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(54) **RADIO-FREQUENCY SYSTEM IN PACKAGE INCLUDING ANTENNA**

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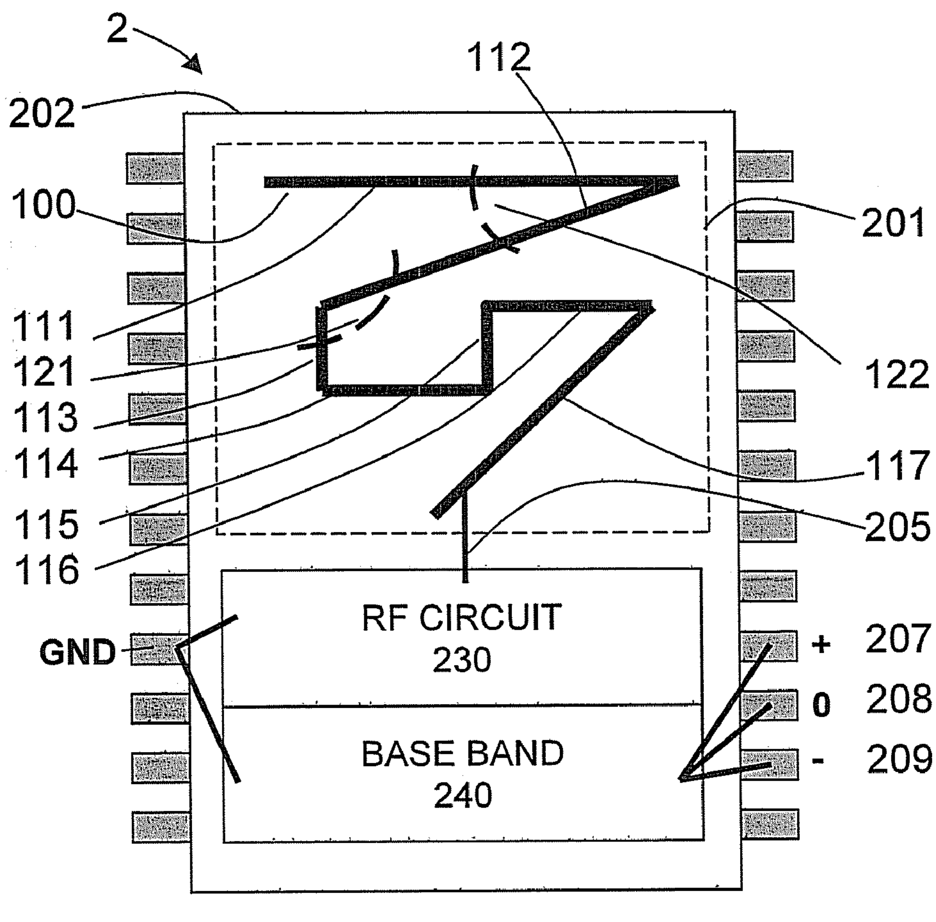
(57) **ABSTRACT**

A system comprising at least one antenna and a circuit, wherein the circuit is at least in part not a semiconductor chip or a die. The at least one antenna and the circuit are arranged on a package. Alternatively described is a system comprising at least one antenna and at least one circuit, wherein the at least one antenna and the at least one circuit are arranged on a package, wherein the at least one circuit performs a radio-frequency and optionally a base-band and/or a digital functionality.



