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(54) Title: APPARATUS AND METHOD FOR THERMAL MANAGEMENT IN ANTENNAS

(57) Abstract: An antenna wherein the antenna incorporates a patch and a plurality of fins extending orthogonally from the surface of the patch. The antenna can be powered to produce electromagnetic radiation having a certain wavelength. Each fin has a height orthogonal to the surface of the patch in the range from a quarter of the wavelength to the wavelength. In an embodiment, all of the fins are of substantially the same height. The antenna can be incorporated into an antenna system including an antenna feed line for providing an electrical connection to the antenna. In an embodiment, the antenna system includes a dielectric material and/or a ground plane. In a further embodiment, the antenna system incorporates communication circuitry configured to drive the antenna. In an embodiment, the antenna incorporates other circuitry or devices. In an embodiment, the antenna dissipates heat from incorporated circuitry or other devices.



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DESCRIPTION

APPARATUS AND METHOD FOR THERMAL MANAGEMENT IN ANTENNAS

5 CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application Serial No. 61/186,969, filed June 15, 2009, which is hereby incorporated by reference herein in its entirety, including any figures, tables, or drawings.

10 FIELD OF THE DISCLOSURE

The present disclosure relates generally to thermal management and more specifically to an apparatus and method for thermal management in antennas.

BACKGROUND OF INVENTION

15 Heat dissipation in high-power amplifiers and high-speed microprocessors typically requires the use of a heatsink. As chip densities increase and advances in packaging technologies chaperon high-density 3-D SiP (system-in-package) and SoC (system-on-chip) products into the market, the heatsink may be around for some time. In applications such as high-power RF transmitters, the heatsink can be used as an antenna to reduce the number of
20 components and overall size/cost of the system.

BRIEF SUMMARY

Embodiments of the subject invention relate to a method and apparatus for thermal management in antennas. An embodiment of the subject invention includes an antenna
25 wherein the antenna incorporates a patch and a plurality of fins extending orthogonally from the surface of the patch. In an embodiment, the antenna can be powered to produce electromagnetic radiation having a certain wavelength. In an embodiment, the patch is a square patch having dimensions of a half of the wavelength by a half of the wavelength. Each fin has a height orthogonal to the surface of the patch. In an embodiment, one or more
30 of the fins have a height in the range from a quarter of the wavelength to the wavelength. The fin height can also be in the range from a quarter of the wavelength to a half of the wavelength. In an embodiment, the fin height is about a quarter of the wavelength. In an

embodiment, each of the fins has such a height. In a further embodiment, all of the fins are of substantially the same height.

In an embodiment, an antenna, such as the heatsink antennas discussed herein, is incorporated into an antenna system. In an embodiment, the antenna system includes an antenna feed line for providing an electrical connection to the antenna. In an embodiment, the antenna system includes a dielectric material and/or a ground plane. In a further embodiment, the antenna system incorporates communication circuitry configured to drive the antenna. In an embodiment, the antenna incorporates other circuitry or devices. In an embodiment, the antenna dissipates heat from incorporated circuitry or other devices.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a top view of a planar patch antenna according to an embodiment of the subject invention.

Figure 2 is a side view of an antenna system according to an embodiment of the subject invention.

Figures 3A-3B depict an antenna system according to another embodiment of the subject invention, wherein Figure 3A shows a bottom view of the system and Figure 3B shows an inverted side view of the system.

Figures 4A-4C depict three antenna systems with various fin configurations according to embodiments of the subject invention.

Figure 5 depicts measured and simulated resonant frequencies versus fin height for various fins parallel to non-radiating edges (FPNRE) embodiments of the subject invention.

Figure 6 depicts measured and simulated resonant frequencies versus fin height for various fins parallel to radiating edges (FPRE) embodiments of the subject invention.

Figure 7 depicts measured and simulated return loss of a 3-fin heatsink antenna with 16 mm fins parallel to non-radiating edges (FPNRE) according to an embodiment of the subject invention.

Figure 8 depicts measured and simulated return loss of a 3-fin extruded-fin heatsink antenna with 12 mm fins parallel to radiating edges (FPRE) according to an embodiment of the subject invention.

Figure 9 depicts E-field vector plots showing primary (left, E-plane) and alternate resonances (right, H-plane)) of a 3-fin extruded-fin heatsink antenna with 12 mm fins parallel to non-radiating edges (FPNRE) according to an embodiment of the subject invention.

Figure 10 depicts E-field vector plots showing primary (left, E-plane) and alternate resonances (right, H-plane) of a 2-fin extruded-fin heatsink antenna with 12 mm fins parallel to non-radiating edges (FPNRE) according to an embodiment of the subject invention.

Figure 11 depicts E-Field vector plots showing primary (left, E-plane) and alternate resonances (right, E-plane) of a 3-fin extruded-fin heatsink antenna with 12 mm fins parallel to radiating edges (FPRE) according to an embodiment of the subject invention.

Figure 12 depicts E-field vector plots showing primary (left, E-plane) and alternate resonances (right, E-plane) of a 2-fin extruded-fin heatsink antenna with 12 mm fins parallel to radiating edges (FPRE) according to an embodiment of the subject invention.

Figure 13 depicts an equivalent circuit model of a 3-fin extruded-fin heatsink antenna with fins parallel to non-radiating edges (FPNRE) according to an embodiment of the subject invention.

Figure 14 depicts an equivalent circuit model of a 3-fin extruded-fin heatsink antenna with fins parallel to radiating edges (FPRE) according to an embodiment of the subject invention.

Figure 15 depicts a comparison of S_{11} given by equivalent circuit model and HFSS electromagnetic solver of a 3-fin extruded-fin heatsink antenna (FPNRE) with 14-mm fins according to an embodiment of the subject invention.

Figure 16 depicts a comparison of S_{11} given by equivalent circuit model and HFSS electromagnetic solver of 3-fin extruded-fin heatsink antenna (FPRE) with 12-mm fins according to an embodiment of the subject invention.

Figure 17 depicts simulated peak directivity versus fin height for various pin-fin antennas and extruded-fin heatsink antennas according to embodiments of the subject invention.

Figure 18 depicts surface currents on fins for an FPNRE fin orientation (left) and an FPRE fin orientation (right) for 3-fin extruded-fin heatsink antenna at 5.80 GHz according to embodiments of the subject invention.

Figure 19 depicts simulated radiation efficiency versus fin height for pin-fin antennas and extruded-fin heatsink antennas according to embodiments of the subject invention.

Figure 20 depicts simulated peak gain versus fin height of various 3-fin extruded-fin and pin-fin heatsink antennas according to embodiments of the subject invention.

Figure 21 depicts measured peak gain versus fin height for various 3-fin extruded-fin heatsink antennas according to embodiments of the subject invention.

Figure 22 depicts simulated gain patterns (dB scale) of extruded-fin heatsink antennas FPNRE (top) and FPRE (bottom) for various fin heights at 5.80 GHz according to embodiments of the subject invention.

Figure 23 depicts measured gain patterns (dB scale) of extruded-fin heatsink antennas FPNRE (top) and FPRE (bottom) for various fin heights at 5.80 GHz according to embodiments of the subject invention.

Figure 24 depicts 3-D far-zone array factor (linear scale) for 2 elements spaced $\lambda/2$ apart along the x-axis with an excitation phase difference of 180 degrees according to an embodiment of the subject invention.

DETAILED DISCLOSURE

Embodiments of the subject invention relate to a method and apparatus for thermal management in antennas. An embodiment of the subject invention includes an antenna wherein the antenna incorporates a patch and a plurality of fins extending orthogonally from the surface of the patch. In an embodiment, the antenna can be powered to produce electromagnetic radiation having a certain wavelength. In an embodiment, the patch is a square patch having dimensions of a half of the wavelength by a half of the wavelength. Each fin has a height orthogonal to the surface of the patch. In an embodiment, one or more of the fins have a height in the range from a quarter of the wavelength to the wavelength. The fin height can also be in the range from a quarter of the wavelength to a half of the wavelength. In an embodiment, the fin height is about a quarter of the wavelength. In an embodiment, each of the fins has such a height. In a further embodiment, all of the fins are of substantially the same height.

In an embodiment, an antenna, such as the heatsink antennas discussed herein, is incorporated into an antenna system. In an embodiment, the antenna system includes an antenna feed line for providing an electrical connection to the antenna. In an embodiment, the antenna system includes a dielectric material and/or a ground plane. In a further embodiment, the antenna system incorporates communication circuitry configured to drive the antenna. In an embodiment, the antenna incorporates other circuitry or devices. In an embodiment, the antenna dissipates heat from incorporated circuitry or other devices.

Various radiation frequencies can be used with the subject invention. In an embodiment, the frequency is in the range from 9 kilohertz to 3000 gigahertz. In another embodiment, the frequency is in the range from 1 gigahertz to 30 gigahertz. In another

embodiment, the frequency is in the range from 30 gigahertz to 100 gigahertz. In another embodiment, the frequency is above 100 gigahertz. In a particular embodiment, the frequency is about 2.4 gigahertz. In another embodiment, the frequency is about 5.8 gigahertz.

5 In one embodiment of the present disclosure, an antenna is provided that includes a patch having a radiating edge and a non-radiating edge; a plurality of fins that are substantially parallel to each other and to the non-radiating edge, wherein the fins are integrally formed with the patch, and wherein current flow in the plurality of fins is in a same direction as current flow in the patch.

10 In another embodiment of the present disclosure, an antenna includes a patch having a radiating edge and a non-radiating edge; a plurality of fins that are substantially parallel to each other and to the radiating edge, wherein the fins are integrally formed with the patch, and wherein current flow in the plurality of fins is in a direction orthogonal to current flow in the patch.

15 In another embodiment of the present disclosure, an antenna system includes a patch antenna that provides radio communications, the patch antenna being a substantially planar surface; a heat dissipation member mechanically coupled to the patch antenna and including a plurality of fins that dissipate heat from the patch antenna, the heat dissipation member providing a ground plane for the patch antenna, the fins being substantially parallel to each other and substantially orthogonal to the patch antenna, the fins being one of substantially parallel to a non-radiating edge of the patch antenna or substantially parallel to a radiating edge of the patch antenna; and an antenna feed line coupled to the patch antenna and providing an electrical connection between the patch antenna and an RF circuit.

25 The exemplary embodiments described herein are directed towards thermal management of antennas, such as RF transmitters. The heatsink in high-power RF transmitters can be used as an antenna to improve printed-circuit board (PCB) patch antenna performance and reduce the overall size and cost of a system. The antenna performance can be highly dependent on the heatsink parameters such as fin height, fin orientation and heatsink type. These heatsink parameters and their effects on the antenna performance can be evaluated including the impact on resonant frequency, radiation efficiency, directivity, gain and radiation pattern. The exemplary embodiments can be used with various frequencies and is not intended to be limited to 5.8 GHz. Additionally, dimensions and/or configurations, including fin height and number of fins can be varied for the exemplary embodiments.

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Two types of heatsinks presented here are extruded-fin and pin-fin heatsinks. While pin-fin heatsink antennas have only one orientation due to their symmetry, extruded-fin heatsinks have two orthogonal orientations with respect to a patch antenna's radiating and non-radiating edges. This orientation can play a role in the antennas' performance. The fin height can also affect antenna performance.

In an embodiment, heatsink antennas are designed based on a modified patch antenna platform. If the heatsink is placed over a planar substrate, as the fin height and heatsink base thickness approach zero, the heatsink antenna becomes a patch antenna. In an embodiment, the bottom of the heatsink base is a patch; therefore, a patch antenna with dimensions equal to the heatsink base planar dimensions can be used as a heatsink attachment and alignment surface. In this manner, the heatsink antenna can be excited by feeding the patch. In an embodiment, the patch antenna is designed and matched at 5.8 GHz and fed from the edge with a quarter-wave transformer and a section of 50-ohm microstrip line.

The planar antenna can provide a suitable attachment surface for the heatsink. In an embodiment, the patch antenna was designed using basic square patch antenna design procedures as known in the art. Figure 1 shows the planar layout for a suitable square patch antenna which includes a square patch, quarter-wave transformer (Section 1), a 50- Ω -line (Section 2), and a tuning stub (Section 3) in an edge-fed design. In another embodiment, a rectangular or other shaped patch is used. In a further embodiment, a fractal patch antenna is used. In an embodiment, a coaxial feed from the ground layer beneath can be used for potential 3D integration. In a particular embodiment, the patch size is 11.79 mm X 11.79 mm. Section 1 is 0.63 mm in width and 7.27 mm in length, Section 2 is 3.24 mm in width and 7.27 mm in length. These patch dimensions can be used to construct heatsink antennas with Fins PNRE and heatsink antennas with Fins PRE. Section 3 can be used to tune the impedance matching of such heatsink antennas. Additional information regarding heatsink antennas based on a planar patch can be found in Lance Covert, Jenshan Lin, et al., *5.8 GHz orientation-specific extruded-fin heatsink antennas for 3D RF system integration*, Microwave and Optical Technology Letters (April 23, 2008), which is incorporated by reference herein in its entirety.

