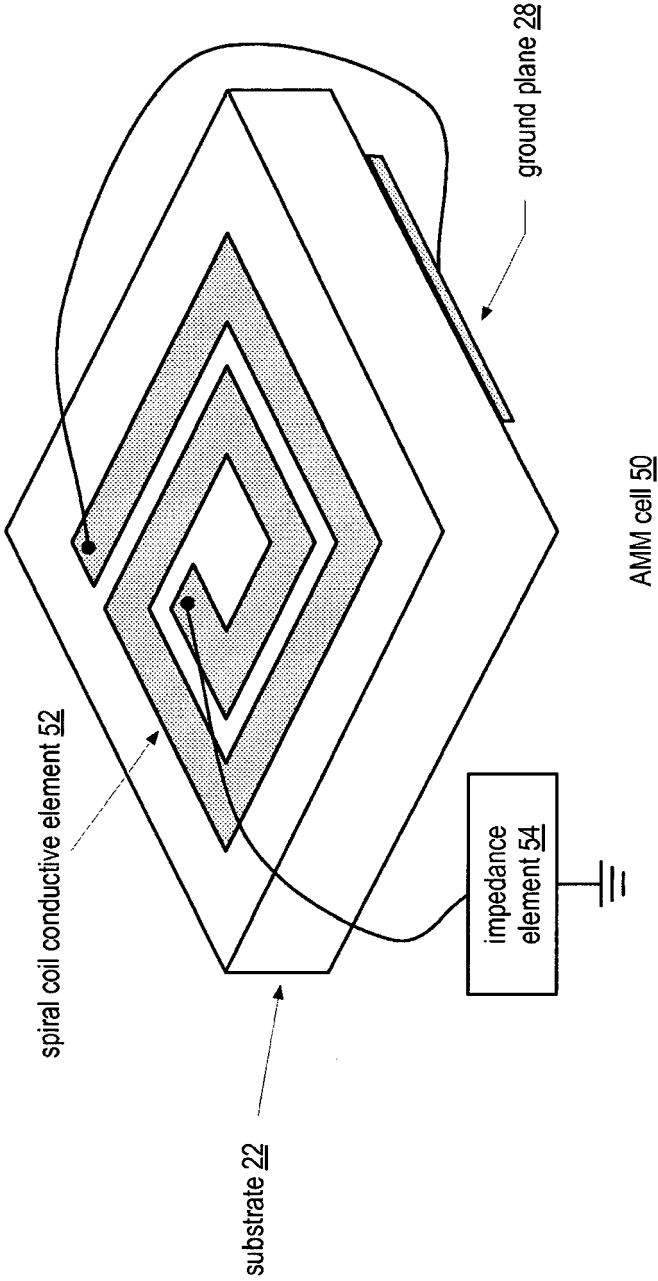


FIG. 11

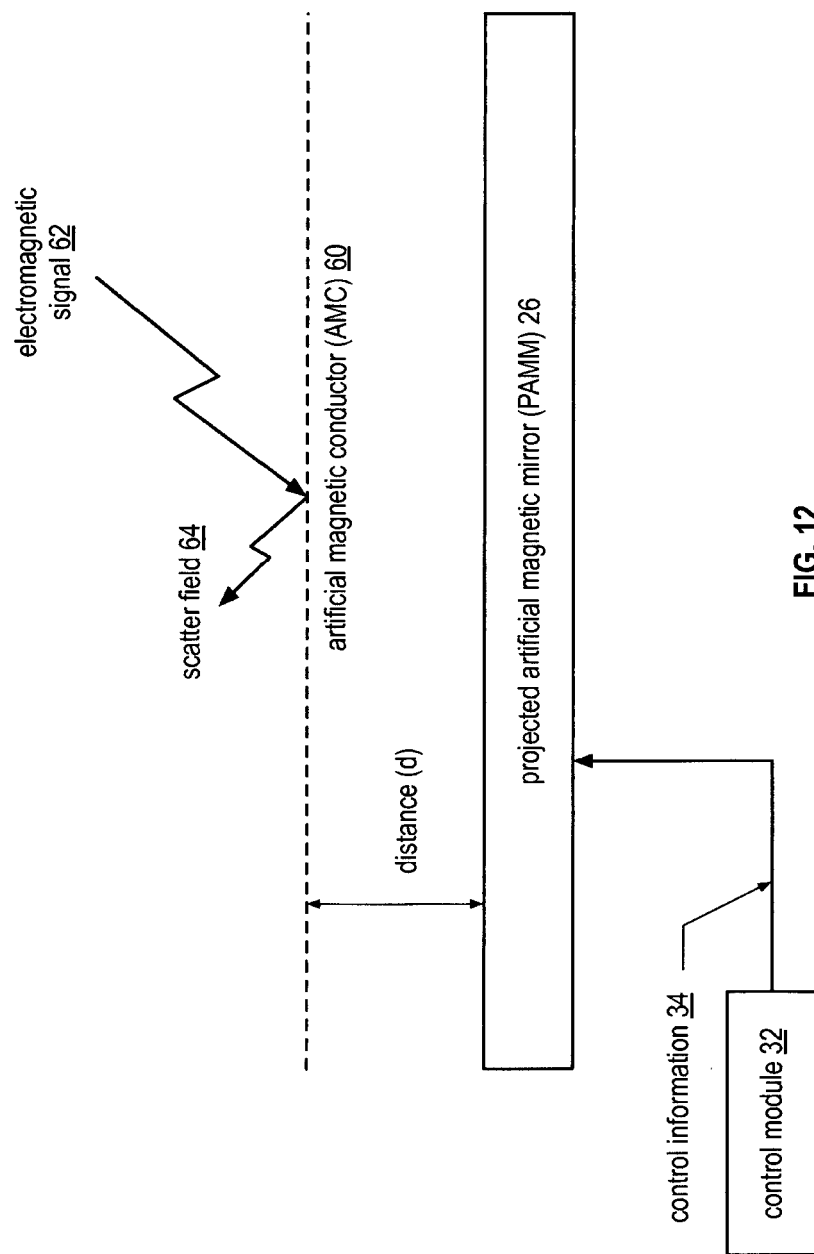