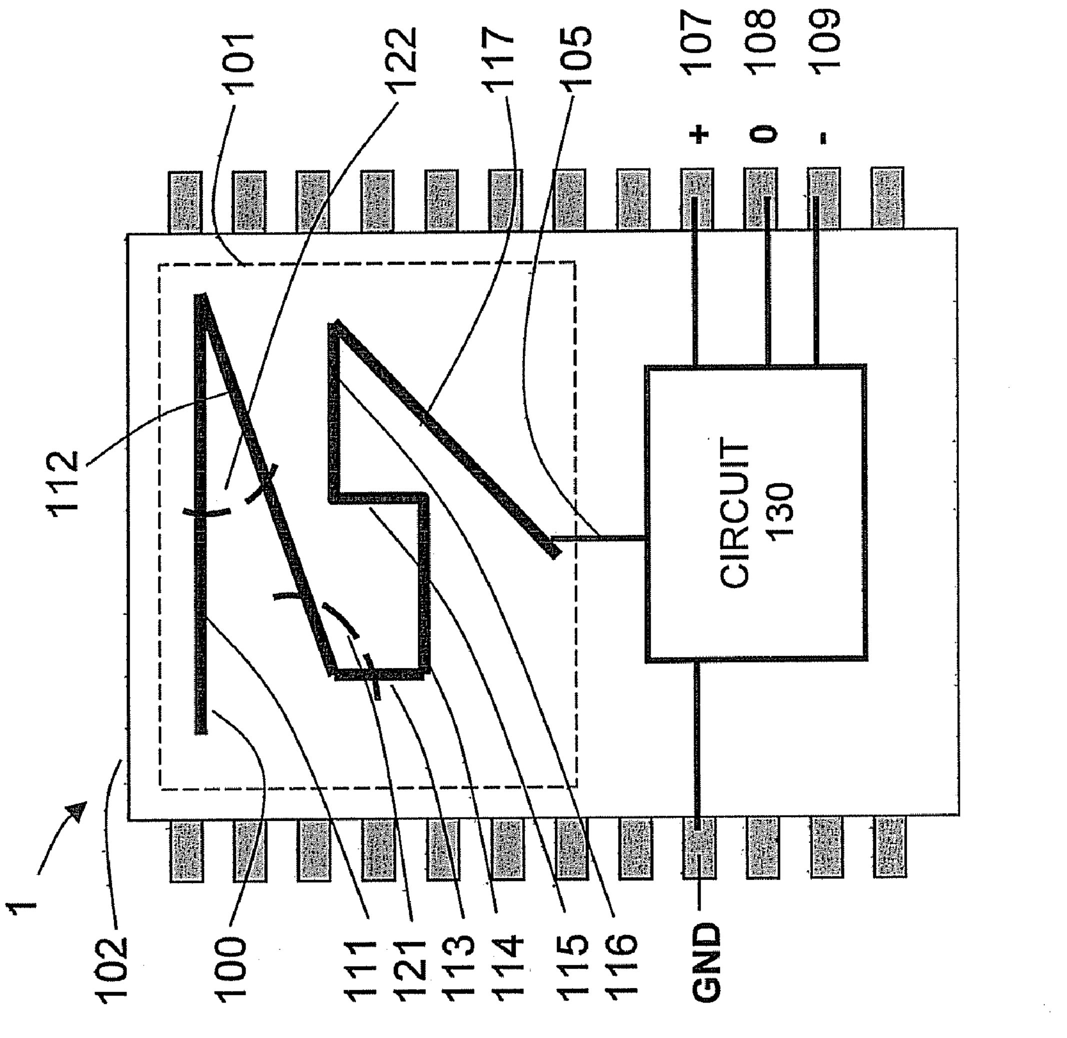

1
102
100
111
121
113
114
115
116
GND
112
101
122
117
105
107
108
109
+
0
-
CIRCUIT
130

Fig.1

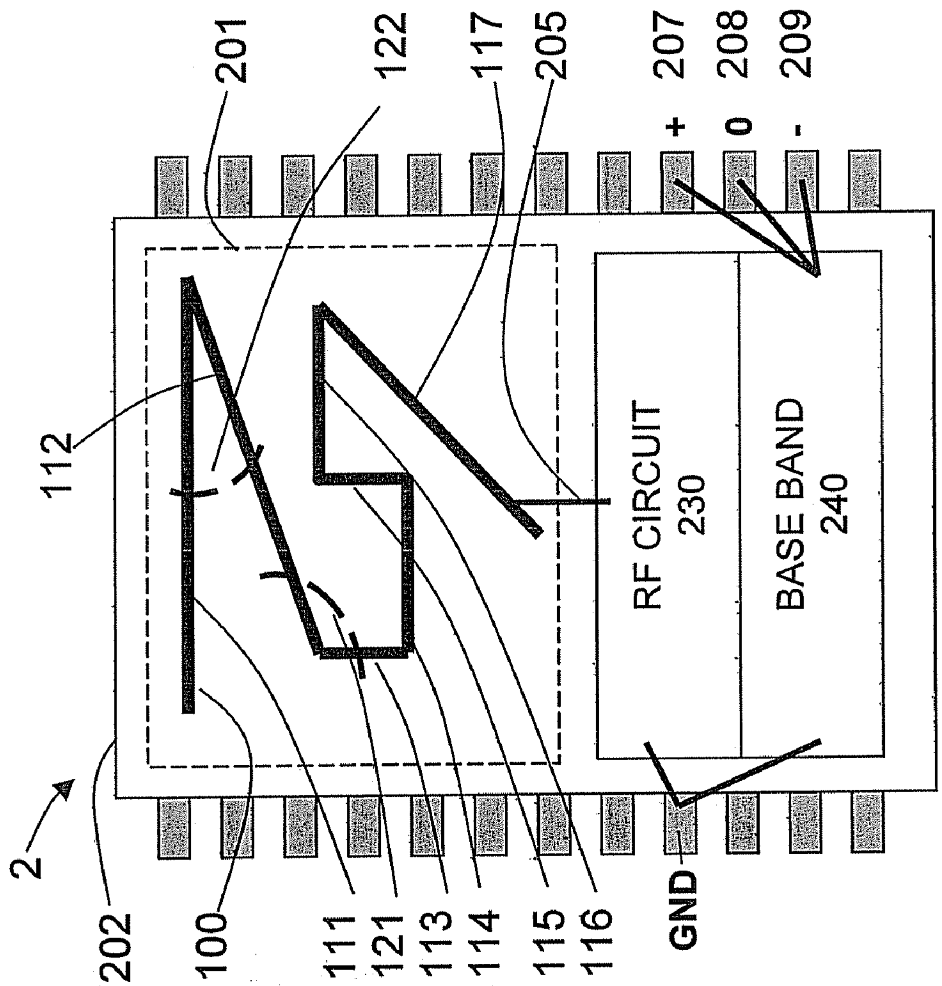

201
122
117
205
207
208
209