In a particular embodiment, such antennas can be fabricated on a low-cost FR4 substrate with a dielectric constant of 4.2, a loss tangent of 0.02, and a thickness of 1.6 mm. Ten extruded-fin aluminum heatsink antennas were fabricated using this platform including five different fin heights (2 mm, 6 mm, 12 mm, 16 mm, and 20 mm) and two fin orientations:

1) fins parallel to the non-radiating edges (FPNRE) of the patch; and 2) fins parallel to the radiating edges (FPRE) of the patch. Other suitable dielectric materials are known in the art and can be used with the subject invention.

The heatsinks can be custom-machined. For example, all of the heatsink antennas can have heatsink base dimensions of 11.8 mm x 11.8 mm which matches the planar square patch dimensions. The heatsink base can be operably connected to the patch antenna using various methods known in the art such that the connection allows thermal and/or electrical conduction between the patch antenna and the heatsink base. For example, a silver, conductive epoxy can be used. In another embodiment, the patch antenna forms the heatsink base such that the fins extend directly from the patch antenna. Various thicknesses and widths can be used for the patch antenna, heatsink base, and/or fins. In a particular embodiment, the heatsink base thickness and fin width are 1 mm.

Figures 2 and 3A-3B depict exemplary antenna systems according to embodiments of the subject invention. Figure 2 is a side view of an antenna system according to an embodiment of the subject invention. In the embodiment shown, a heatsink/antenna structure is disposed on a top surface of a dielectric material and a ground plane is disposed on an opposing side of the dielectric material. As shown, the heatsink/antenna structure includes a base in contact with the dielectric and a plurality of fins extending orthogonally from the surface of the base. In the embodiment shown, the heatsink/antenna structure is electrically connected to a three-dimensional RF system-on-ship through the dielectric material via a feed pin. The RF system can thus drive the heatsink/antenna to transmit electromagnetic radiation.

Figures 3A-3B depict an antenna system according to another embodiment of the subject invention. Figure 3A shows a bottom view of the system and Figure 3B shows an inverted side view of the system. In the embodiment shown, a commercial power amplifier from RFMD is integrated with a heatsink antenna. The heatsink acts as the antenna while simultaneously being used for heat transfer. In the embodiment shown, the IC is an RFMD 2126 high-power linear amplifier with a maximum output power of 1.3 Watts and a gain of 12 dB. Other power amplifiers or other devices can be incorporated into such an antenna system. In the embodiment shown, the PA circuit was setup to operate at 2.45 GHz. Other frequencies can be used. The heatsink shown has a base dimension of 19.8 mm on each side with a base thickness of 2mm. The heatsink has 11 fins each with a height of 8 mm not including the base. Various other dimensions can be used in embodiments of the subject

invention. In the embodiment shown, the package has a slug on the backside which is used as a ground and a thermal sink. This slug can be connected to the heatsink on the opposite side of the FR4 board with an electrically-insulating thermal via as shown. A separate electrical via can be used to feed the antenna with the RF signal. The placement of the heatsink with respect to the fixed feed determines the impedance matching which is similar to determining the feed point for matching a patch antenna. Additional information regarding integrating heatsink antennas into various antenna systems can be found in Lance Covert, Jenshan Lin, *Simulation and measurement of a heatsink antenna: a dual-function structure*, IEEE Trans. on Antennas & Prop (April 2006) and Lance Covert, Jenshan Lin, et al., *Dual Function 3-D Heatsink Antenna for High Density 3-D Integration*, Radio-Frequency Integration Tech (December 2007), which are incorporated by reference herein in their entirety.

Simulations can be performed in a high-frequency structure simulator (HFSS). Extruded-fin and pin-fin heatsink antennas can be simulated. 3-D HFSS models of various embodiments of the subject invention are shown in Figures 4A-C. Figure 4A depicts an extruded-fin embodiment wherein the fins are parallel to the antenna's non-radiating edges (FPNRE). Figure 4B depicts an extruded-fin embodiment wherein the fins are parallel to the antenna's radiating edges (FPRE). Figure 4C depicts a pin-fin embodiment wherein each fin has a regular cross-section. In the embodiment shown in Figure 4C, each fin has a square cross-section and dimensions of 1 mm x 1 mm.

The heatsink type, fin height, and orientation can significantly affect the resonant frequencies of the antenna. The resonant frequencies versus fin height for the fins parallel to the non-radiating edges (FPNRE) orientation are shown in Figure 5. Both measured and simulated data are shown. The primary resonance is labeled such due to its origination from the fundamental TM_{10} mode of the patch. As the fin height increases, a second resonance appears. This resonance is labeled *alternate resonance* instead of *secondary resonance* since the frequency can be higher or lower than the primary depending on the fin height. The primary resonance is relatively flat across the fin height range; and thus, the fundamental mode of the patch is practically unaltered by the heatsink in this orientation. The alternate frequency decreases monotonically with fin height and is due to the resonance between the center fin and the two outer fins (refer to the field plots in Figure 9). Removing the center fin eliminates this alternate resonance but has almost no effect on the primary resonance.

The measured and simulated resonant frequencies for the fins parallel to the radiating edges (FPRE) orientation are shown in Figure 6. In this case, the increasing fin height significantly lowers the primary resonant frequency. The fins being parallel to the radiating edges of the patch effectively increase the length of the patch which lowers the resonant frequency. An alternate resonance also occurs with this fin orientation; however, it is not caused by the center fin. Removing the center fin has almost no effect on the primary and alternate resonant frequencies with this orientation. Also, shown in the figure are the resonant frequencies of a pin-fin heatsink antenna with 36 fins. The fins have the same thickness as the extruded-fin heatsink antenna with 3 fins. As shown, the resonant frequencies of the pin-fin antenna match very well with those of the extruded-fin antenna with fins parallel to the radiating edges (FPRE). This demonstrates that the pin-fin antenna behaves more closely with the extruded-fin FPRE orientation rather than the FPNRE orientation. Both the pin-fin antenna and the FPRE extruded-fin antenna are discontinuous in heatsink material along the direction of the patch current flow and prohibit longitudinal fin currents. The other orientation (FPNRE) has fins longitudinal with the patch current flow and allows longitudinal fin currents.

The S_{11} return loss was measured for the ten antennas on an Agilent E8361A vector network analyzer. The measured data matched well with the simulated data for all ten antennas of different fin heights and orientations. The measured and simulated return loss data for the 3-fin extruded-fin heatsink antennas with 12-mm fins parallel to the non-radiating edges are shown in Figure 7. The antennas are perfectly impedance-matched with no heatsink present (patch antenna only), and the same feed network is used for heatsinks of all fin heights and orientations. This allows isolation of a single parameter (fin height or fin orientation) in the experiment. Therefore, the return loss is low ($|S_{11}| > -10$ dB) for larger fin heights due to the heat sink's effect on the input impedance. Increasing the fin height increases the parallel conductance of the slots (due to higher radiation efficiency) and reduces the size of the locus on the Smith chart. This can be addressed by modifying the input matching for an actual antenna design. The primary and alternate resonances are clearly shown in the Figure 7. The alternate resonance of the FPNRE orientation is very narrowband and is caused by the resonance between the center fin and the outer fins. The 2-fin heatsink return loss is also plotted in Figure 7. Removing the center fin removes the alternate resonance (see inset in Figure 7) but has almost no other effect on the antenna parameters.

The measured and simulated return loss data for the 3-fin extruded-fin heatsink antennas with 12-mm fins parallel to the radiating edges are shown in Figure 8. The dual-frequency nature of the heatsink antenna in this orientation is shown in the figure having a primary and alternate resonance. Also shown in the figure is the return loss of a 2-fin heatsink antenna created by removing the center fin. Removing the center fin has almost no effect on the return loss with this orientation (unlike with the FPNRE orientation, the alternate resonance still exists). In this case, the alternate resonance is due to an e-field variation along the vertical dimension of the outer fins.

The E-field plots for the primary and alternate resonances of the 3-fin extruded-fin heatsink antenna are shown in Figure 9 and Figure 11 for the non-radiating and radiating edge case, respectively. Figure 10 and Figure 12 show the E-field plots for the 2-fin radiating and non-radiating edge cases, respectively. Comparing the images on the right of Figure 9 and Figure 10, it is observable how removing the center fin eliminates the alternate resonance in the FPNRE case. However, comparing Figure 11 and Figure 12 shows that in the FPRE case removing the center fin does not affect the alternate resonance for this orientation.

Equivalent circuits can model the behavior of the input reflection coefficient of the antennas with frequency. This allows simulation and prediction of the antenna's S_{11} without using rigorous electromagnetic solvers. Equivalent circuit models were developed for the heatsink antennas of both orientations (FPNRE and FPRE). To make the models, the fins were replaced with lumped inductance and resistance. Lumped capacitors were used to model the capacitance between the heatsink fins. The circuit models are shown in Figure 13 and Figure 14 for the FPNRE and FPRE orientations, respectively. In both cases, the patch was modeled by a microstrip transmission line in addition to the 50- Ω transmission line and the quarter-wave transformer in microstrip. However, two shunt capacitances and resistances (C_{slot} and R_{slot}) account for the radiation from the two slots of the patch which are included in the models of both orientations.

For the FPNRE orientation, the heatsink can be modeled by two capacitances (C_{fin1} and C_{fin3}) which are shunted to the center of the patch by a fin inductance, L_{fin2} , and a fin resistance, R_{fin2} , and modification of R_{slot} and C_{slot} . The center of the patch is a virtual ground, so a similar behavior is obtained by shunting the fin inductance and resistance to ground. The S_{11} of this model compared with those obtained by HFSS electromagnetic simulations at a fin height of 14 mm are shown in Figure 15. By increasing the fin inductance, L_{fin} , which corresponds to an increase in fin height, the alternate resonant

frequency is reduced; however, this has no effect on the primary resonance. This is the same behavior as shown in Figure 5 for the simulated and measured resonant frequencies of the FPNRE heatsink antenna versus fin height. The fin resistance is related to the diameter of the alternate resonant locus on the Smith chart. Increasing the fin resistance reduces the diameter of the alternate resonant locus and lowers the magnitude of the return loss at that frequency ($|S_{11}|$ closer to 0 dB) but has no effect on the primary resonant locus. Increasing the fin capacitance, however, reduces both the primary and alternate resonant frequencies. Thus, for this model to be accurate, an increase in fin height cannot lead to a significant increase in fin capacitance. It must also be noted that the capacitances are connected between the radiating slots while they actually lie along the non-radiating slots. Along these non-radiating edges the current distribution goes through a phase change (Figure 9, left), and thus, a distributed model may be more appropriate. However, the same figure shows that the majority of the fields due to the alternate resonance (coming out of page) are located near the center of the patch along the length which is a virtual ground. This may explain how this simple lumped-element model is able to behave closely with the heatsink antenna.

For the FPFE orientation, the model is shown in Figure 14. In this case, the center fin has almost no effect on the antenna's S_{11} . Therefore, only lumped components due to the outer fins are included in the model which consists of the fin inductance, resistance and capacitance, L_{fin} , R_{fin} , and C_{fin} , including modified R_{slot} and C_{slot} . Increasing the fin inductance (to represent an increase in fin height) with this model lowers both the alternate and primary resonant frequencies. With increasing inductance the alternate resonance decreases significantly initially and finally stops decreasing and remains constant with further increases in fin inductance. The primary resonant frequency continues to decrease with increasing fin inductance. This behavior is very similar to that shown in Figure 6 showing the simulated and measured primary and alternate resonant frequencies versus fin height. Unlike the FPNRE case, increasing the fin resistance, R_{fin} , reduces the diameter of both the alternate and primary resonant loci and lowers the magnitude of the return loss at those frequencies ($|S_{11}|$ closer to 0 dB).

The peak directivity versus fin height is shown in Figure 17 for both orientations of the extruded-fin heatsink antenna as well as the pin-fin heatsink antenna at 5.8 GHz. As shown in the figure, the directivity displays a significant dependence on fin height increasing and decreasing in the radiating edge case. In the non-radiating edge case, the change in directivity is relatively small over the fin height range. In this case, the fins are parallel with

the current on the patch antenna (x-axis). Therefore, the radiation pattern is very similar to that of a patch antenna for all fin heights shown. However, for the radiating edge case, the fins are transverse to the current flow on the patch. As the fin height increases in this case, vertical currents begin to appear on the outer fins. This has a significant impact on the radiation pattern and thus, also alters the peak directivity substantially.

Plots of the fin currents are given in Figure 18 for both FPNRE and FPPE orientations. For the FPNRE case, the fin currents are horizontal and parallel to the currents on the patch. In the FPPE case, however, the fin currents cannot flow parallel to the patch currents due to the fin arrangement. Instead, the currents flow vertically on the fins (along the z-axis).

The radiation efficiency versus fin height for the three heatsink antenna types is shown in Figure 19 given at 5.8 GHz. The efficiency increase for the non-radiating edge case is almost entirely monotonic with fin height. The heatsink having fins parallel to the non-radiating edge (or longitudinal to the patch current flow) allows the antenna to behave like a patch antenna while reducing dielectric losses. The result is that efficiency enhancement can be achieved even with a low-profile heatsink. The opposite orientation with fins parallel to the radiating edges shows a decrease in efficiency for low fin heights and a discontinuous jump in efficiency at 10 mm. At this fin height and above, the alternate resonance from Figure 5 becomes the operating mode as its frequency has shifted near 5.8 GHz. Again, the pin-fin antenna behaves very similarly to the latter extruded-fin antenna orientation (FPPE).