FIG. 12

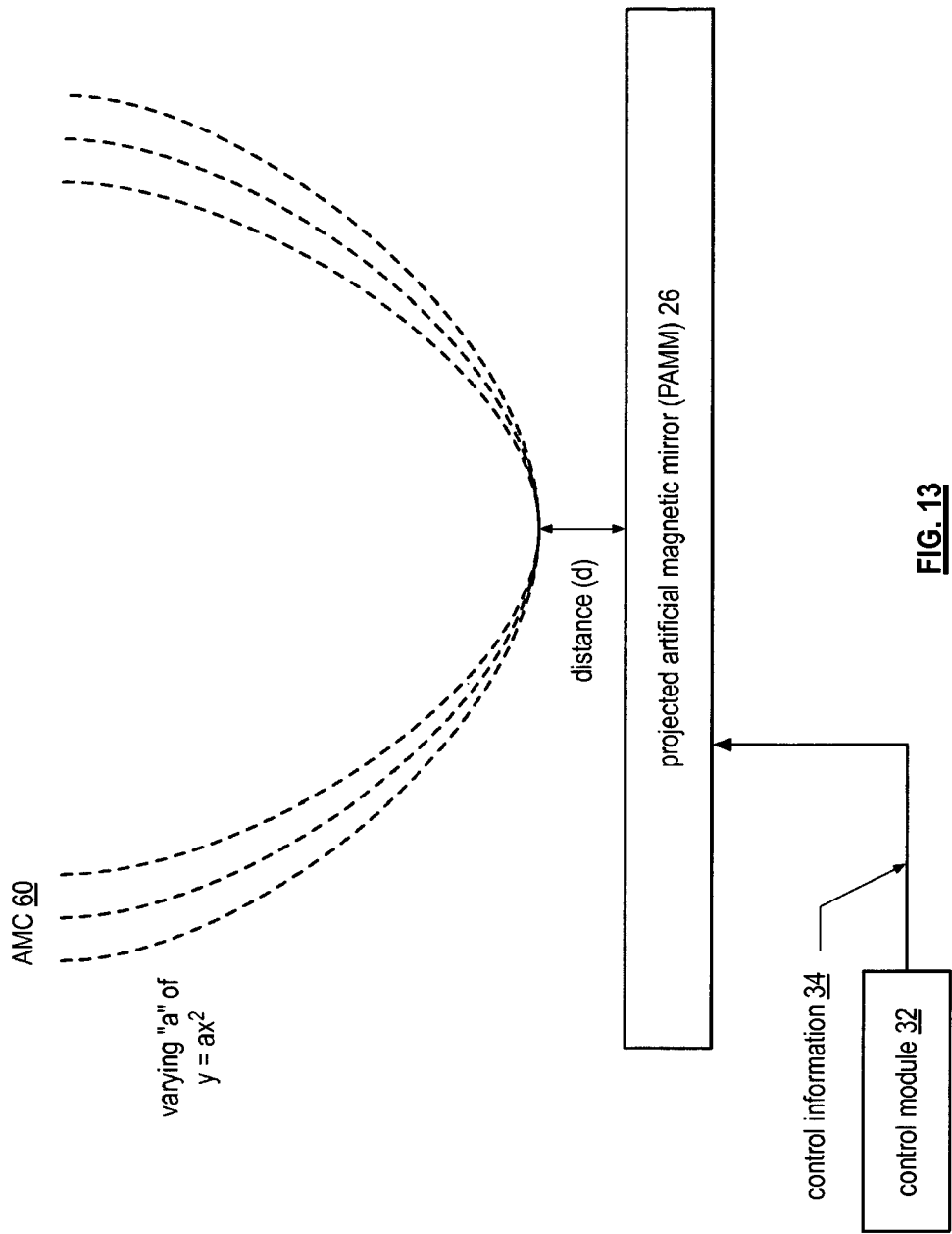


FIG. 13

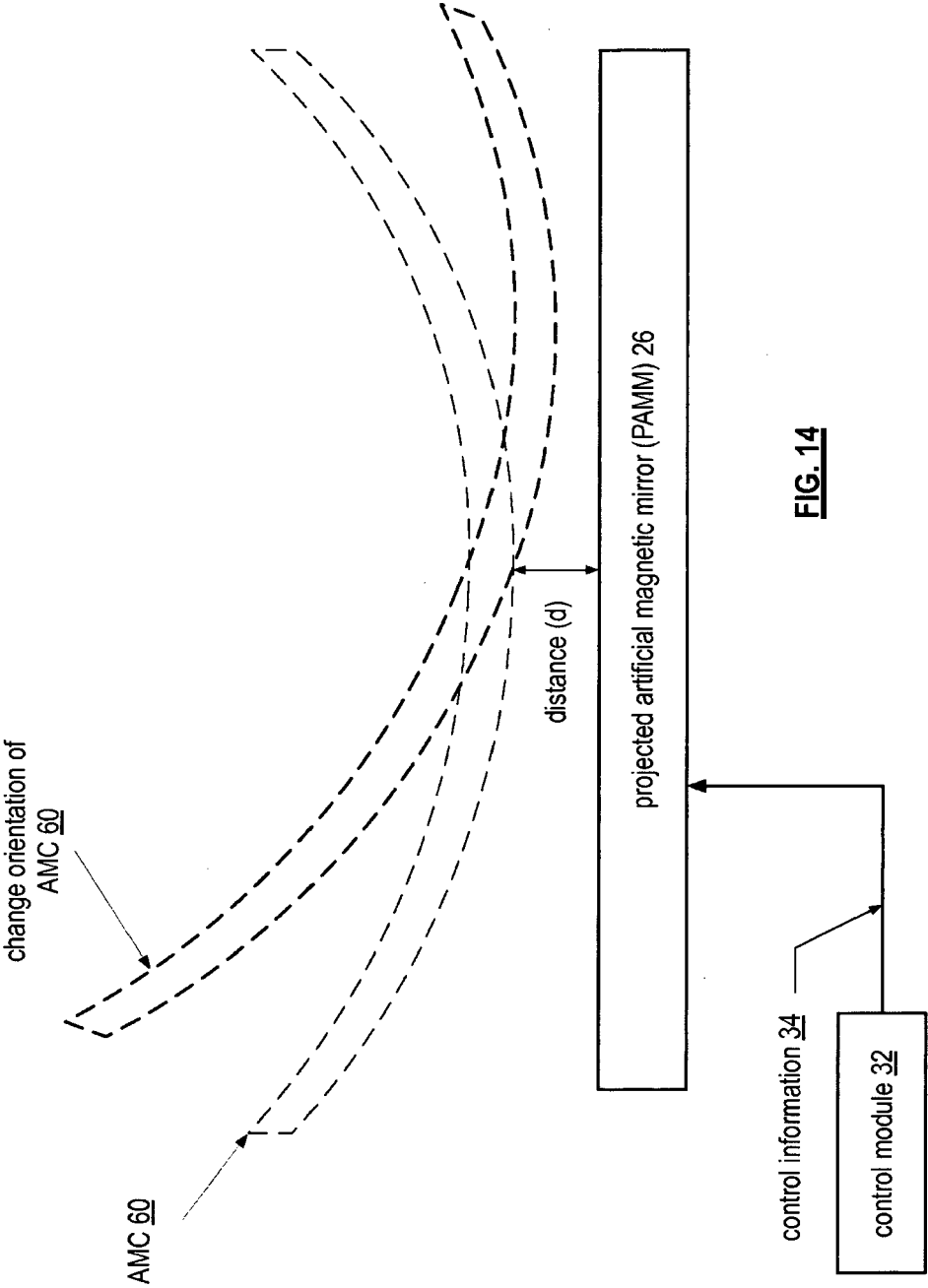