+
0
-
112
RF CIRCUIT
230
BASE BAND
240
2
202
100
111
121
113
114
115
116
GND

Fig.2

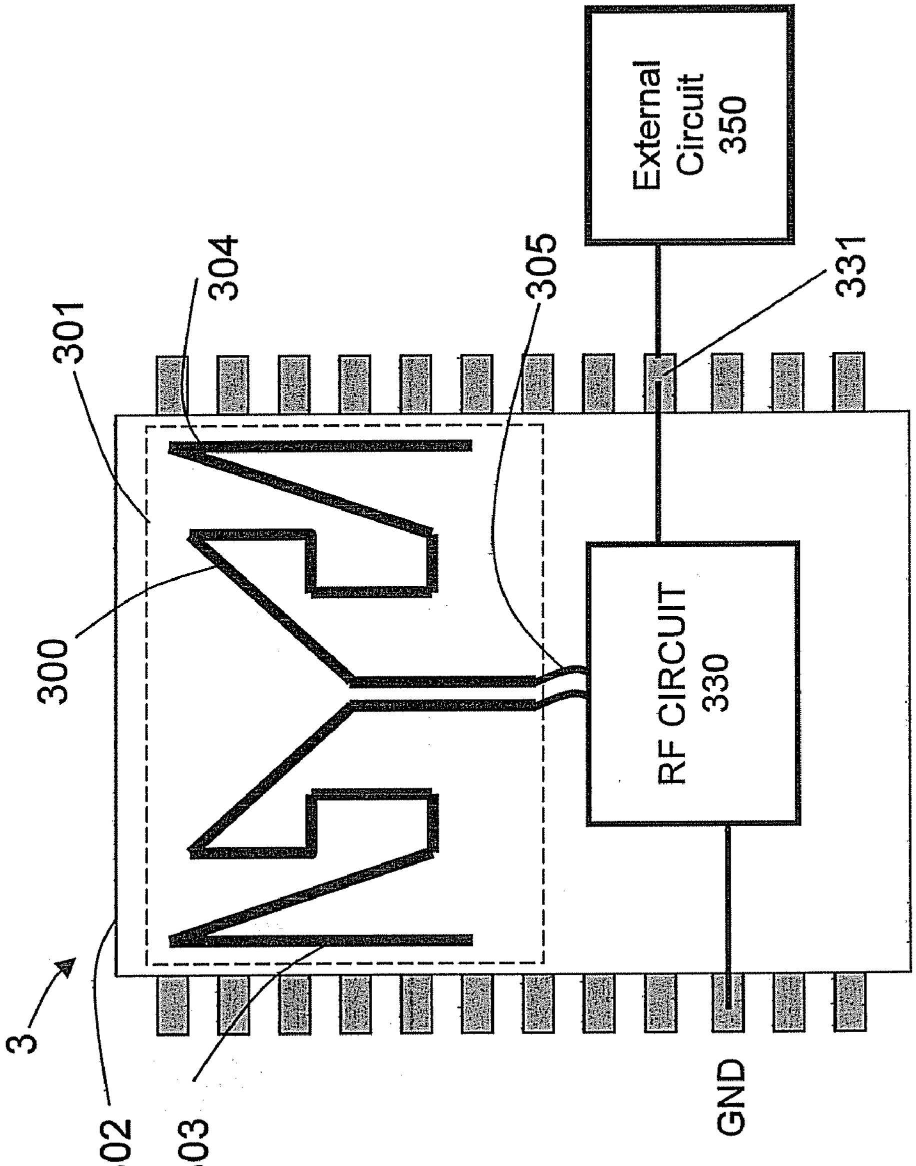
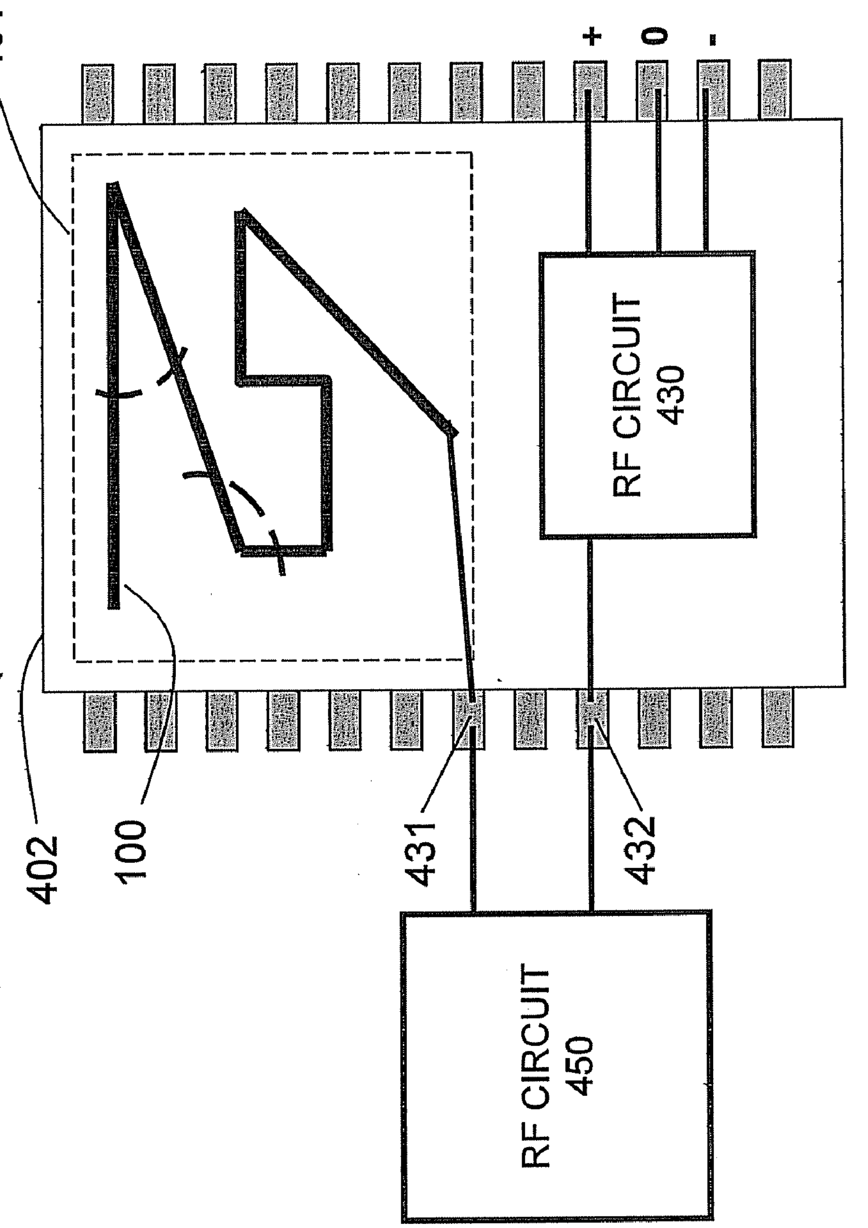
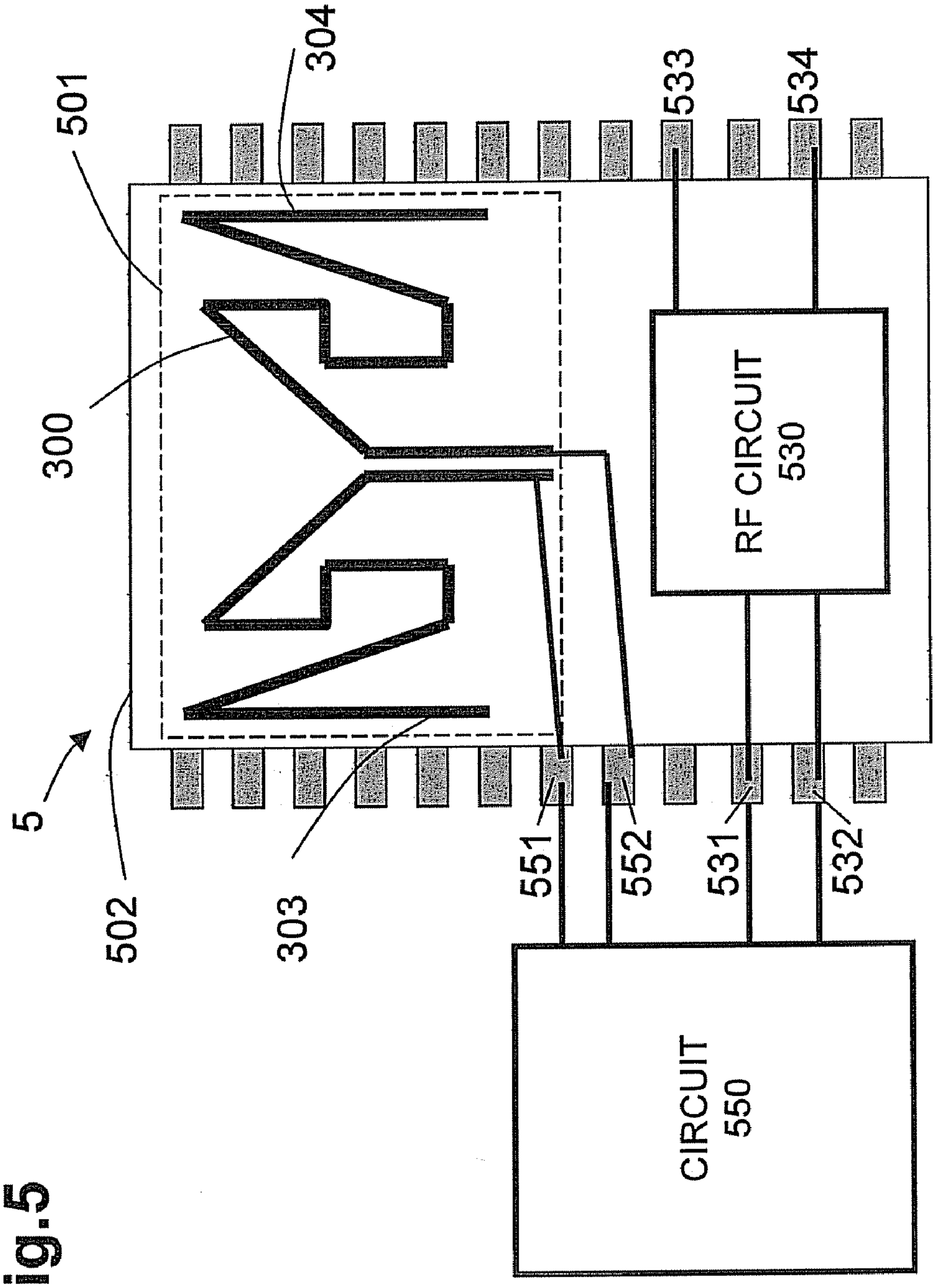