The simulated peak gain (peak directivity x efficiency) versus fin height for the three heatsink antenna types is shown in Figure 20 at 5.80 GHz. The gain of the extruded-fin antennas was also measured and is reported in Figure 21 for comparison. The measured data consist of results from the ten fabricated antennas (five different fin heights at two different fin orientations). The trends of the simulated and measured data versus fin height are consistent for both fin orientations. The directivity of the non-radiating edge case is less dependent on fin height but has an increasing efficiency. This gives a slight increase in gain for an increase in fin height. However, for the radiating edge case, the peak gain is affected by the fin height considerably as shown in Figure 20 and Figure 21. This is mainly due to impact of the fin orientation and height on the radiation pattern. The slight increase in measured peak gain over the simulated peak gain is due to the lower backside radiation levels in measurement which can depend on the mounting of the antenna. The peak gain of the pin-

fin heatsink antenna versus fin height is very similar to the peak gain of the extruded-fin heatsink antenna with fins parallel to the radiating edges as shown in Figure 20.

The 2-D antenna co-polarization gain patterns for the extruded-fin heatsink antennas at both orientations are shown in Figure 22 (simulated) and Figure 23 (measured). Both E- and H-plane gain patterns are given at various fin heights (2 mm, 6 mm, 12 mm, 16 mm, and 20 mm) for each fin orientation. The measured data match well with simulation. The pattern for the heatsink antenna with fins parallel to the non-radiating edges (FPNRE) is similar to the broadside pattern of a patch antenna as shown in the top of Figure 22 and Figure 23. Increasing the fin height increases the gain with this orientation. However, with fins parallel to the radiating edges (FPRE), the pattern changes significantly with fin height. This is shown in bottom of Figure 22 and Figure 23. Over the fin height range of 2 mm to 6 mm, the gain increases while maintaining a single, broadside lobe. However, the pattern changes for fin heights above 6 mm; specifically, two end-fire sidelobes appear in the E-plane, and the broadside lobe recedes as shown at 12 mm. This end-fire radiation may be desirable in certain applications. As the fin height increases even further the broadside lobe returns and the sidelobes start to recede as shown at 16 mm. This is consistent with the peak gain plots of Figure 20 and Figure 21 which show the peak gain varying significantly with fin height. Vertical currents are generated on the outer fins in this case which act like an array of monopoles spaced $\lambda/2$ and excited $\sim 180^\circ$ apart (see Figure 18). For elements spaced along the x -axis the 3-D far-zone array factor is given by:

$$AF = \sum_{n=1}^N a_n e^{j(n-1)\psi} \quad (1)$$

$$\psi = kd \cos(\gamma) + \beta \quad (2)$$

$$\gamma = \cos^{-1}(\sin(\theta)\cos(\phi)) \quad (3)$$

where θ is the elevation angle, ϕ (insert symbol) is the azimuth angle and k is the propagation constant ($k = 2\pi/\lambda$), d is the physical separation between the elements, a_n is the amplitude excitation of each element, β is the difference in phase excitation between the elements, and γ is the angle between the axis containing the linear array of elements and the radial vector from the origin to the observation point. Using a two-element array spaced $\lambda/2$ apart with a phase excitation difference of 180° leads to an array factor with two lobes in opposite direction oriented along the axis of the array elements (Figure 24). The total pattern is obtained by multiplying the individual element's pattern by the array factor. This explains

the appearance of end-fire sidelobes in E-plane patterns when fin height is above 6mm for FPRE case.

The extruded-fin heatsink antenna with fins parallel to the non-radiating edges (FPNRE) has fins which are longitudinal to the resonant length of the patch. Therefore, the current flow on the fins is allowed to flow in the same direction as the patch current. The radiation efficiency increases since the heatsink causes the fields to be less confined to the lossy substrate. In addition, due to similar current distribution, the radiation pattern is similar to that of a traditional patch antenna. However, the pin-fin heatsink antenna and extruded-fin heatsink antenna with fins parallel to the radiating edges (FPRE) behave similar to each other but very differently from a patch antenna. In these cases, the fins are not longitudinal with the current flow on the patch which prohibits the flow of horizontal current on the fins. At moderate fin heights, vertical currents are generated on the fins. In the extruded-fin FPFE case, the two outer fins are acting as an array of monopole antennas. This creates the two end-fire lobes in the radiation pattern. The effect is similar for the pin-fin heatsink antenna.

Both extruded-fin heatsink antenna fin orientations support additional resonances. However, these resonances originate from different modes depending on the fin orientation; and the effect of fin height on these resonances is significantly dependent on the orientation.

In embodiments, heatsink antennas utilize the volume taken up by the heatsink more efficiently by exploiting the heatsink's ability to function as an antenna. Moreover, the heatsink can actually improve the PCB patch antenna performance substantially including efficiency enhancement, gain increase and the ability to change the radiation pattern. The heatsink antenna can be used in applications requiring a heatsink while wireless communication is also needed such as a high-power RF transmitter or microprocessor with wireless chip-to-chip communications.

The present disclosure contemplates the use of a machine in the form of a computer system within which a set of instructions, when executed, may cause the machine to perform any one or more of the methodologies discussed above. In some embodiments, the machine can operate as a standalone device. In some embodiments, the machine may be connected (e.g., using a network) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client user machine in server-client user network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

The machine can comprise a server computer, a client user computer, a personal computer (PC), a tablet PC, a laptop computer, a desktop computer, a control system, a

network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. It will be understood that a device of the present disclosure can include broadly any electronic device that provides voice, video or data communication. Further, while a single machine is
5 illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein.

The computer system can include a processor (e.g., a central processing unit (CPU), a graphics processing unit (GPU, or both), a main memory and a static memory, which
10 communicate with each other via a bus. The computer system can further include a video display unit (e.g., a liquid crystal display (LCD), a flat panel, a solid state display, or a cathode ray tube (CRT)). The computer system can include an input device (e.g., a keyboard), a cursor control device (e.g., a mouse), a mass storage medium, a signal generation device (e.g., a speaker or remote control) and a network interface device.

The mass storage medium can include a computer-readable storage medium on which
15 is stored one or more sets of instructions (e.g., software) embodying any one or more of the methodologies or functions described herein, including those methods illustrated above. The computer-readable storage medium can be an electromechanical medium such as a common disk drive, or a mass storage medium with no moving parts such as Flash or like non-volatile
20 memories. The instructions can also reside, completely or at least partially, within the main memory, the static memory, and/or within the processor during execution thereof by the computer system. The main memory and the processor also may constitute computer-readable storage media.

Dedicated hardware implementations including, but not limited to, application
25 specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals
30 communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

In accordance with various embodiments of the present disclosure, the methods described herein are intended for operation as software programs running on one or more computer processors. Furthermore, software implementations can include, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein.

The present disclosure also contemplates a machine readable medium containing instructions, or that which receives and executes instructions from a propagated signal so that a device connected to a network environment can send or receive voice, video or data, and to communicate over the network using the instructions. The instructions can further be transmitted or received over a network via the network interface device. While the computer-readable storage medium is described in an exemplary embodiment to be a single medium, the term "computer-readable storage medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "computer-readable storage medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methodologies of the present disclosure. The term "computer-readable storage medium" shall accordingly be taken to include, but not be limited to: solid-state memories such as a memory card or other package that houses one or more read-only (non-volatile) memories, random access memories, or other re-writable (volatile) memories; magneto-optical or optical medium such as a disk or tape. Accordingly, the disclosure is considered to include any one or more of a computer-readable storage medium or a distribution medium, as listed herein and including art-recognized equivalents and successor media, in which the software implementations herein are stored.

Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Each of the standards for Internet and other packet switched network transmission (e.g., TCP/IP, UDP/IP, HTML, HTTP) represent examples of the state of the art. Such standards are periodically superseded by faster or more efficient equivalents having essentially the same functions. Accordingly, replacement standards and protocols having the same functions are considered equivalents.

The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. Other embodiments may be utilized and derived there from, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description as well as the additional information provided in the Appendix which is considered part of the disclosure.

Aspects of the invention can be described in the general context of computer-executable instructions, such as program modules, being executed by a computer. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Such program modules can be implemented with hardware components, software components, or a combination thereof. Moreover, those skilled in the art will appreciate that the invention can be practiced with a variety of computer-system configurations, including multiprocessor systems, microprocessor-based or programmable-consumer electronics, minicomputers, mainframe computers, and the like. Any number of computer-systems and computer networks are acceptable for use with the present invention.

Specific hardware devices, programming languages, components, processes, protocols, formats, and numerous other details including operating environments and the like

are set forth to provide a thorough understanding of the present invention. In other instances, structures, devices, and processes are shown in block-diagram form, rather than in detail, to avoid obscuring the present invention. But an ordinary-skilled artisan would understand that the present invention can be practiced without these specific details. Computer systems, servers, work stations, and other machines can be connected to one another across a communication medium including, for example, a network or networks.

As one skilled in the art will appreciate, embodiments of the present invention can be embodied as, among other things: a method, system, or computer-program product. Accordingly, the embodiments can take the form of a hardware embodiment, a software embodiment, or an embodiment combining software and hardware. In an embodiment, the present invention takes the form of a computer-program product that includes computer-useable instructions embodied on one or more computer-readable media. Methods, data structures, interfaces, and other aspects of the invention described above can be embodied in such a computer-program product.

Computer-readable media include both volatile and nonvolatile media, removable and nonremovable media, and contemplate media readable by a database, a switch, and various other network devices. By way of example, and not limitation, computer-readable media incorporate media implemented in any method or technology for storing information. Examples of stored information include computer-useable instructions, data structures, program modules, and other data representations. Media examples include, but are not limited to, information-delivery media, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile discs (DVD), holographic media or other optical disc storage, magnetic cassettes, magnetic tape, magnetic disk storage, and other magnetic storage devices. These technologies can store data momentarily, temporarily, or permanently. In an embodiment, non-transitory media are used.

The invention can be practiced in distributed-computing environments where tasks are performed by remote-processing devices that are linked through a communications network or other communication medium. In a distributed-computing environment, program modules can be located in both local and remote computer-storage media including memory storage devices. The computer-useable instructions form an interface to allow a computer to react according to a source of input. The instructions cooperate with other code segments or modules to initiate a variety of tasks in response to data received in conjunction with the source of the received data.

The present invention can be practiced in a network environment such as a communications network. Such networks are widely used to connect various types of network elements, such as routers, servers, gateways, and so forth. Further, the invention can be practiced in a multi-network environment having various, connected public and/or private networks.

Communication between network elements can be wireless or wireline (wired). As will be appreciated by those skilled in the art, communication networks can take several different forms and can use several different communication protocols.

Embodiments of the subject invention can be embodied in a processing system. Components of the processing system can be housed on a single computer or distributed across a network as is known in the art. In an embodiment, components of the processing system are distributed on computer-readable media. In an embodiment, a user can access the processing system via a client device. In an embodiment, some of the functions or the processing system can be stored and/or executed on such a device. Such devices can take any of a variety of forms. By way of example, a client device may be a desktop, laptop, or tablet computer, a personal digital assistant (PDA), an MP3 player, a communication device such as a telephone, pager, email reader, or text messaging device, or any combination of these or other devices. In an embodiment, a client device can connect to the processing system via a network. As discussed above, the client device may communicate with the network using various access technologies, both wireless and wireline. Moreover, the client device may include one or more input and output interfaces that support user access to the processing system. Such user interfaces can further include various input and output devices which facilitate entry of information by the user or presentation of information to the user. Such input and output devices can include, but are not limited to, a mouse, touch-pad, touch-screen, or other pointing device, a keyboard, a camera, a monitor, a microphone, a speaker, a printer, a scanner, among other such devices. As further discussed above, the client devices can support various styles and types of client applications.

All patents, patent applications, provisional applications, and publications referred to or cited herein are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be

suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

CLAIMS

What is claimed is:

1. An antenna, comprising:
 - a patch having a top surface, wherein the patch comprises a radiating edge and a non-radiating edge; and
 - a plurality of fins, wherein each fin of the plurality of fins has a corresponding length, width, and height in directions orthogonal to each other, wherein the length is greater than the width, wherein the height is in a direction orthogonal to the top surface of the patch, wherein each of the fins of the plurality of fins is substantially parallel to each of the other fins of the plurality of fins along the length of the fins, wherein each of the fins of the plurality of fins extends from the top surface of the patch in a direction substantially orthogonal to the top surface of the patch,
 - wherein when a current is applied to the antenna the antenna produces electromagnetic radiation having a wavelength, and wherein one or more of the fins of the plurality of fins has a corresponding height in the range from a quarter of the wavelength to the wavelength.
2. The antenna of claim 1, wherein the antenna produces electromagnetic radiation having a frequency in the range from one gigahertz to 30 gigahertz.
3. The antenna of claim 1, wherein the antenna produces electromagnetic radiation having a frequency in the range from 30 gigahertz to 100 gigahertz.
4. The antenna of claim 1, wherein each of the fins of the plurality of fins has a corresponding height in the range from a quarter of the wavelength to the wavelength.
5. The antenna of claim 1, wherein each of the fins of the plurality of fins extends from the top surface of the patch in a direction orthogonal to the top surface of the patch.
6. The antenna of claim 1, wherein each of the fins of the plurality of fins is substantially parallel to the non-radiating edge along the corresponding length of the fins.