FIG. 14

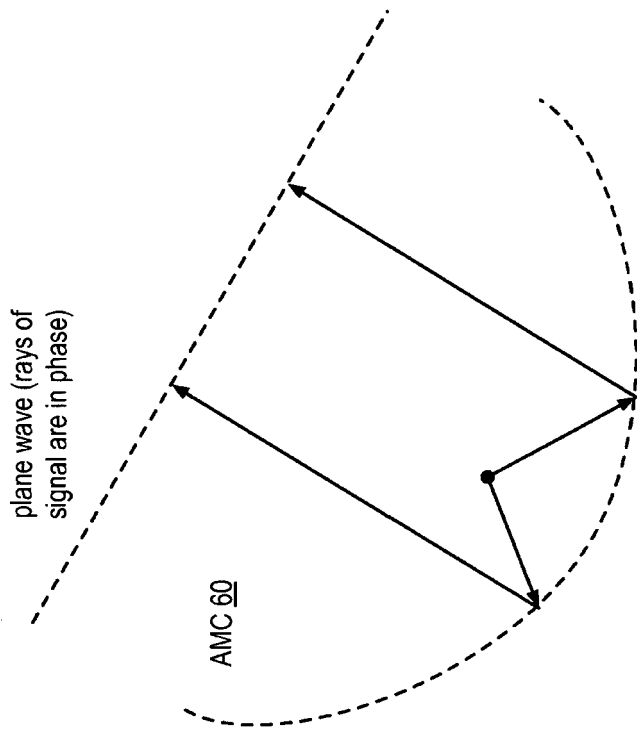
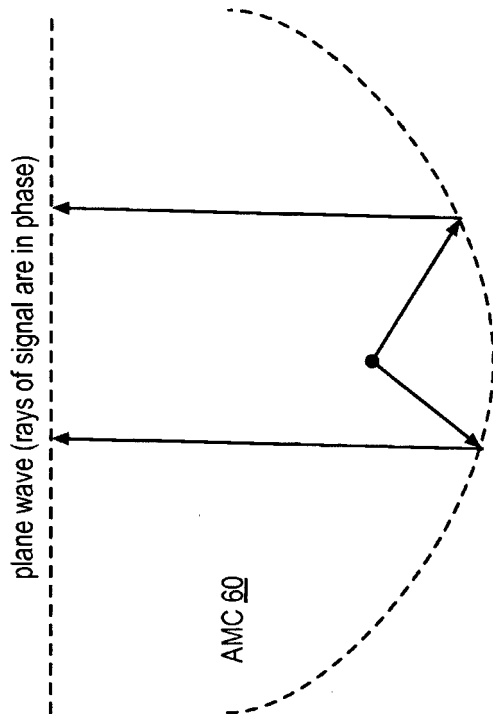