External Circuit 350
304
301
305
331
300
RF CIRCUIT 330
3
302
303
GND

Fig.3

Fig.4

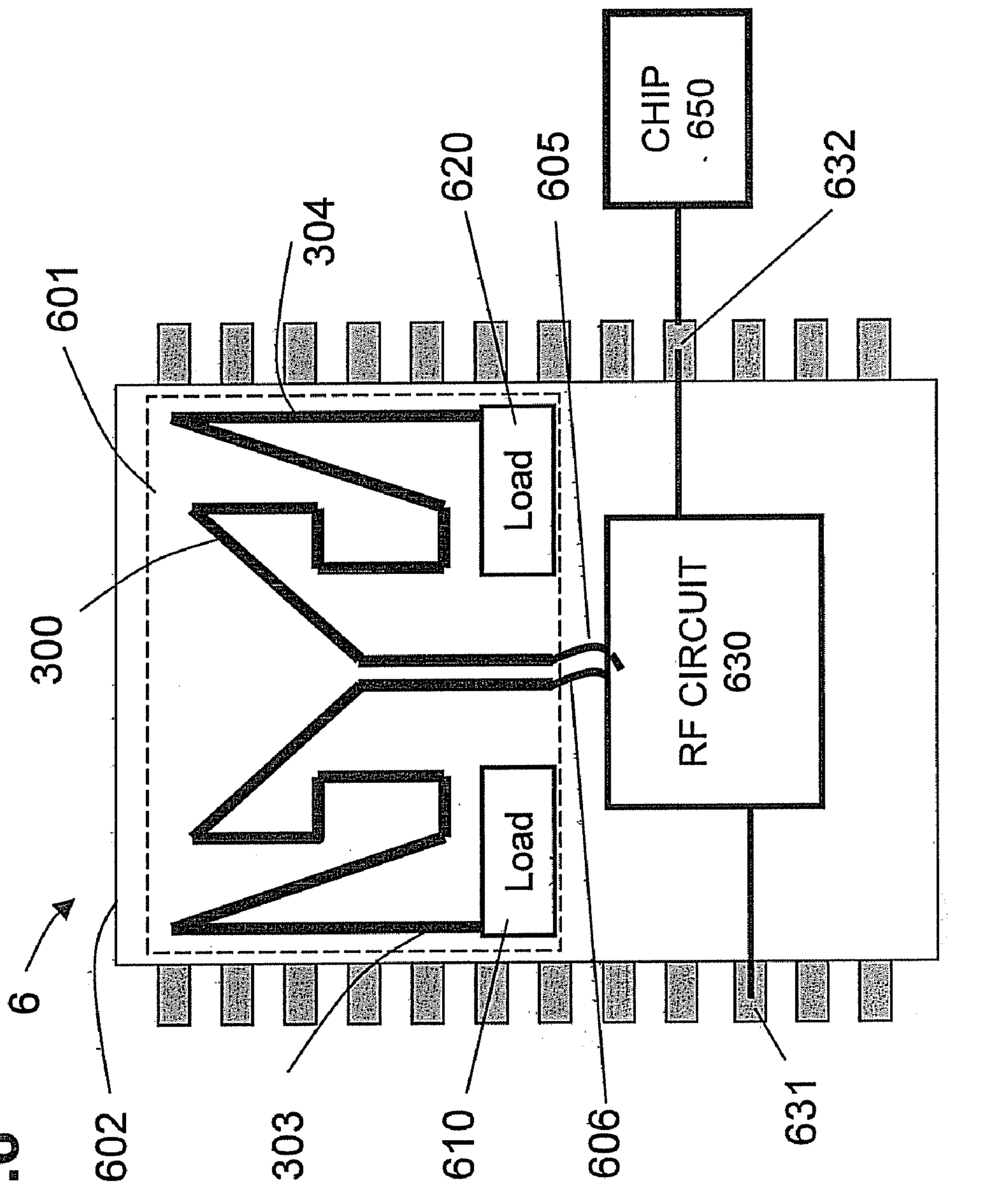




5
501
502
300
303
304
533
534
551
552
531
532
RF CIRCUIT
530
CIRCUIT
550

Fig.5

Fig.6


6
601
602
300
303
304
610
620
605
606
Load
Load
RF CIRCUIT
630
CHIP
650
631
632

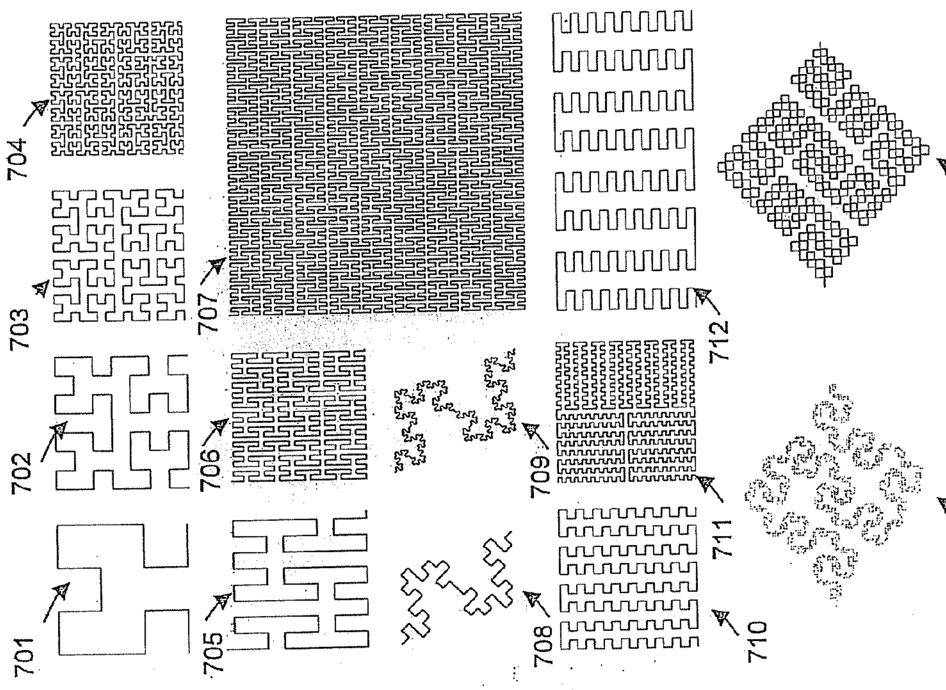
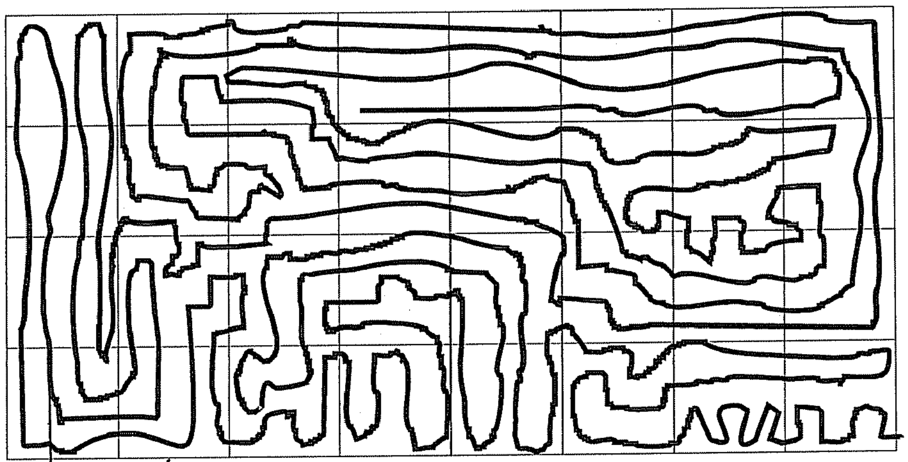