7. The antenna of claim 6, wherein when the current is applied to the antenna the current flows along the lengths of the fins of the plurality of fins in substantially a same direction as the current flows in the patch.
8. The antenna of claim 1, wherein each of the fins of the plurality of fins is substantially parallel to the radiating edge along the corresponding length of the fins.
9. The antenna of claim 8, wherein when the current is applied to the antenna the current flows along the height of the fins of the plurality of fins in a direction substantially orthogonal to a direction that the current flows in the patch.
10. The antenna of claim 1, wherein each fin of the plurality of fins is integrally formed with the patch.
11. The antenna of claim 1, wherein one or more fins of the plurality of fins are mechanically coupled to the patch.
12. The antenna of claim 1, wherein when the antenna is in thermal contact with a device that is at a higher temperature than a temperature of the antenna, wherein the antenna dissipates heat from the device.
13. The antenna of claim 1, wherein the patch is a planar base.
14. The antenna of claim 1, wherein the plurality of fins is two fins.
15. The antenna of claim 1, wherein the plurality of fins is three fins.
16. The antenna of claim 1, wherein one or more fins of the plurality of fins has a corresponding height in the range from a quarter of the wavelength to a half of the wavelength.
17. The antenna of claim 16, wherein one or more fins of the plurality of fins has a corresponding height of about a quarter of the wavelength.

18. The antenna of claim 17, wherein each fin of the plurality of fins has a corresponding height of about a quarter of the wavelength.
19. The antenna of claim 18, wherein the patch has a patch width orthogonal to the height of the fins of the plurality of fins, the patch has a patch length orthogonal to the height of the fins of the plurality of fins and orthogonal to the patch width, and the patch width and patch length are each about half of the wavelength.
20. The antenna of claim 18, wherein all of the fins of the plurality of fins have substantially equal corresponding heights.
21. The antenna of claim 1, wherein one or more of the fins of the plurality of fins has a corresponding height of 6 mm or greater.
22. The antenna of claim 1, wherein each of the fins of the plurality of fins has a corresponding height thereby providing end-fire radiation.
23. The antenna of claim 1, wherein each of the fins of the plurality of fins has a corresponding height of 10 mm or less.
24. The antenna of claim 1, wherein each of the fins of the plurality of fins has a corresponding height in the range from 2 mm to 6 mm.
25. An antenna system, comprising:
 - a patch antenna that provides radio communications, the patch antenna having a substantially planar surface;
 - a heat dissipation member positioned proximate to the patch antenna and including a plurality of fins, wherein each fin of the plurality of fins has a corresponding length, width, and height in directions orthogonal to each other, wherein the length is greater than the width, wherein the height is in a direction orthogonal to the substantially planar surface, wherein each of the fins of the plurality of fins is substantially parallel to each of the other fins of the plurality of fins along the length of the fins, and substantially

orthogonal to the substantially planar surface, all of the fins of the plurality of fins being one of substantially parallel to a non-radiating edge of the patch antenna or substantially parallel to a radiating edge of the patch antenna; and

an antenna feed line coupled to the patch antenna and providing an electrical connection between the patch antenna and radio communications circuitry,

wherein when a current is applied to the patch antenna via the antenna feed line the patch antenna produces electromagnetic radiation having a wavelength, and wherein one or more of the fins of the plurality of fins has a corresponding height in the range from a quarter of the wavelength to the wavelength.

26. The system of claim 25, wherein the heat dissipation member provides a ground plane for the patch antenna.

27. The system of claim 25, further comprising:

a dielectric layer having first and second opposing sides, wherein the patch antenna is disposed on the first side of the dielectric layer; and

a ground plane, wherein the ground plane is disposed on the second side of the dielectric layer.

28. The system of claim 27, further comprising a thermal via, wherein the thermal via provides thermal conductivity between the ground plane and the heat dissipation member.

29. The system of claim 25, wherein the patch antenna produces electromagnetic radiation having a frequency in the range from one gigahertz to 30 gigahertz.

30. The system of claim 25, wherein the patch antenna produces electromagnetic radiation having a frequency in the range from 30 gigahertz to 100 gigahertz.

31. The system of claim 25, wherein one or more fins of the plurality of fins dissipate heat from the patch antenna when the patch antenna is at a higher temperature than a temperature of each of the one or more of the plurality of fins.

32. The system of claim 25, wherein the heat dissipation member is integrally formed with the patch antenna.
33. The system of claim 25, wherein the heat dissipation member is mechanically coupled to the patch antenna.
34. The system of claim 25, wherein the plurality of fins is two fins.
35. The system of claim 25, wherein the plurality of fins is three fins.
36. The system of claim 25, wherein the plurality of fins is an odd number of fins.
37. The system of claim 25, wherein one or more fins of the plurality of fins has a corresponding height in the range from a quarter of the wavelength to a half of the wavelength.
38. The system of claim 37, wherein one or more fins of the plurality of fins has a corresponding height of about a quarter of the wavelength.
39. The system of claim 38, wherein each fin of the plurality of fins has a corresponding height of about a quarter of the wavelength.
40. The system of claim 39, wherein the patch antenna has a patch width orthogonal to the height of the fins of the plurality of fins, the patch antenna has a patch length orthogonal to the height of the fins of the plurality of fins and orthogonal to the patch width, and the patch width and patch length are each about half of the wavelength.
41. The system of claim 39, wherein all of the fins of the plurality of fins have substantially equal corresponding heights.
42. The system of claim 25, wherein one or more of the fins of the plurality of fins has a corresponding height of about 6 mm.

43. The system of claim 25, wherein each of the fins of the plurality of fins has a corresponding height thereby providing end-fire radiation.
44. The system of claim 25, wherein each of the fins of the plurality of fins has a corresponding height in the range from 2 mm to 6 mm.
45. An antenna, comprising:
a patch having a top surface, wherein the patch comprises a radiating edge and a non-radiating edge; and
a plurality of fin arrays, wherein each fin array of the plurality of fin arrays has a plurality of pin fins arranged in a line having an array length, wherein each pin fin of the plurality of pin fins has a corresponding length, width, and height in directions orthogonal to each other, wherein the length is equal to the width, wherein the height is in a direction orthogonal to the top surface of the patch, wherein each line corresponding to a fin array is substantially parallel to each of the other lines corresponding to the other fin arrays, wherein each of the pin fins of the plurality of pin fins of each array extends from the top surface of the patch in a direction substantially orthogonal to the top surface of the patch,
wherein when a current is applied to the antenna the antenna produces electromagnetic radiation having a wavelength, and wherein one or more of the pin fins of the plurality of pin fins of each array has a corresponding height in the range from a quarter of the wavelength to the wavelength.
46. The antenna of claim 45, wherein the antenna produces electromagnetic radiation having a frequency in the range from one gigahertz to 30 gigahertz.
47. The antenna of claim 45, wherein the antenna produces electromagnetic radiation having a frequency in the range from 30 gigahertz to 100 gigahertz.
48. The antenna of claim 45, wherein each of the pin fins of the plurality of pin fins of each array has a corresponding height in the range from a quarter of the wavelength to the wavelength.

49. The antenna of claim 45, wherein each of the pin fins of the plurality of pin fins of each array extends from the top surface of the patch in a direction orthogonal to the top surface of the patch.
50. The antenna of claim 45, wherein the line of each of the plurality of pin fins is substantially parallel to the non-radiating edge.
51. The antenna of claim 45, wherein the line of each of the plurality of pin fins is substantially parallel to the radiating edge.
52. The antenna of claim 45, wherein each pin fin of the plurality of pin fins of each array is integrally formed with the patch.
53. The antenna of claim 45, wherein one or more pin fins are mechanically coupled to the patch.
54. The antenna of claim 45, wherein when the antenna is in thermal contact with a device that is at a higher temperature than a temperature of the antenna, wherein the antenna dissipates heat from the device.
55. The antenna of claim 45, wherein the patch is a planar base.
56. The antenna of claim 45, wherein the plurality of pin fin arrays is two arrays.
57. The antenna of claim 45, wherein the plurality of fin arrays is three arrays.
58. The antenna of claim 45, wherein one or more pin fins of the plurality of pin fins of each array has a corresponding height in the range from a quarter of the wavelength to a half of the wavelength.
59. The antenna of claim 58, wherein one or more pin fins of the plurality of pin fins of each array has a corresponding height of about a quarter of the wavelength.

60. The antenna of claim 59, wherein each pin fin of the plurality of pin fins of each array has a corresponding height of about a quarter of the wavelength.
61. The antenna of claim 60, wherein the patch has a patch width orthogonal to the height of the pin fins of the plurality of pin fins, the patch has a patch length orthogonal to the height of the pin fins of the plurality of pin fins and orthogonal to the patch width, wherein the patch width and patch length are each about half of the wavelength.
62. The antenna of claim 60, wherein all of the pin fins of the plurality of pin fins of each array have substantially equal corresponding heights.
63. The antenna of claim 45, wherein one or more of the pin fins of the plurality of pin fins of each array has a corresponding height of 6 mm or greater.
64. The antenna of claim 45, wherein each of the pin fins of the plurality of pin fins of each array has a corresponding height thereby providing end-fire radiation.
65. The antenna of claim 45, wherein each of the pin fins of the plurality of pin fins of each array has a corresponding height of 10 mm or less.
66. The antenna of claim 45, wherein each of the pin fins of the plurality of pin fins of each array has a corresponding height in the range from 2 mm to 6 mm.

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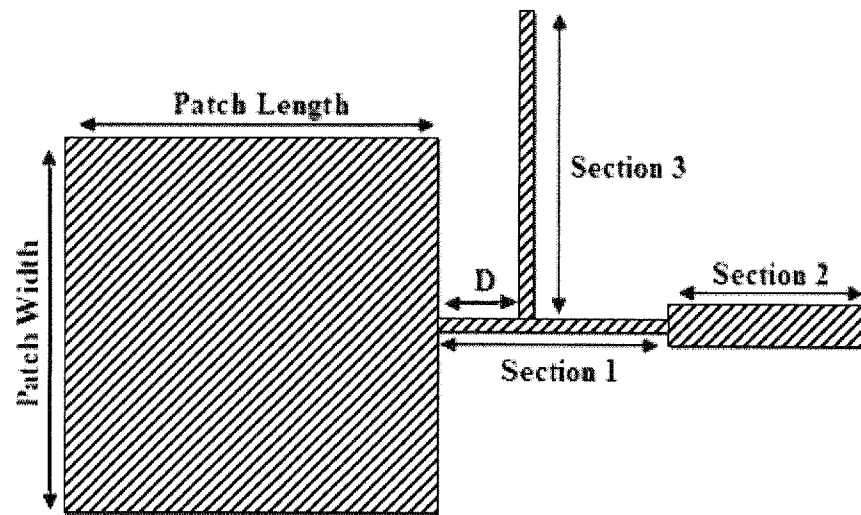