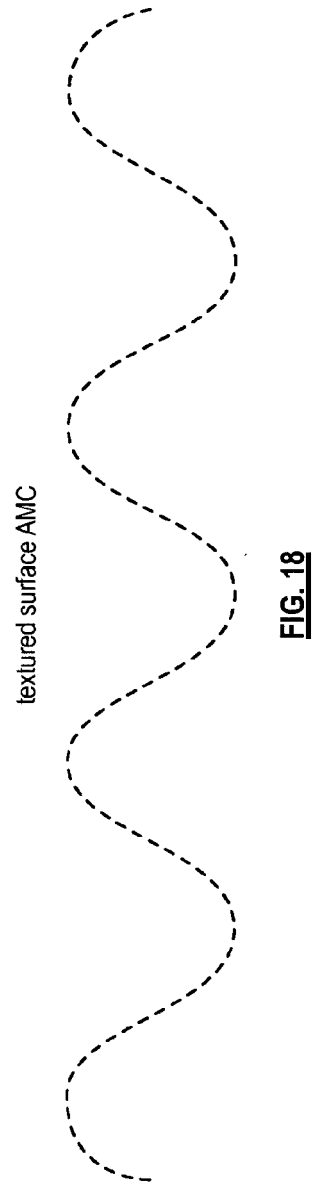
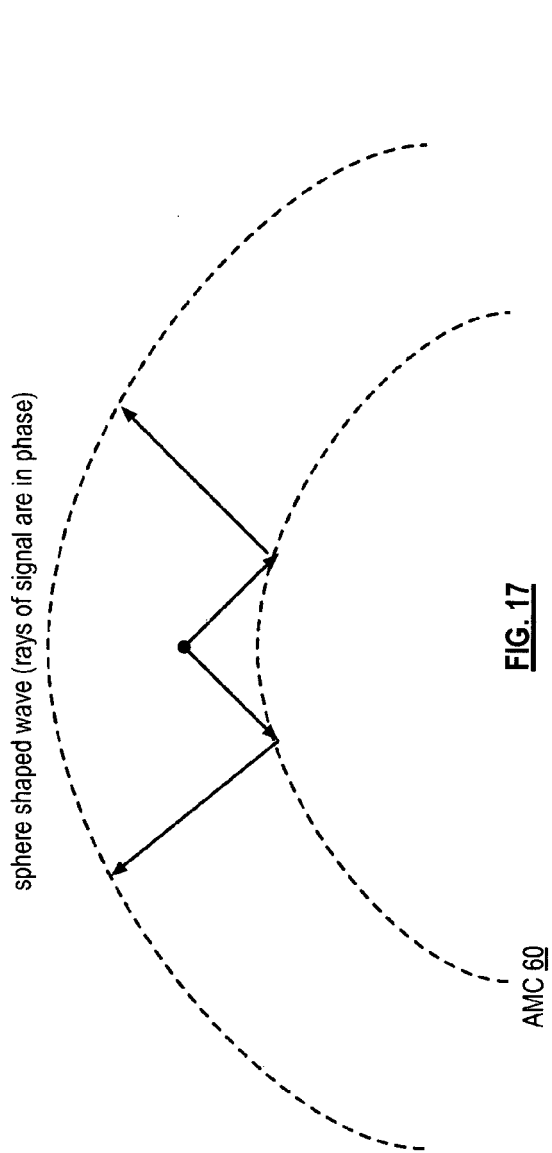