Fig.7

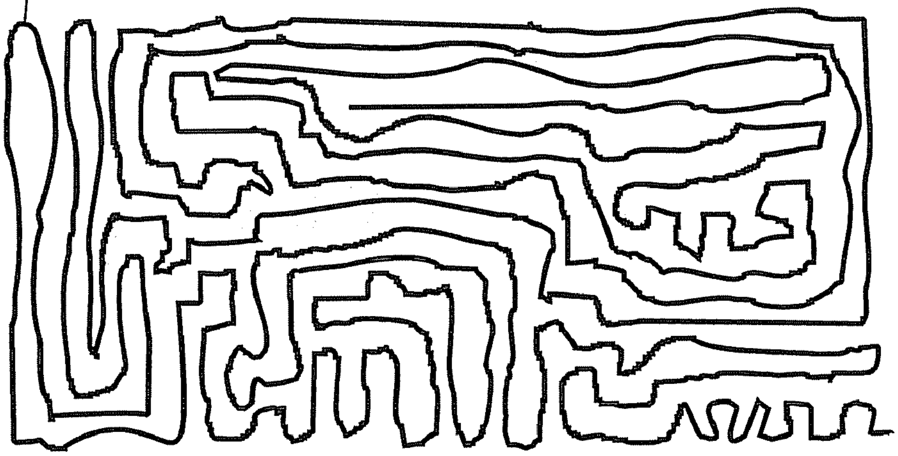
Fig.8B



800

801

Fig.8A



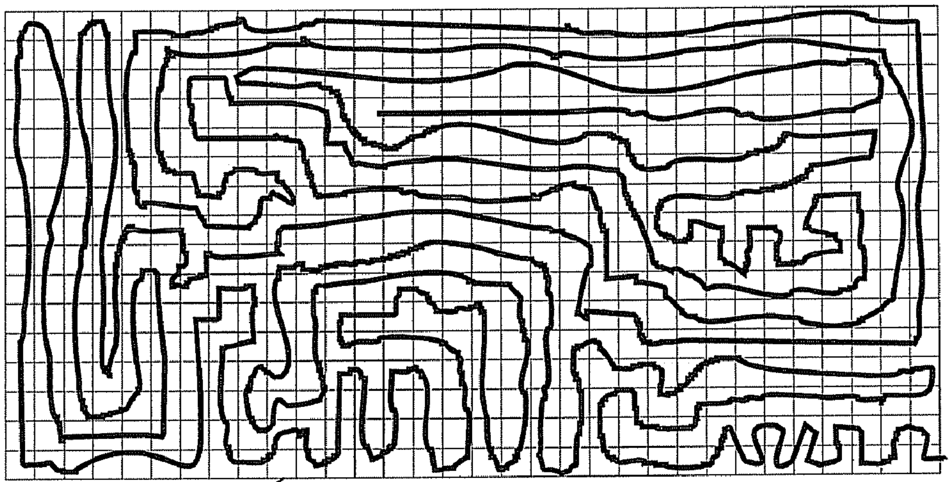


Fig.8D

802

803

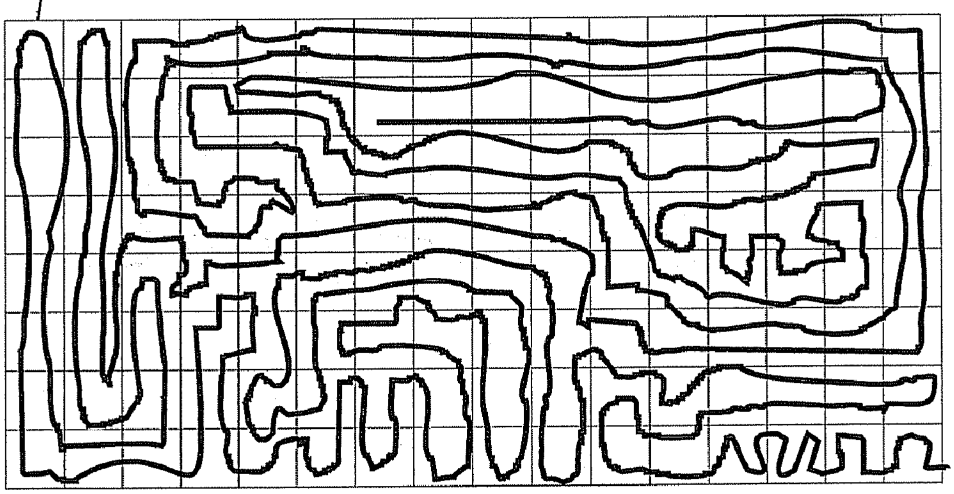


Fig.8C

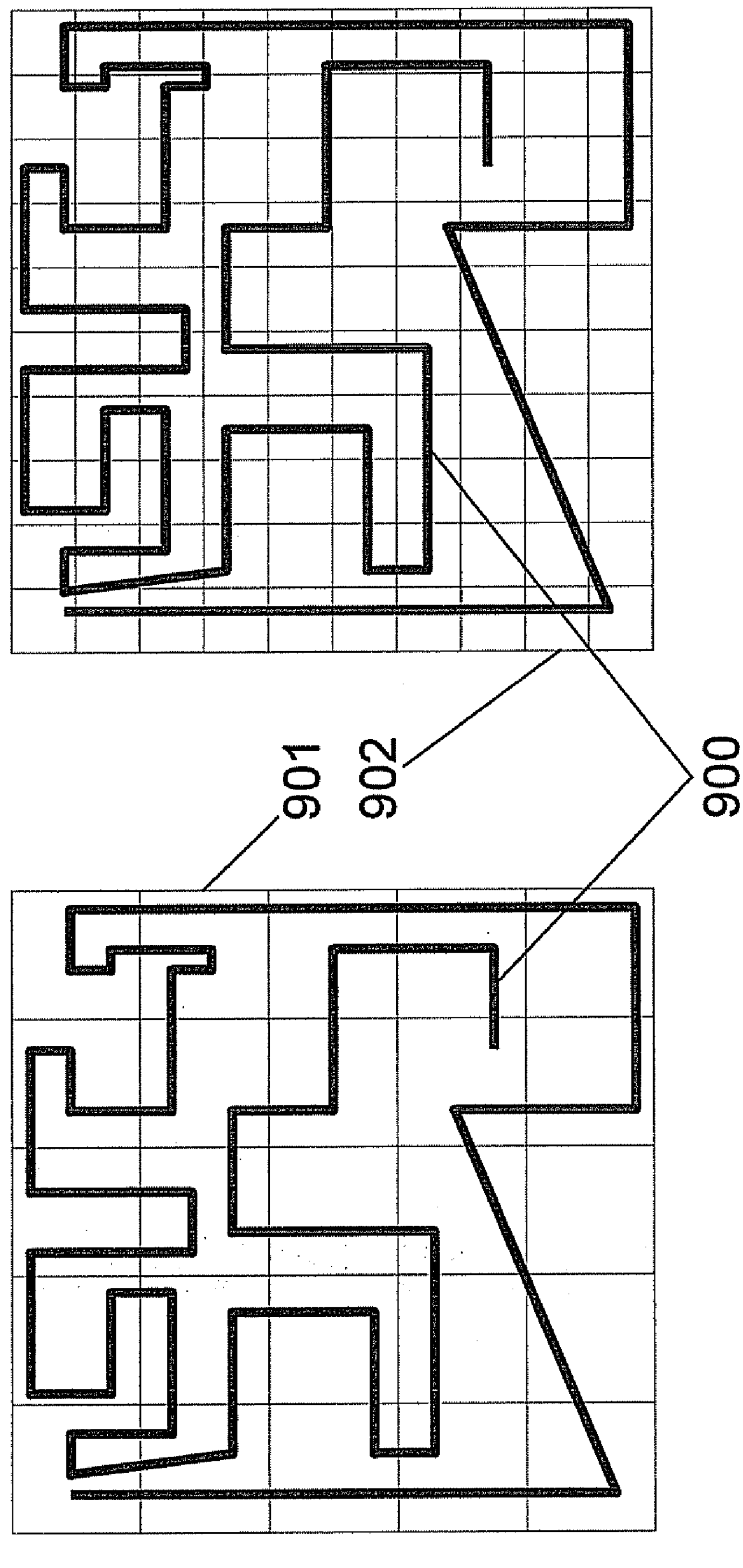


Fig.9B

Fig.9A

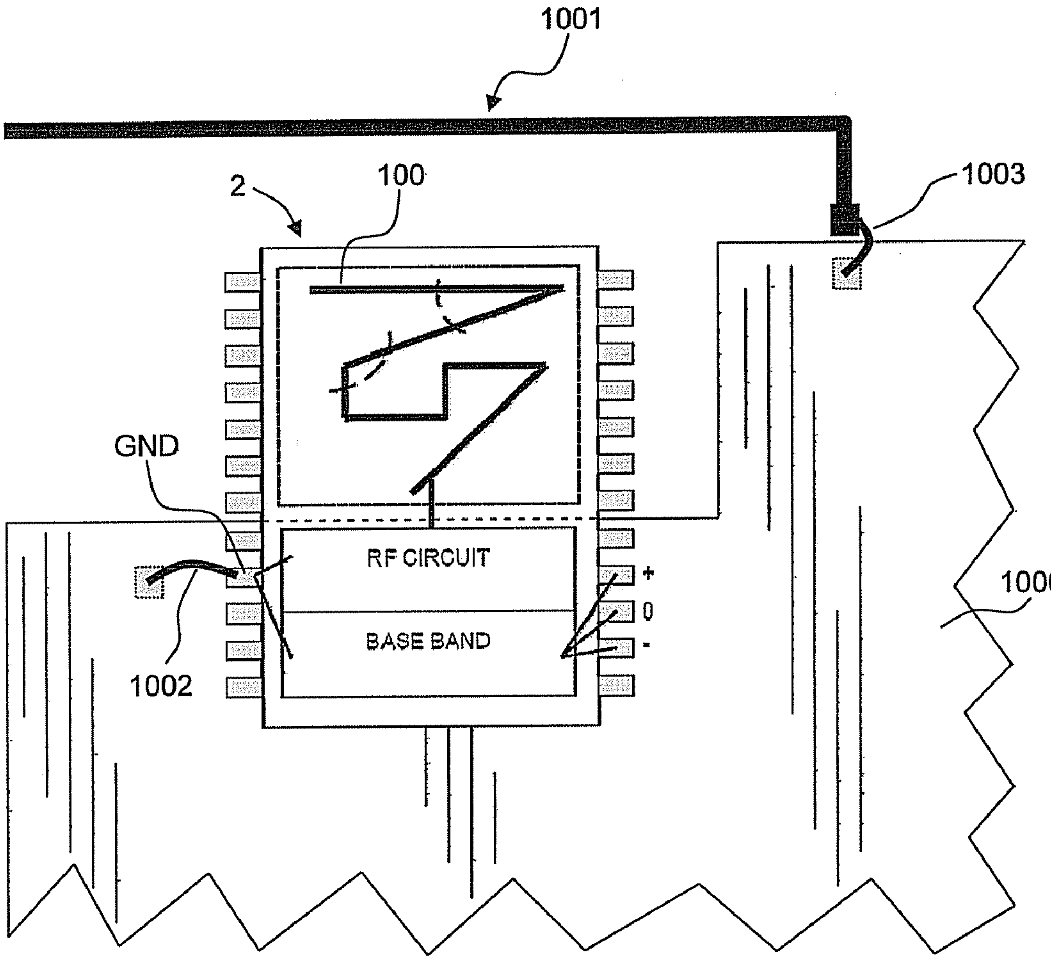


FIG. 10