FIG. 1

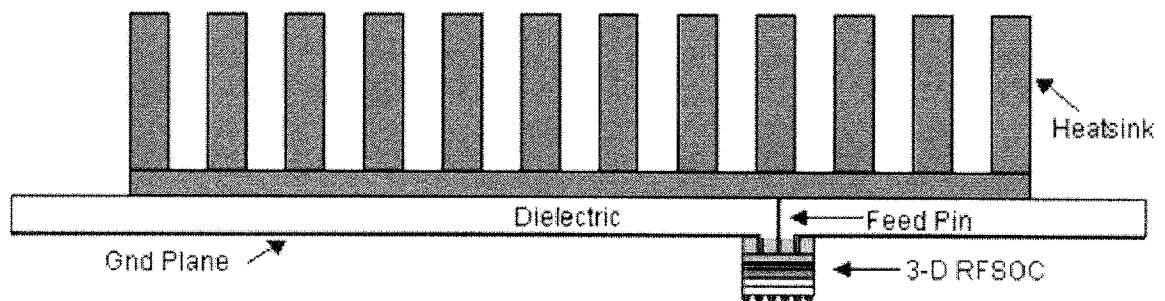


FIG. 2

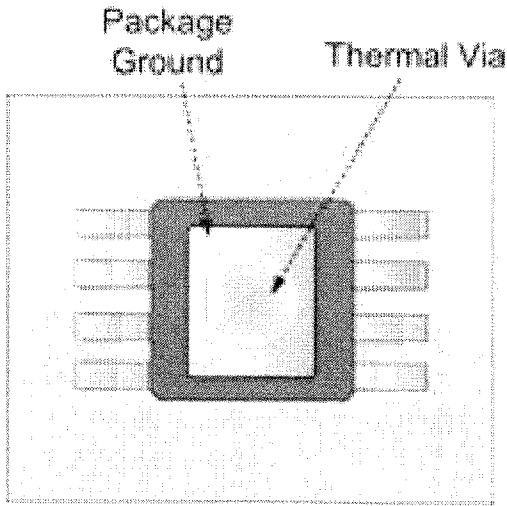


FIG. 3A

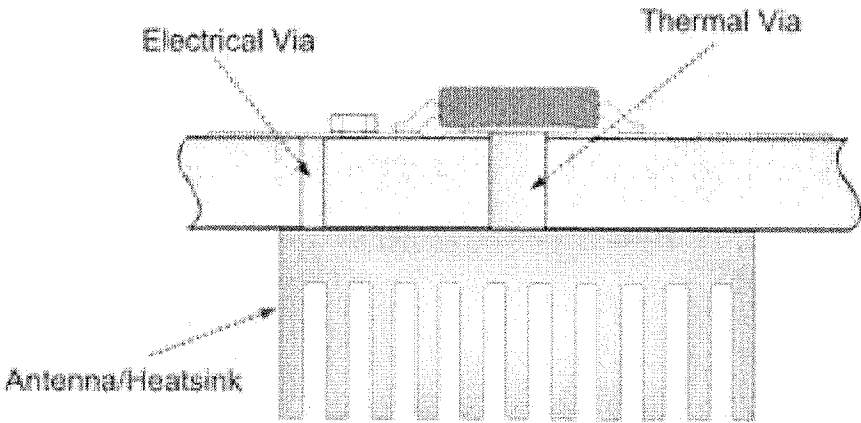


FIG. 3B

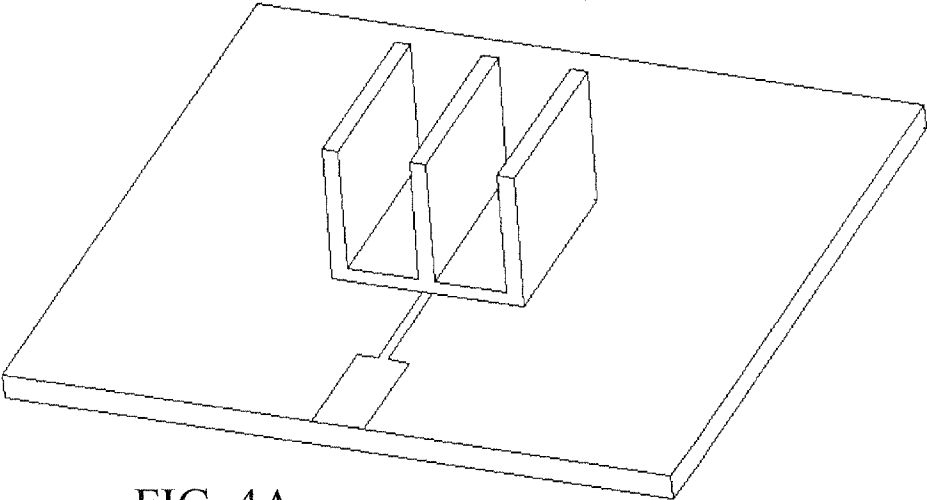


FIG. 4A

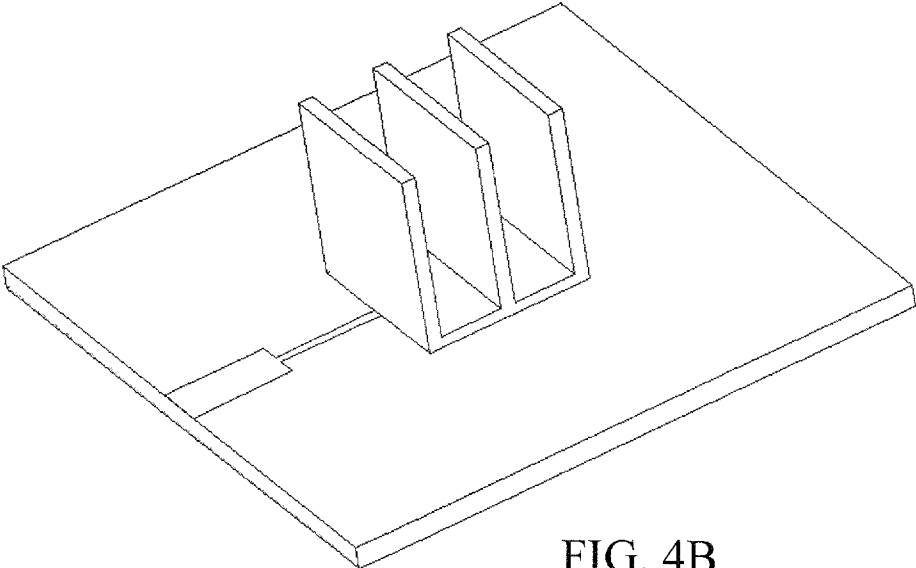


FIG. 4B

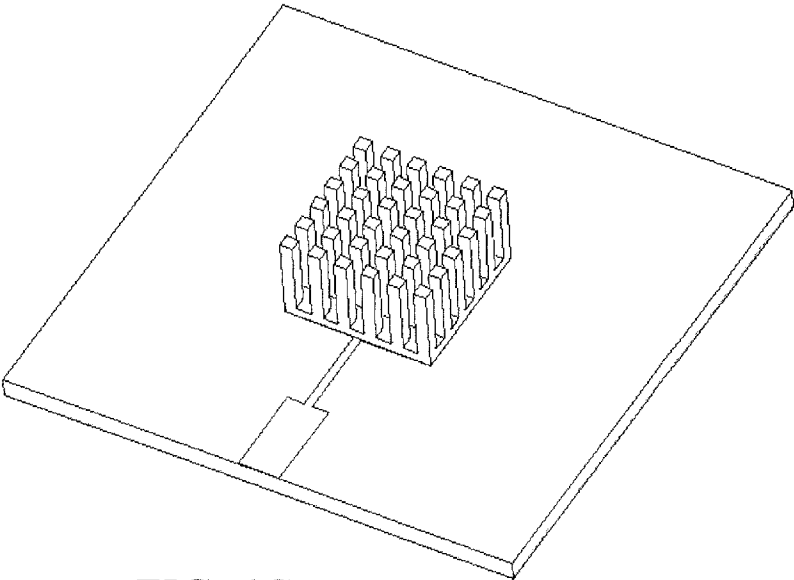


FIG. 4C

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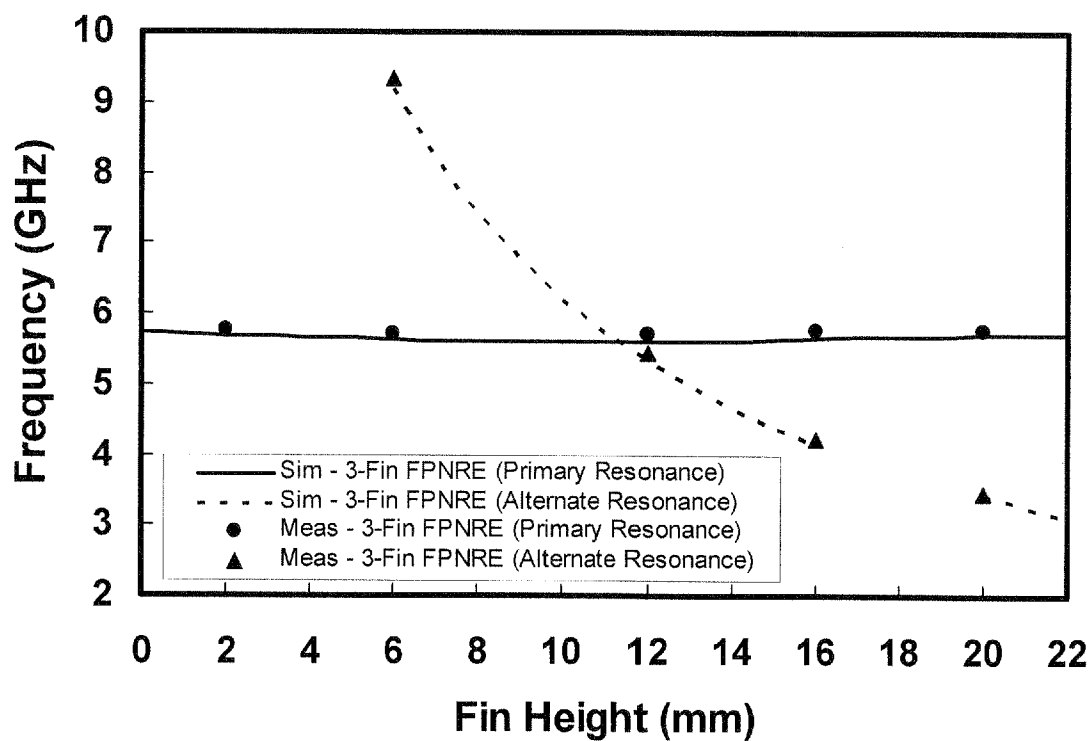


FIG. 5

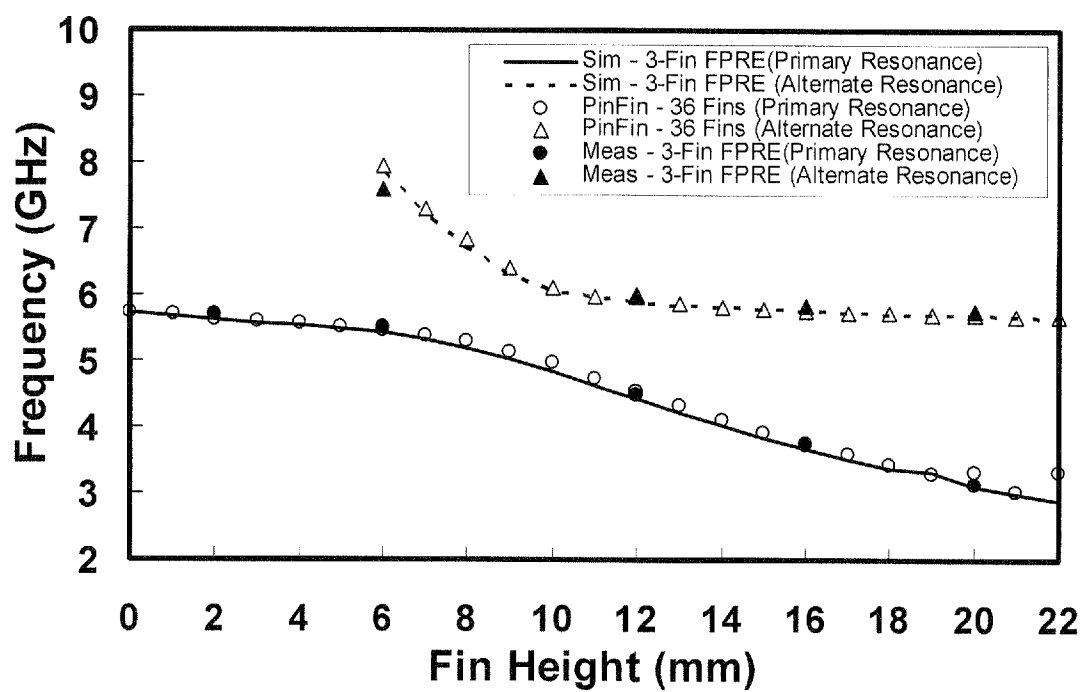


FIG. 6

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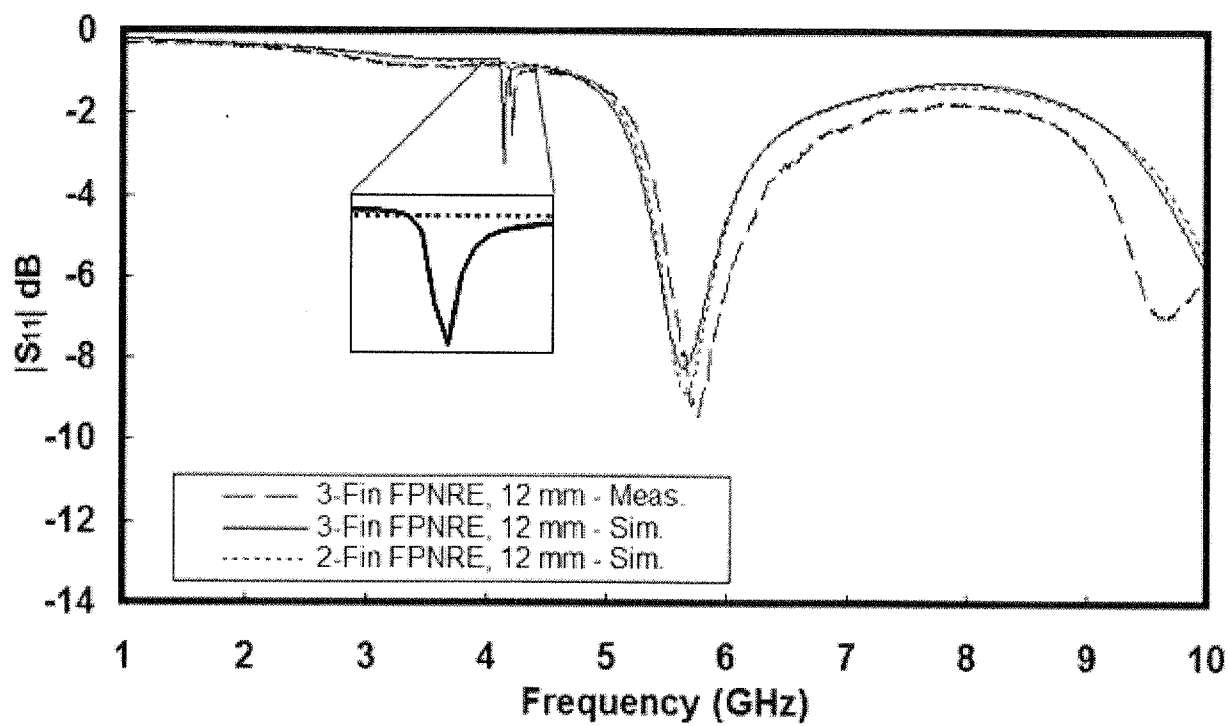