FIG. 16





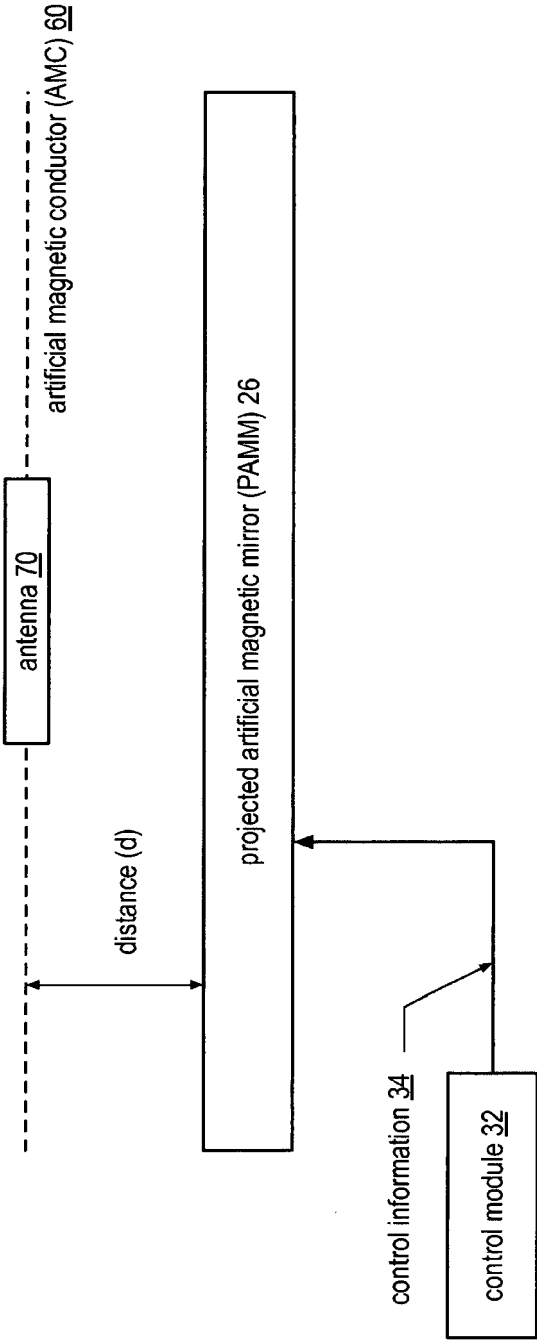


FIG. 19