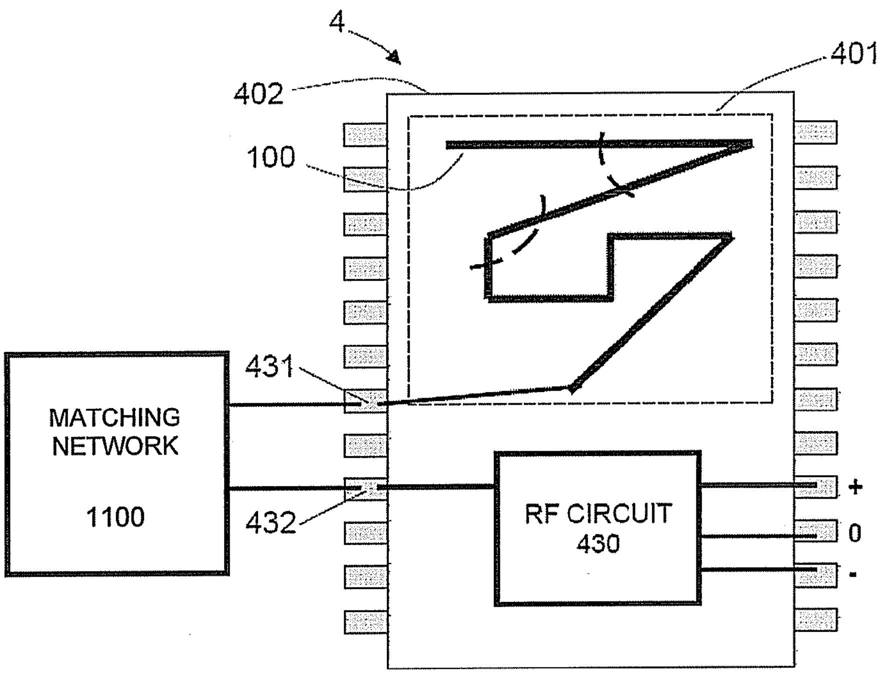

4
401
402
100
MATCHING NETWORK
1100
431
432
RF CIRCUIT
430
+
0
-

FIG. 11

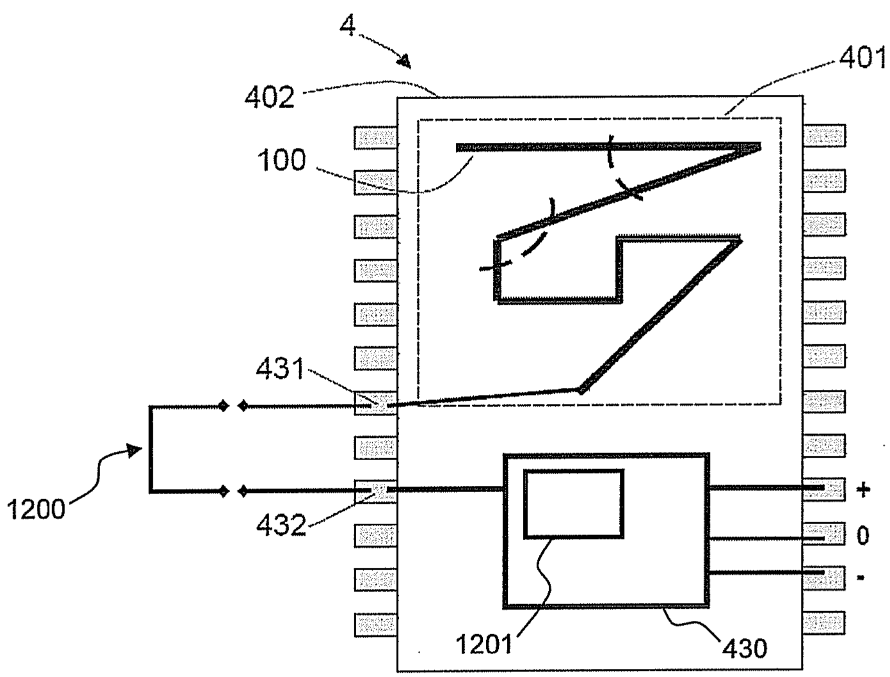

4
401
402
100
431
1200
432
+
0
-
1201
430

FIG. 12

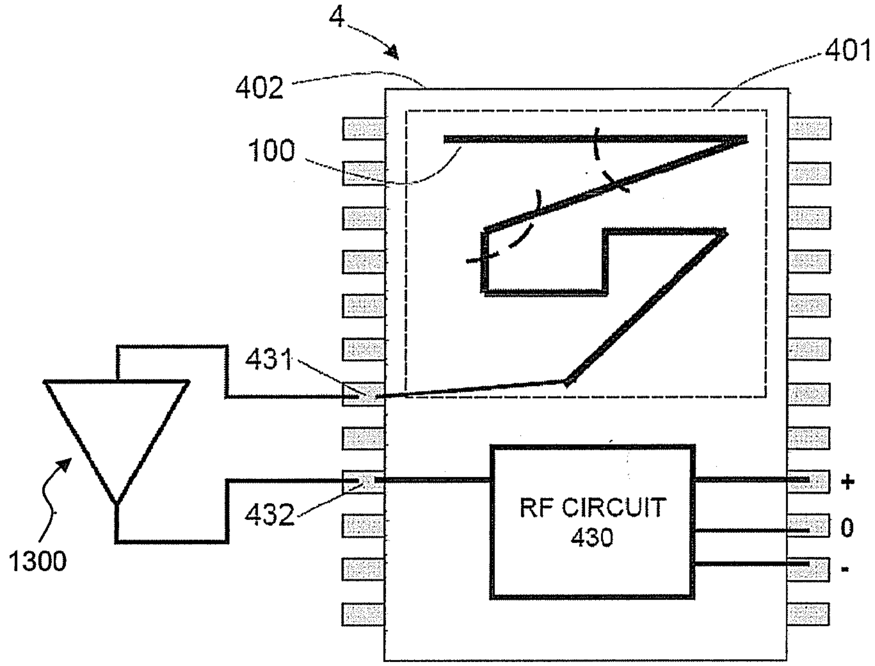

4
401
402
100
431
432
1300
RF CIRCUIT
430
+
0
-

FIG. 13