FIG. 7

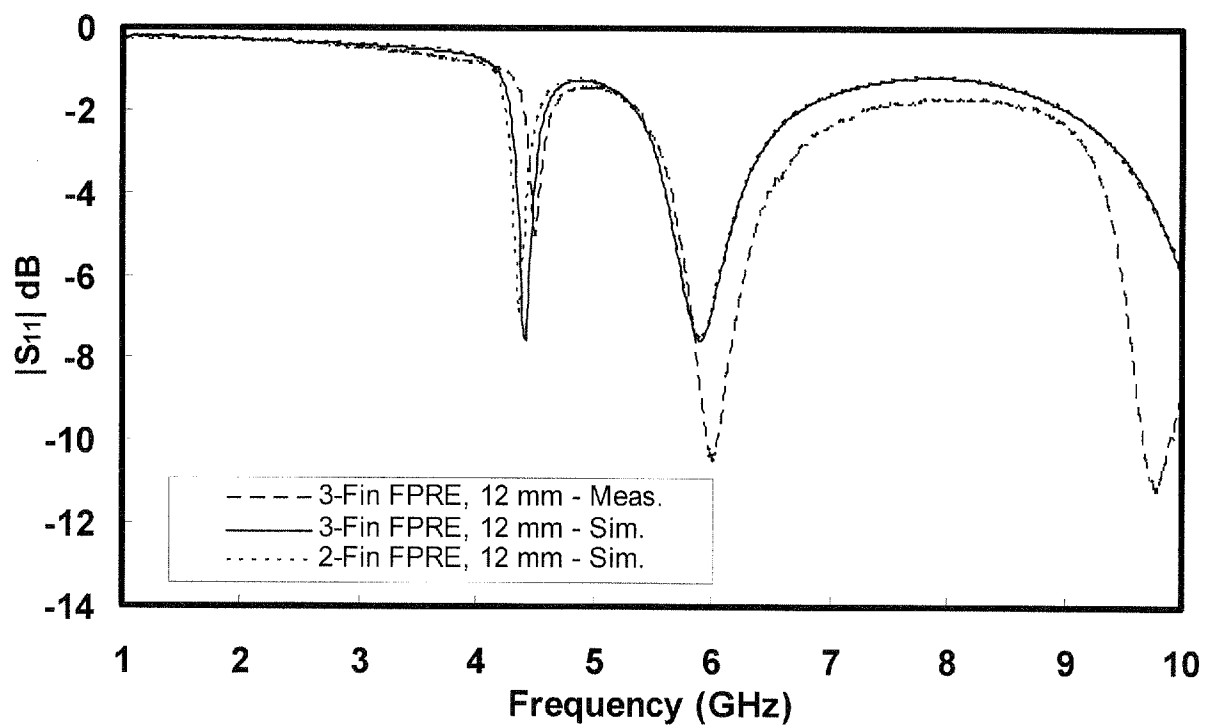
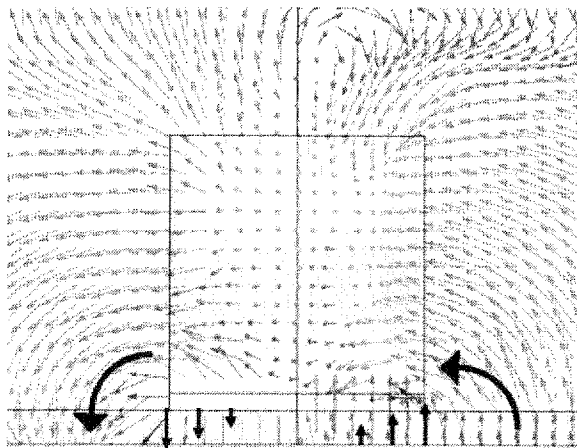
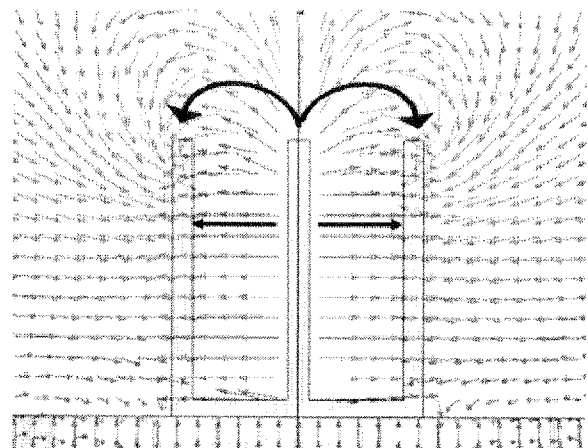


FIG. 8



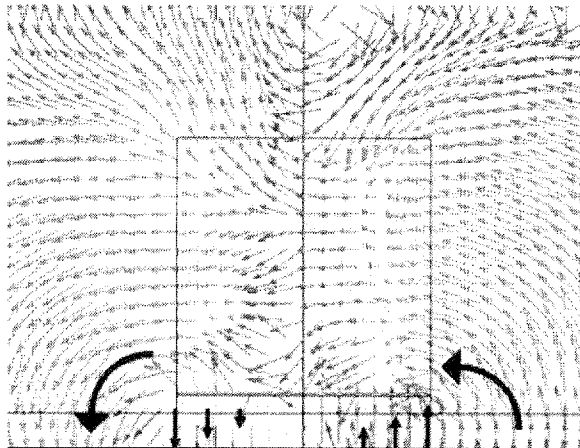
Primary resonance
3-Fin FPNRE

FIG. 9A



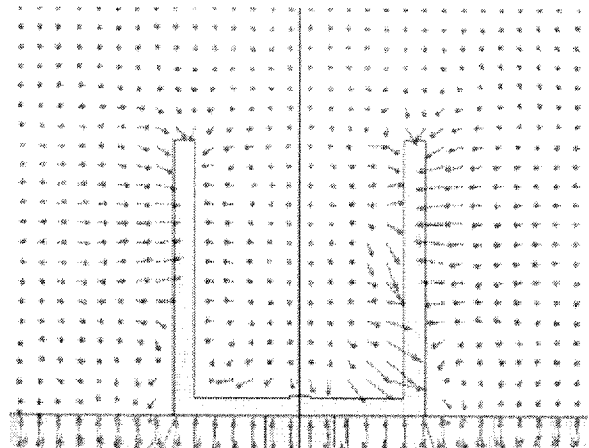
Alternate resonance
3-Fin FPNRE

FIG. 9B



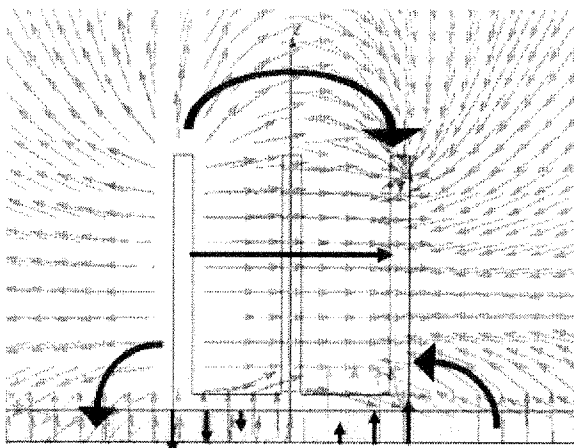
Primary resonance
2-Fin FPNRE

FIG. 10A



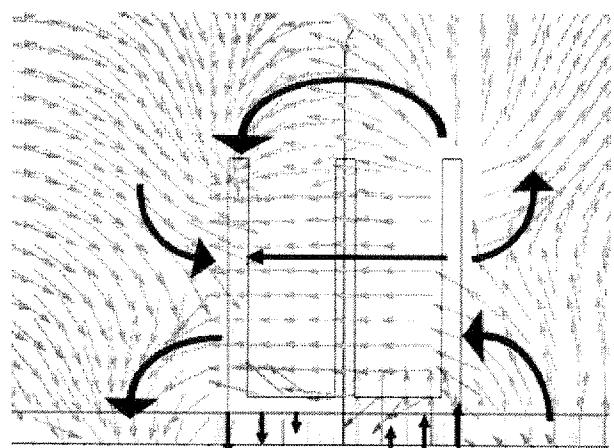
Alternate resonance
2-Fin FPNRE

FIG. 10B



Primary resonance
3-Fin FPRE

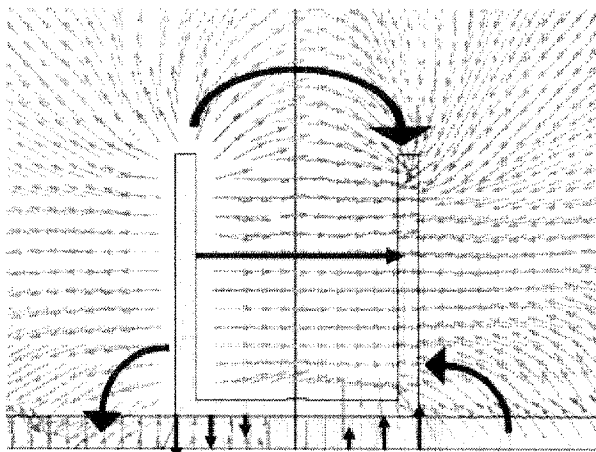
FIG. 11A



Alternate resonance
3-Fin FPRE

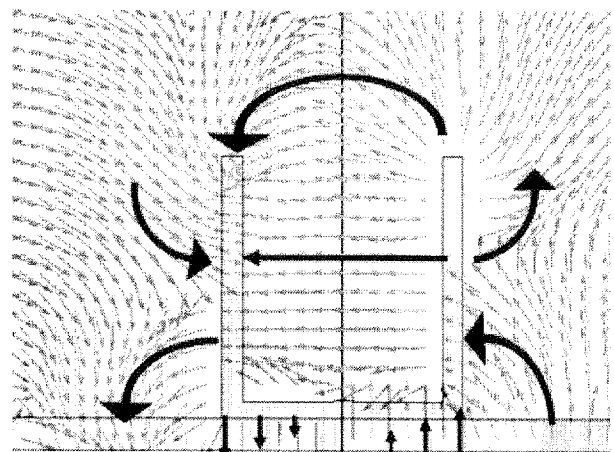
FIG. 11B

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Primary resonance
2-Fin FPRE