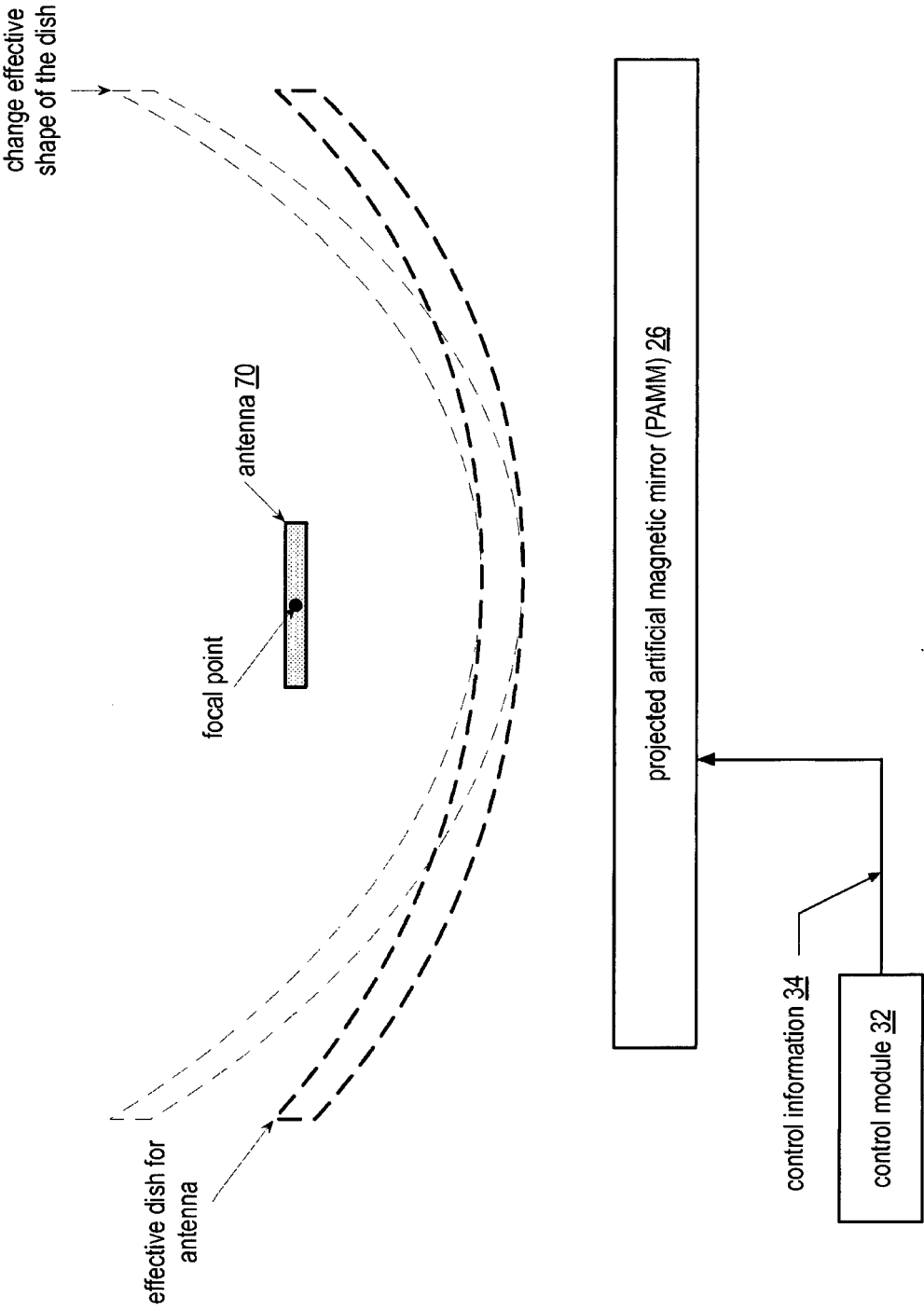
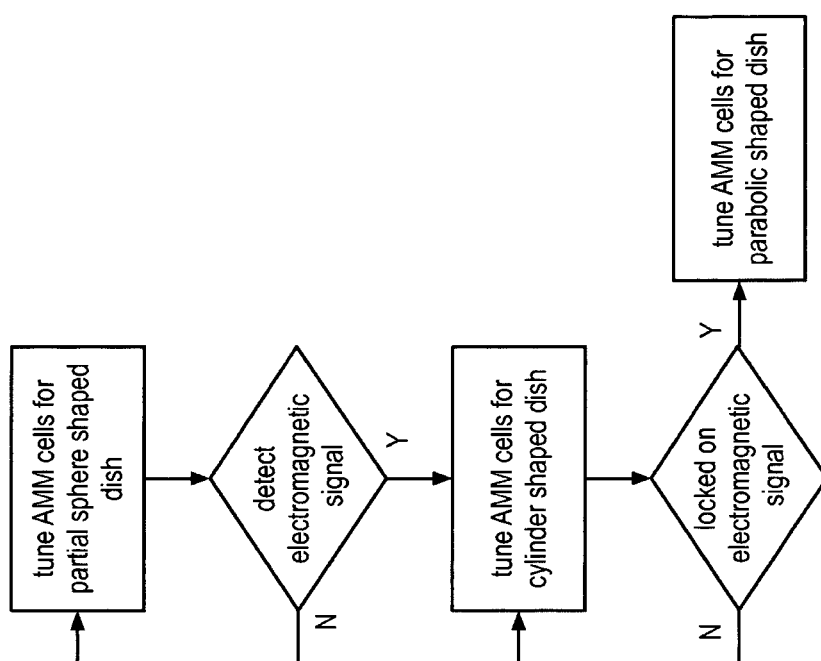