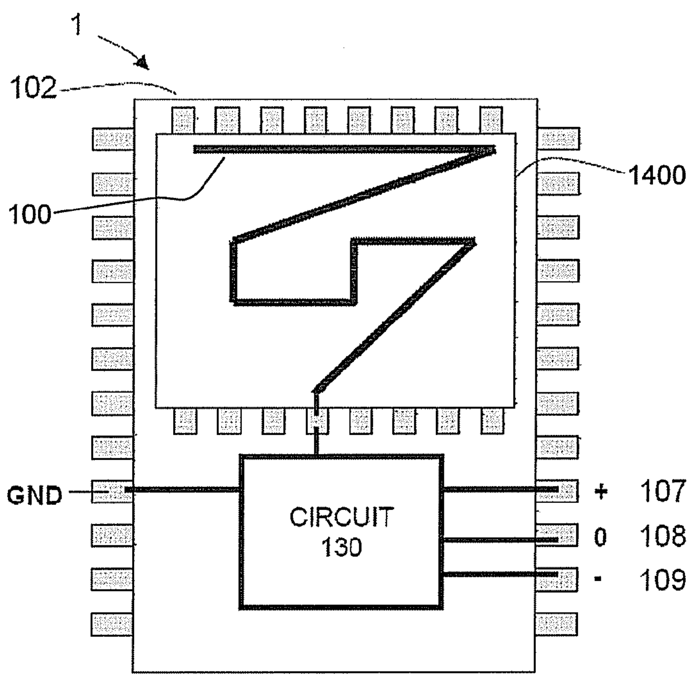

1
102
100
1400
GND
CIRCUIT
130
+
107
0
108
-
109

FIG. 14

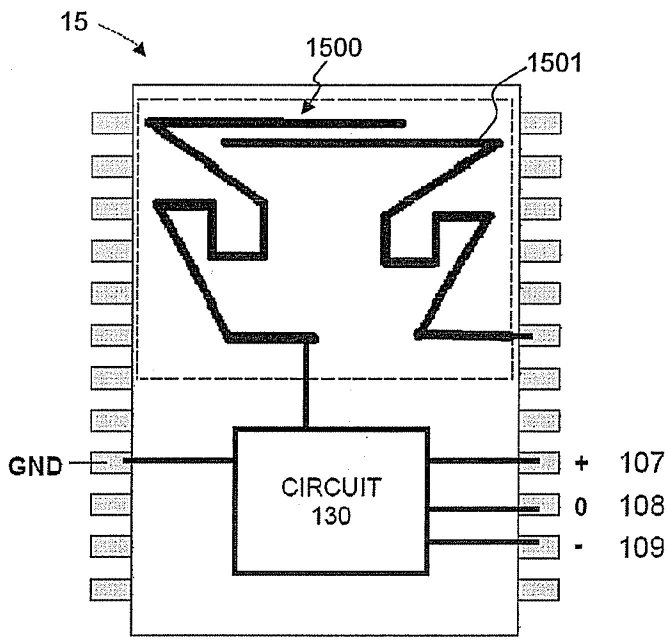

15
1500
1501
GND
CIRCUIT
130
+ 107
0 108
- 109

FIG. 15

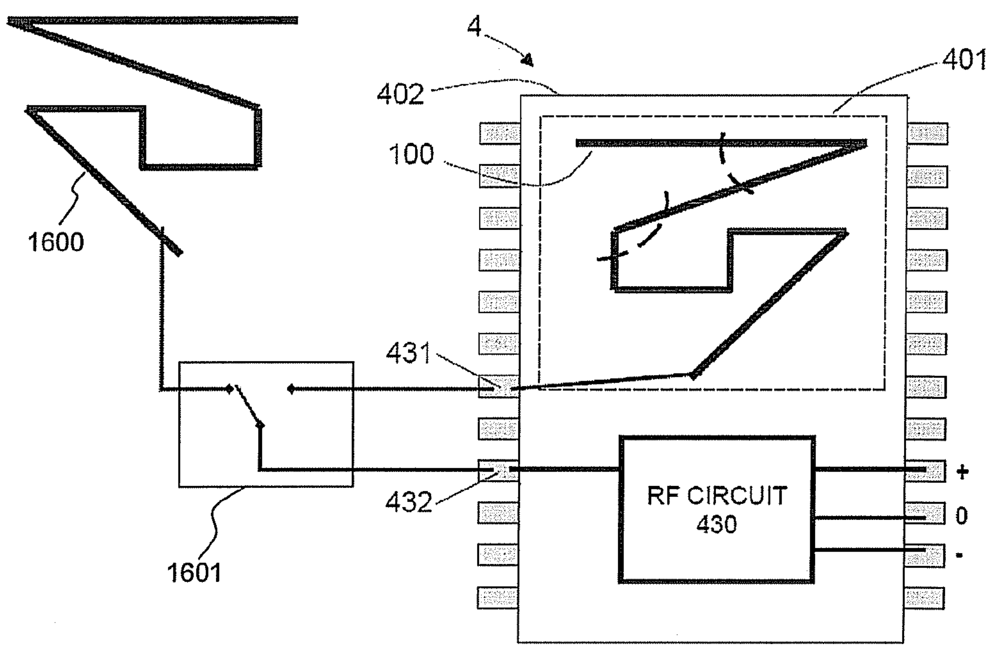

4
401
402
100
1600
431
432
1601
RF CIRCUIT
430
+
0
-

FIG. 16