FIG. 12A



Alternate resonance
2-Fin FPRE

FIG. 12B

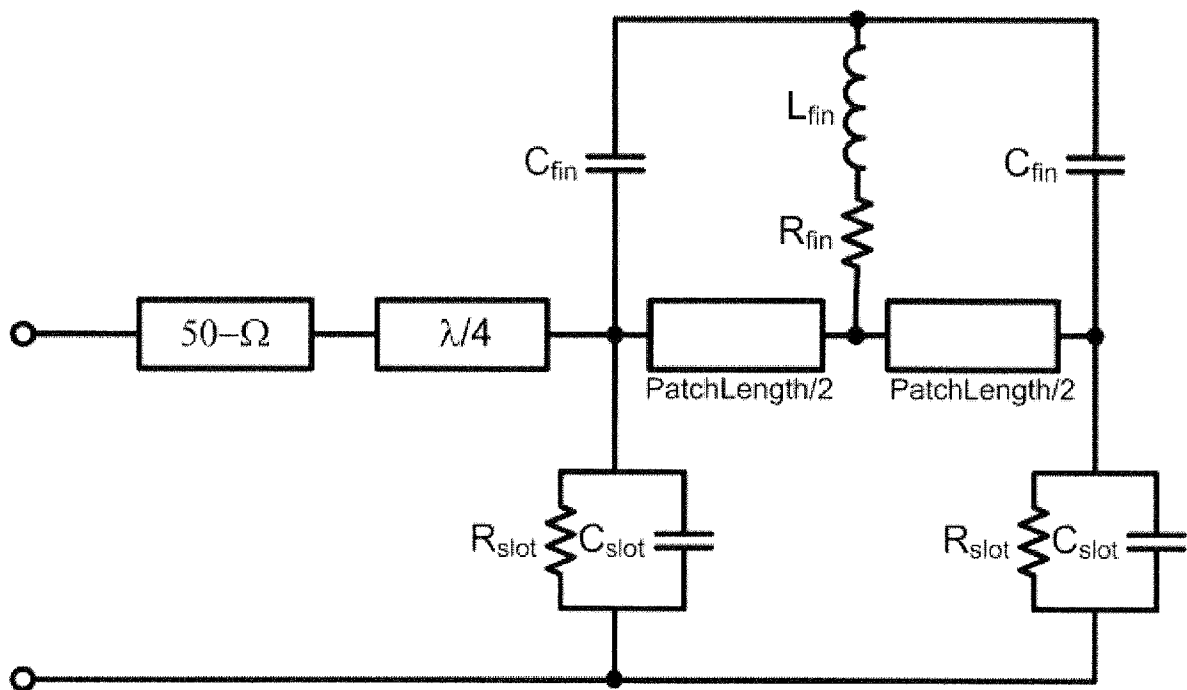


FIG. 13

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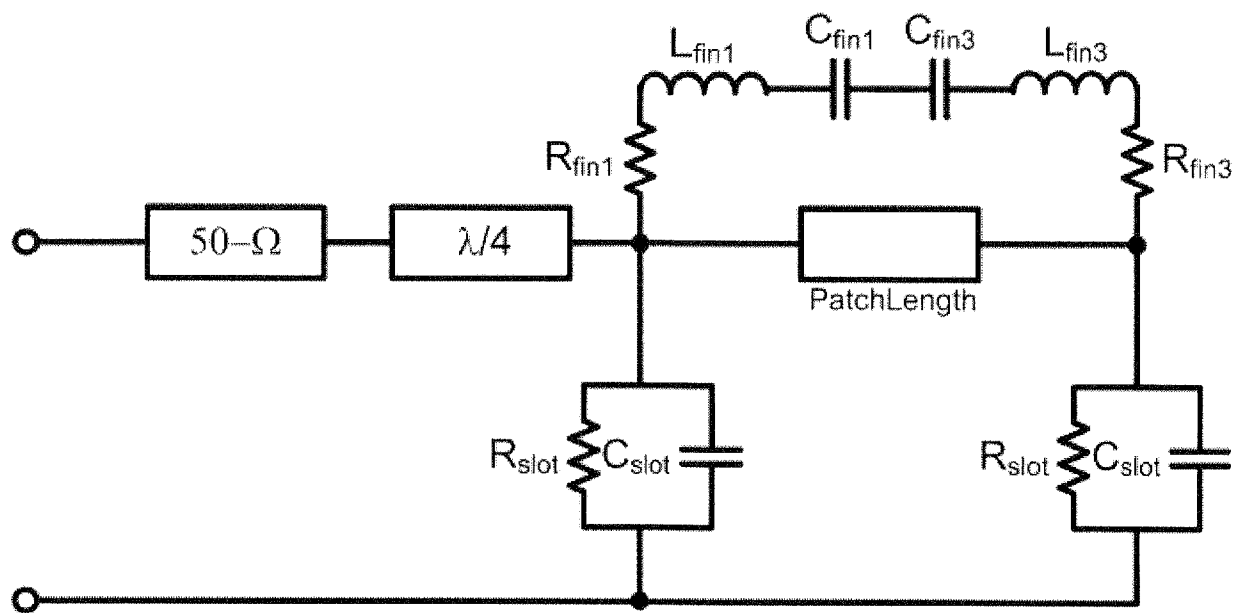
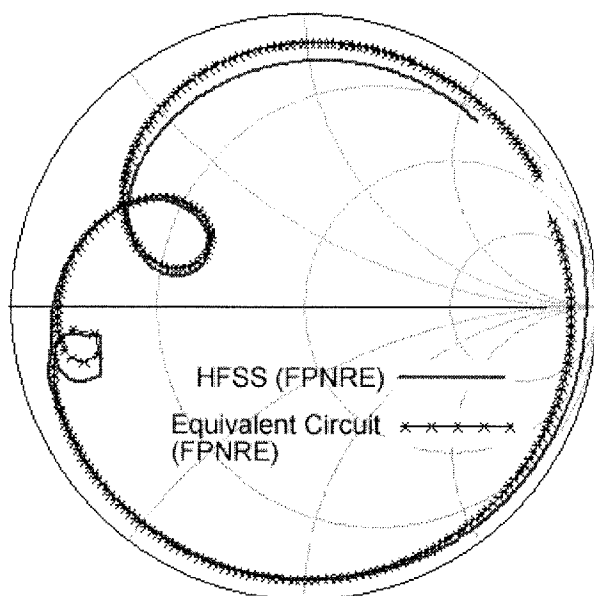
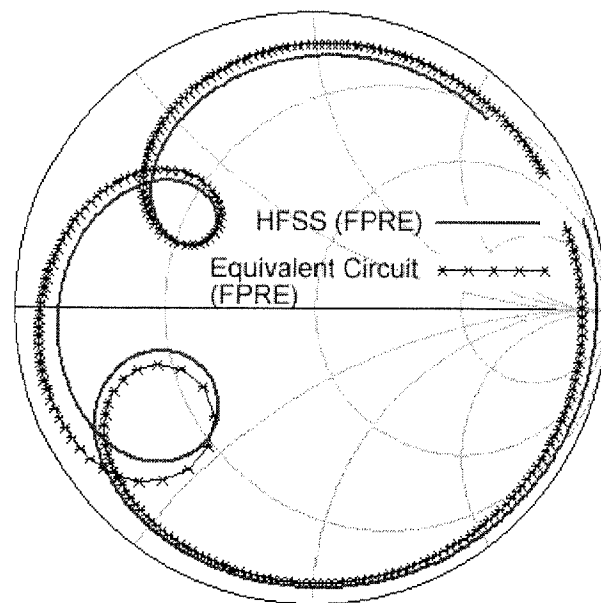


FIG. 14



freq (2.000GHz to 8.000GHz)

FIG. 15



freq (2.000GHz to 8.000GHz)

FIG. 16

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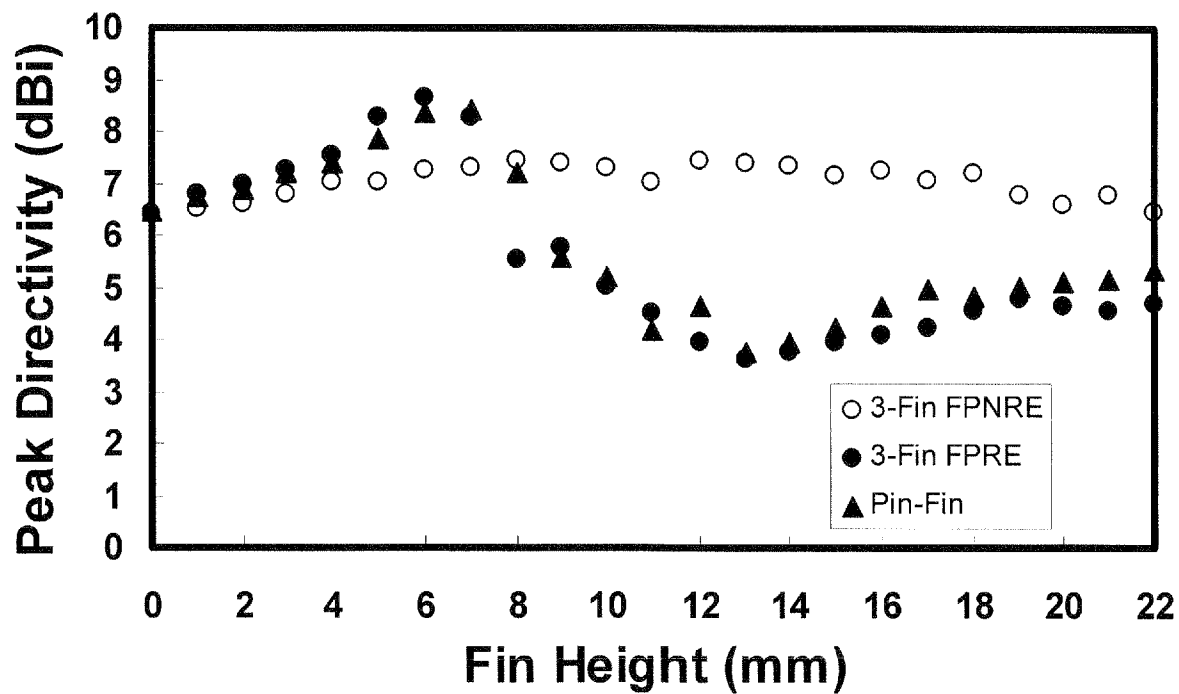
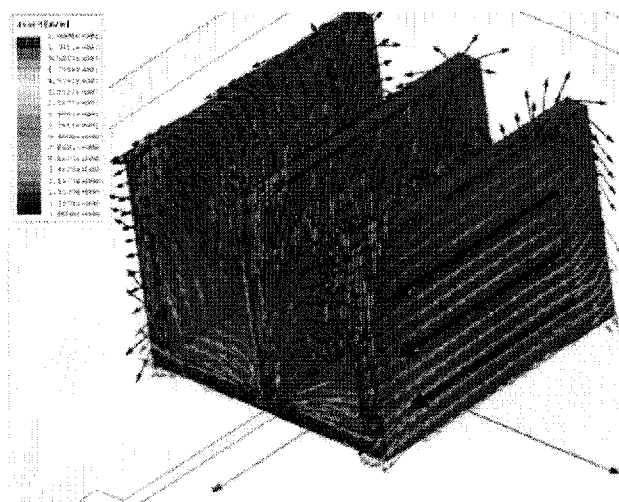
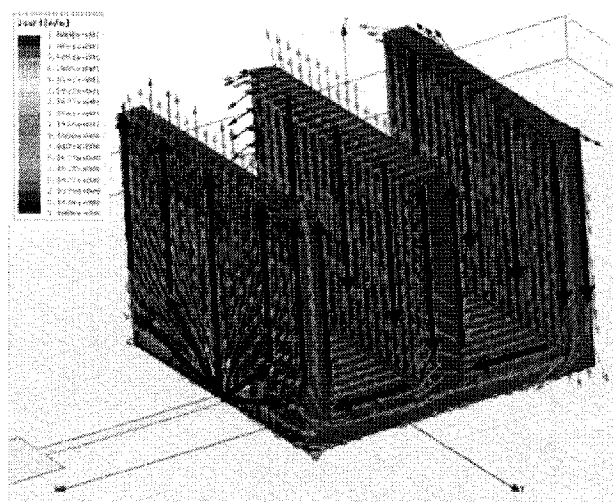