FIG. 20

**FIG. 21**

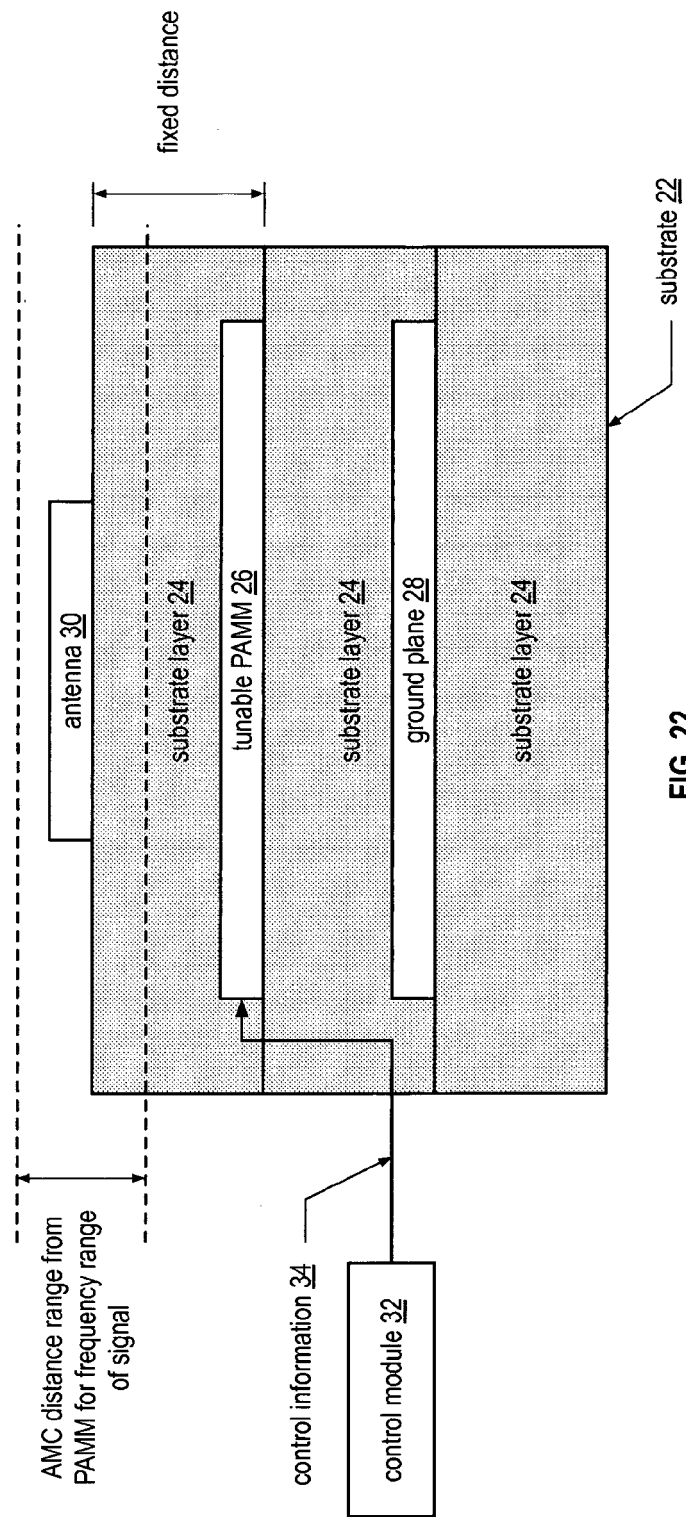


FIG. 22

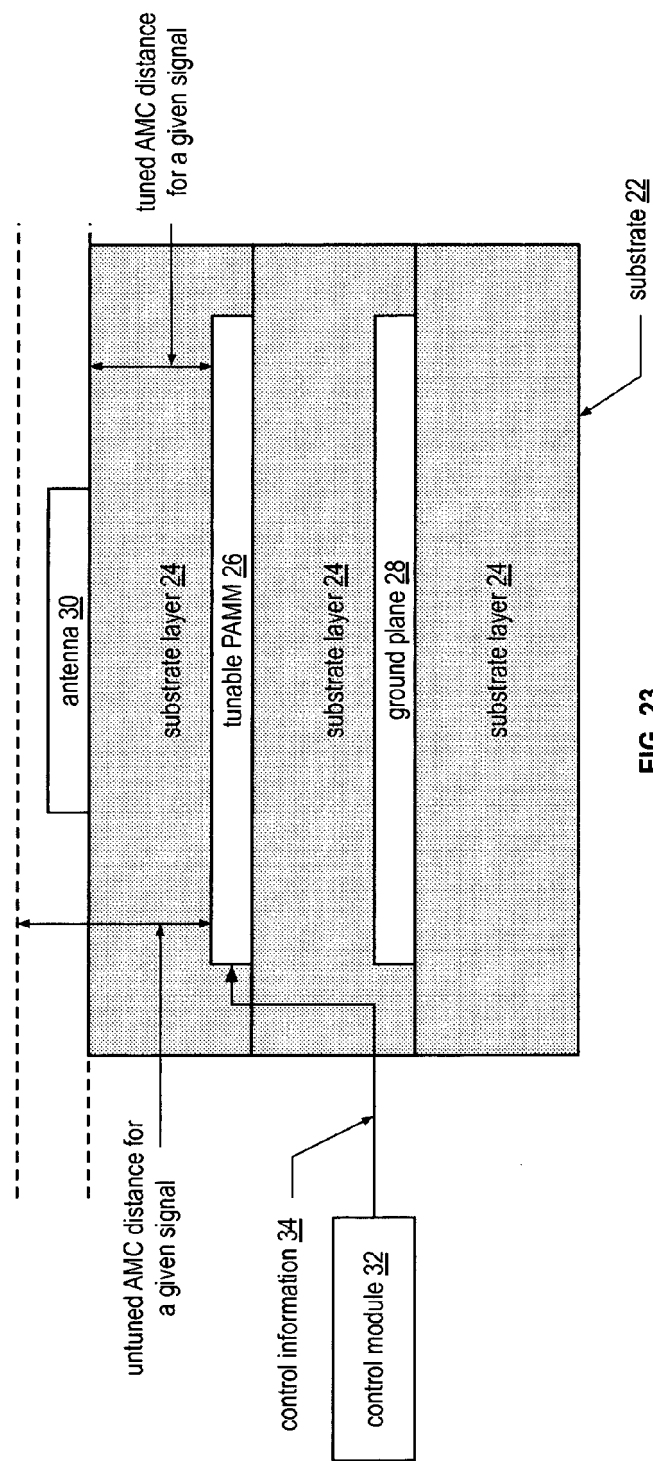


FIG. 23



EUROPEAN SEARCH REPORT

Application Number
EP 13 00 1231

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2003/043077 A1 (ALEXOPOULOS NICOLAOS G [US] ET AL) 6 March 2003 (2003-03-06) * abstract; figures 3a-3c * * paragraphs [0057] - [0060] * -----	1-4,6-15	INV. H01Q15/00
X	EP 2 375 497 A2 (BROADCOM CORP [US]) 12 October 2011 (2011-10-12) * figures 44,45,68,67 * * paragraphs [0112] - [0114] * * paragraph [0154] * -----	1,2,5, 7-13	
A	WO 2008/078284 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS INTELLECTUAL PROPERTY [DE]) 3 July 2008 (2008-07-03) * figures 1,5,6 * * page 9, line 1 - page 10, line 13 * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 7 June 2013	Examiner Unterberger, Michael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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07-06-2013

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