FIG. 17



3-Fin FPNRE

FIG. 18A



3-Fin FPPE

FIG. 18B

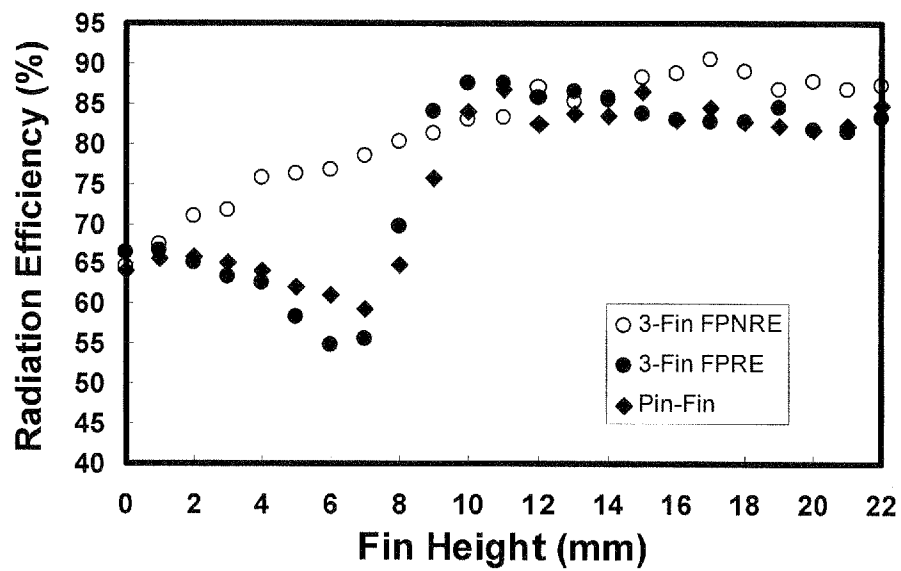


FIG. 19

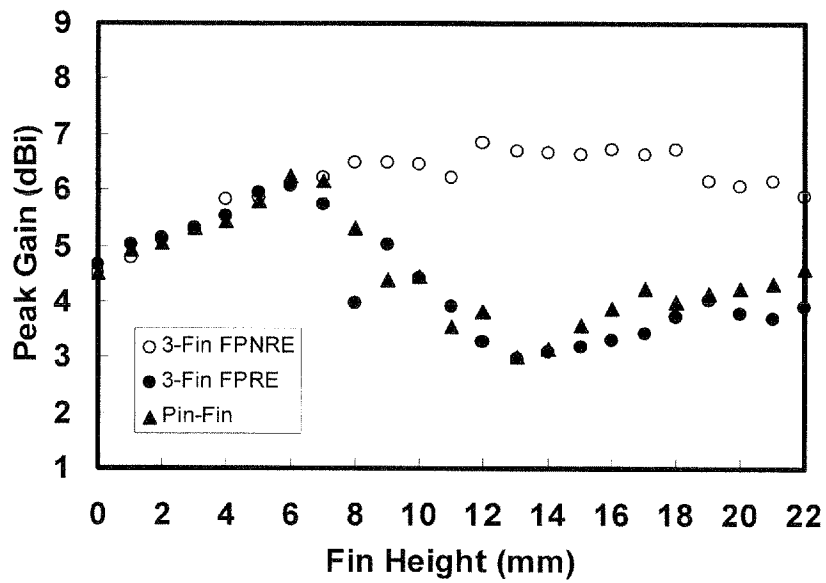


FIG. 20

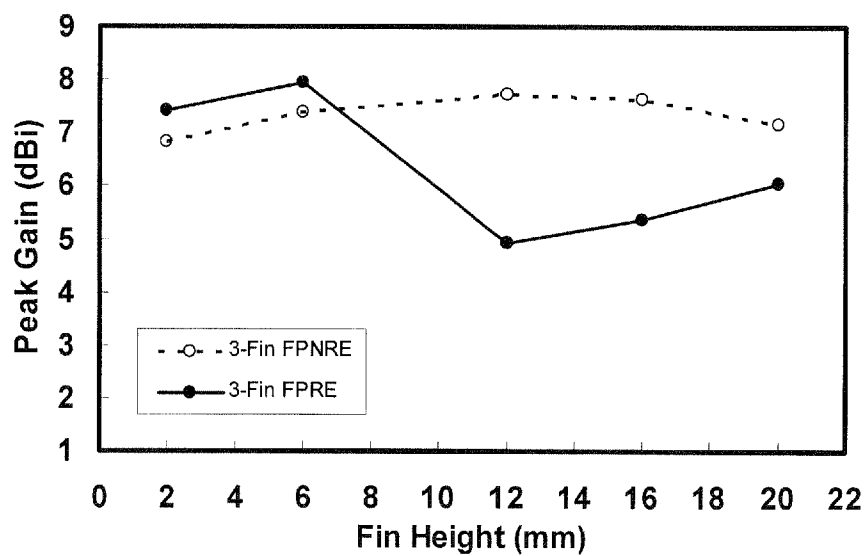


FIG. 21

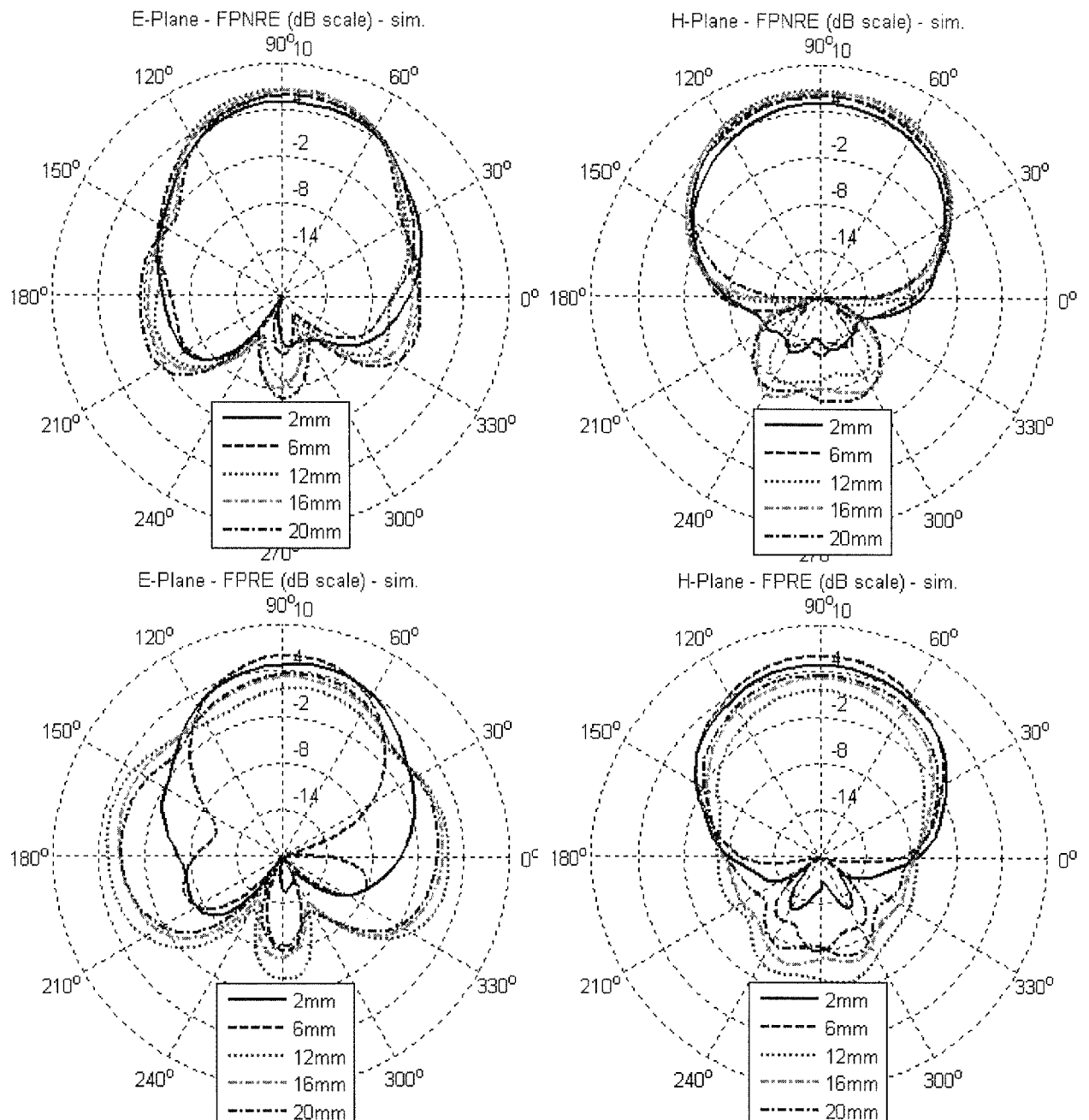


FIG. 22

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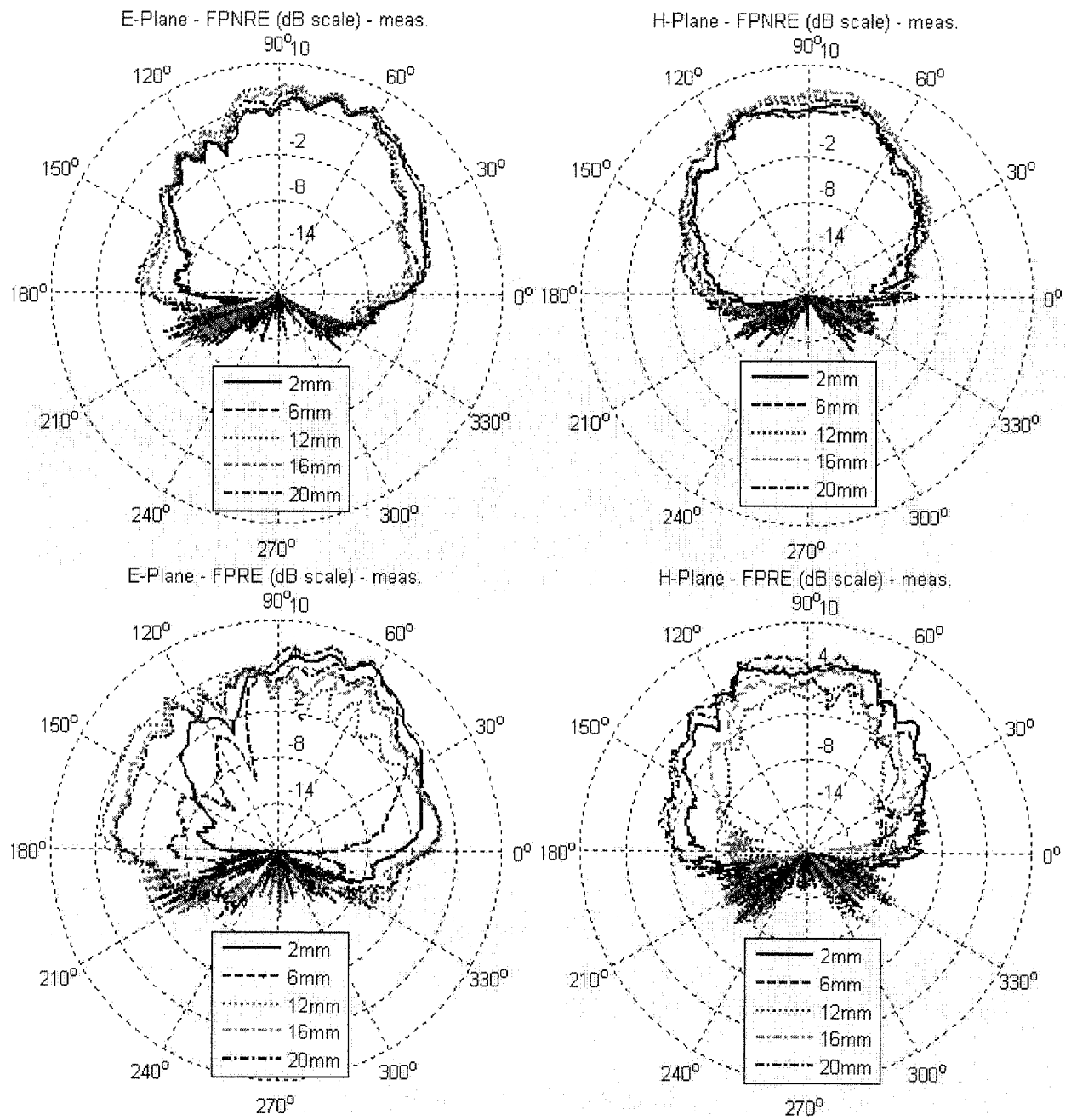


FIG. 23

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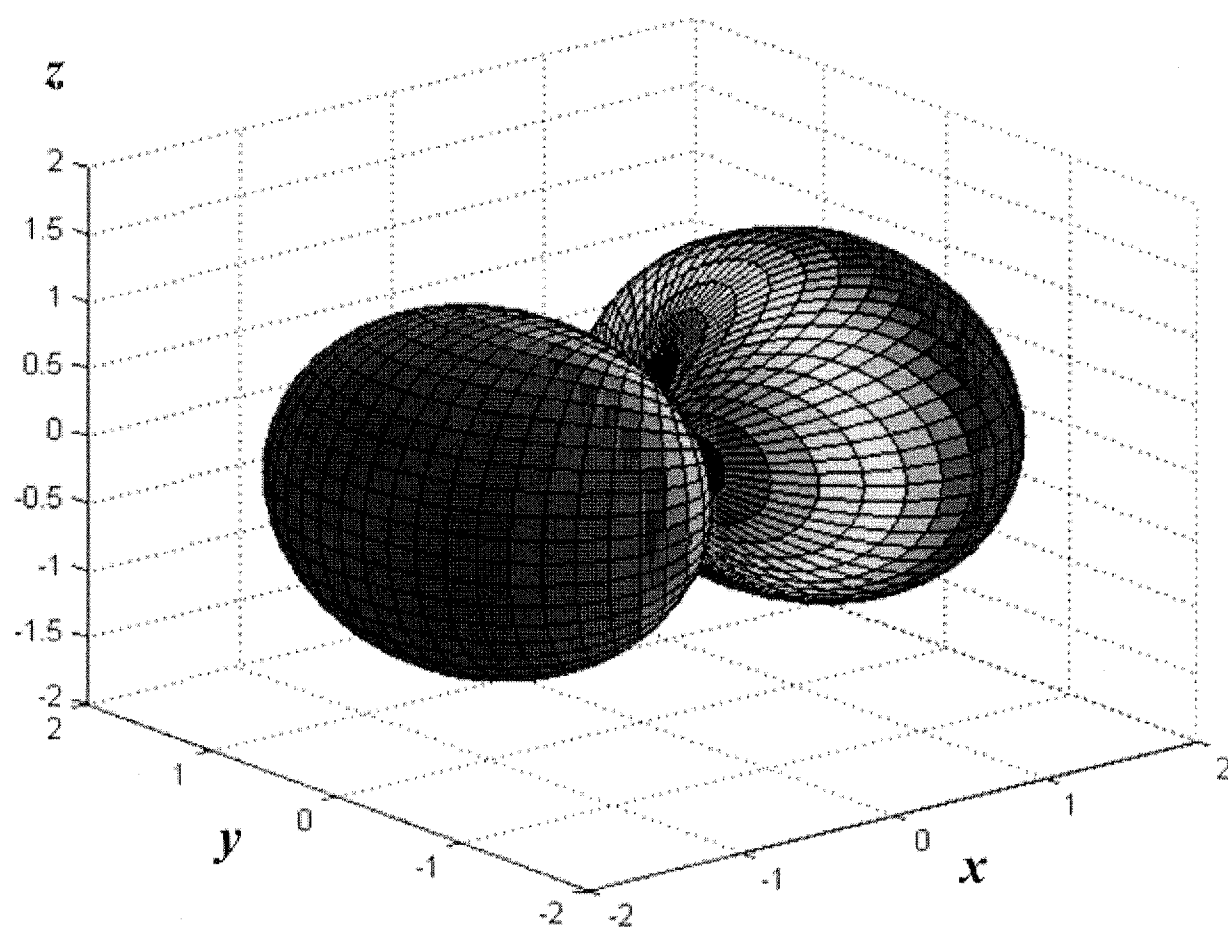


FIG. 24