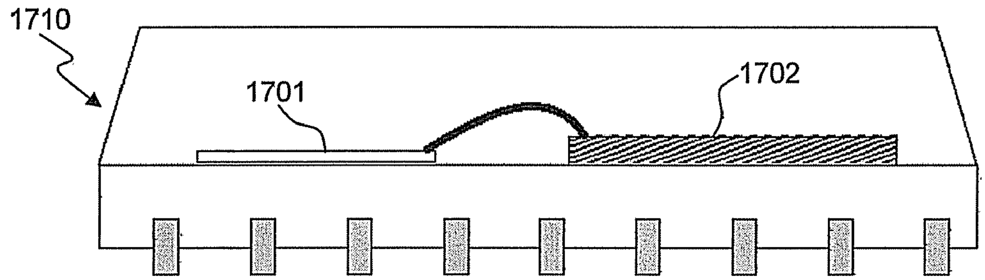


FIG. 17A

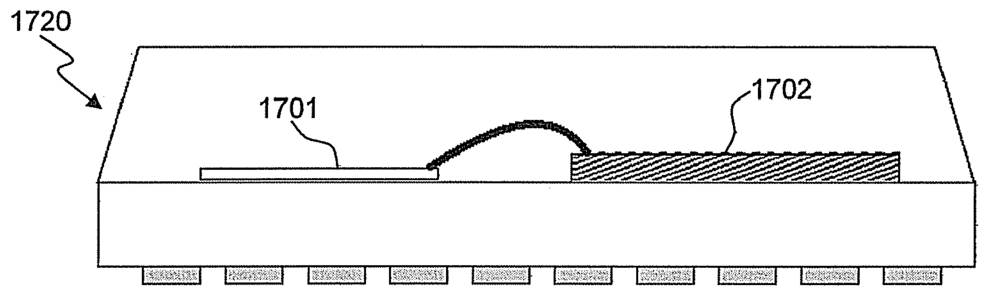


FIG. 17B

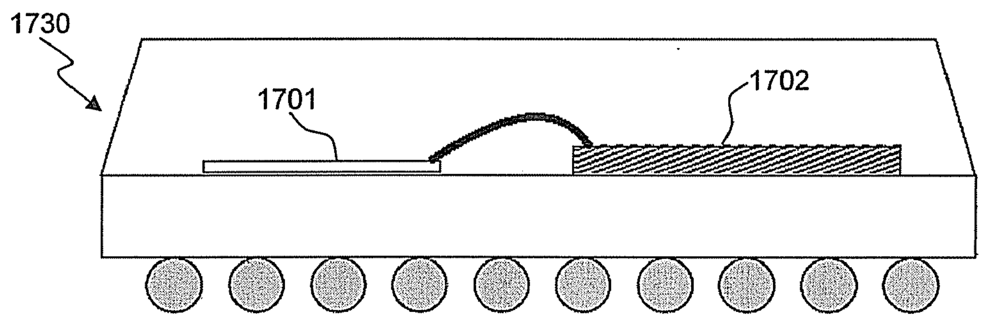


FIG. 17C

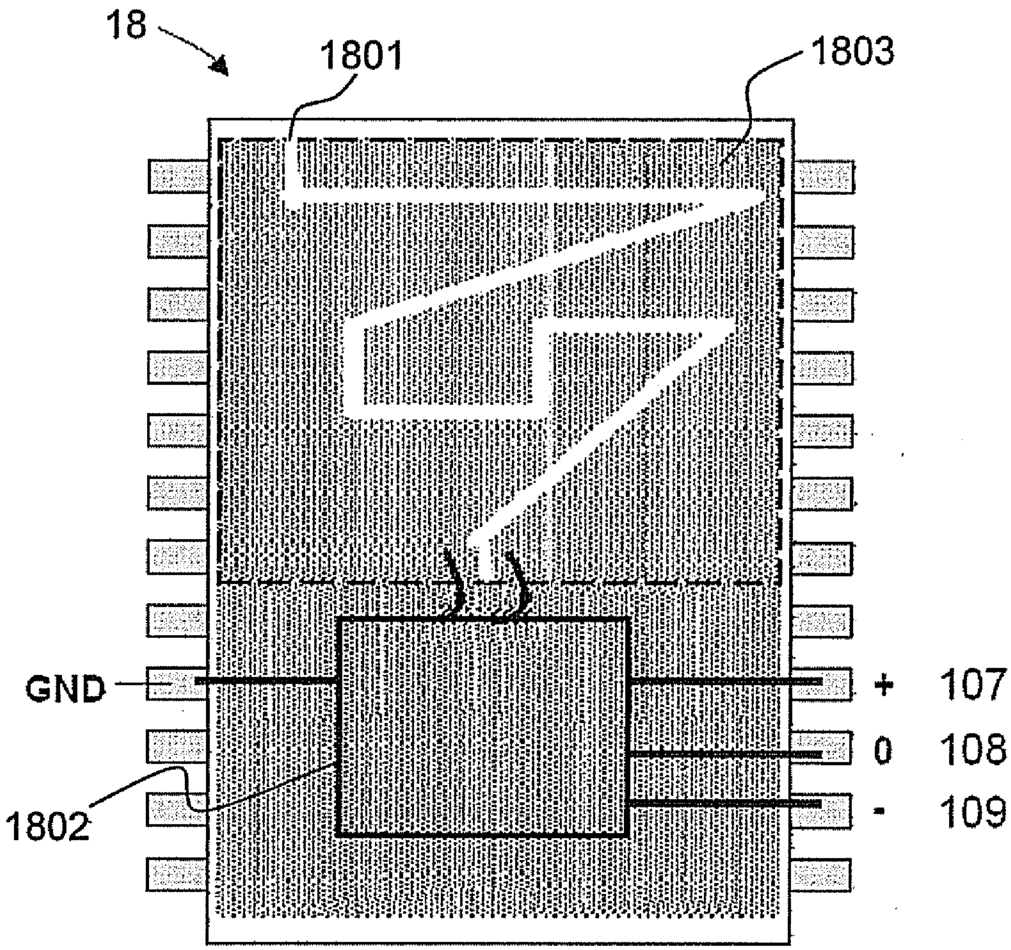


FIG. 18

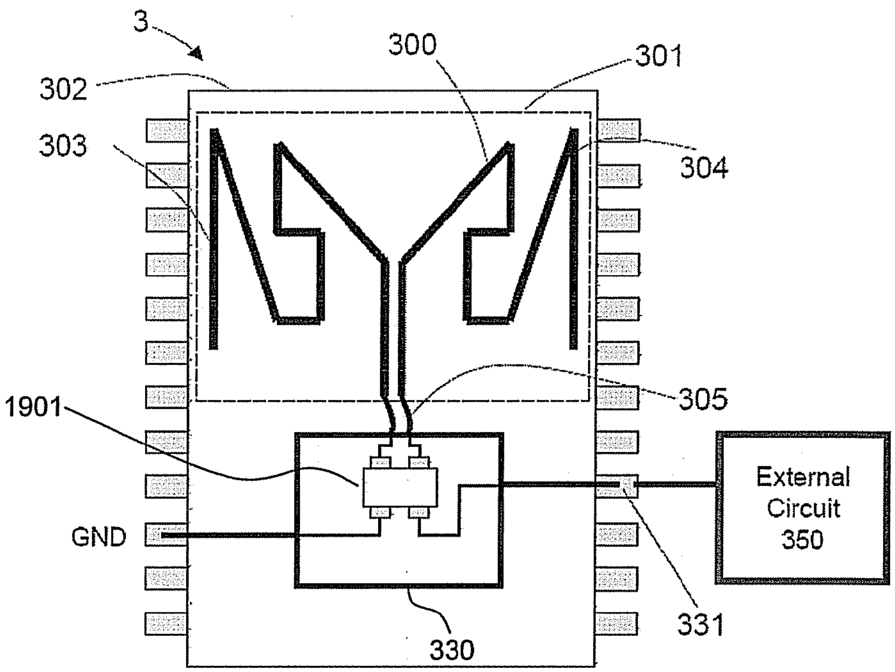


FIG. 19A

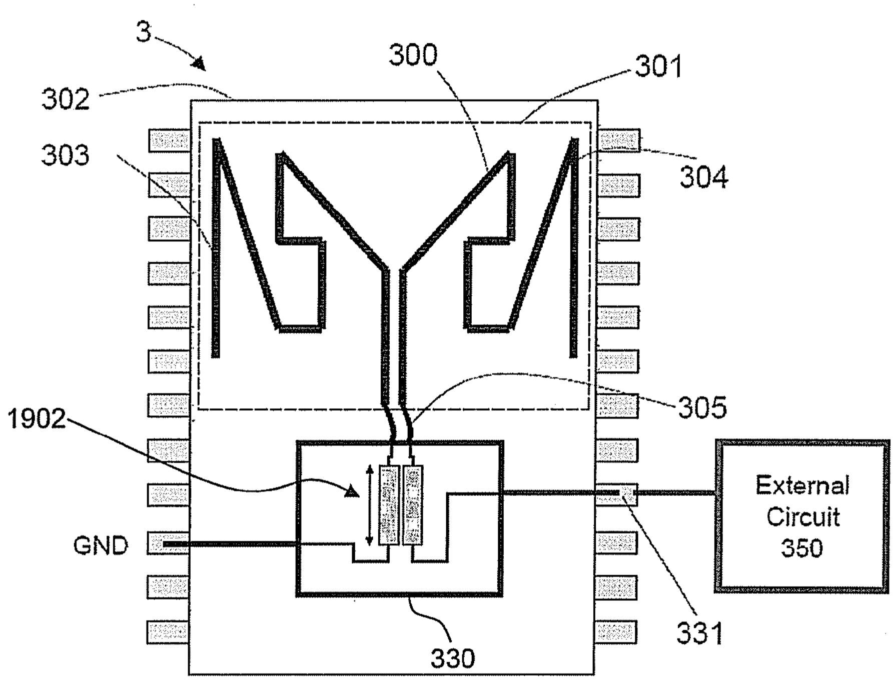


FIG. 19B

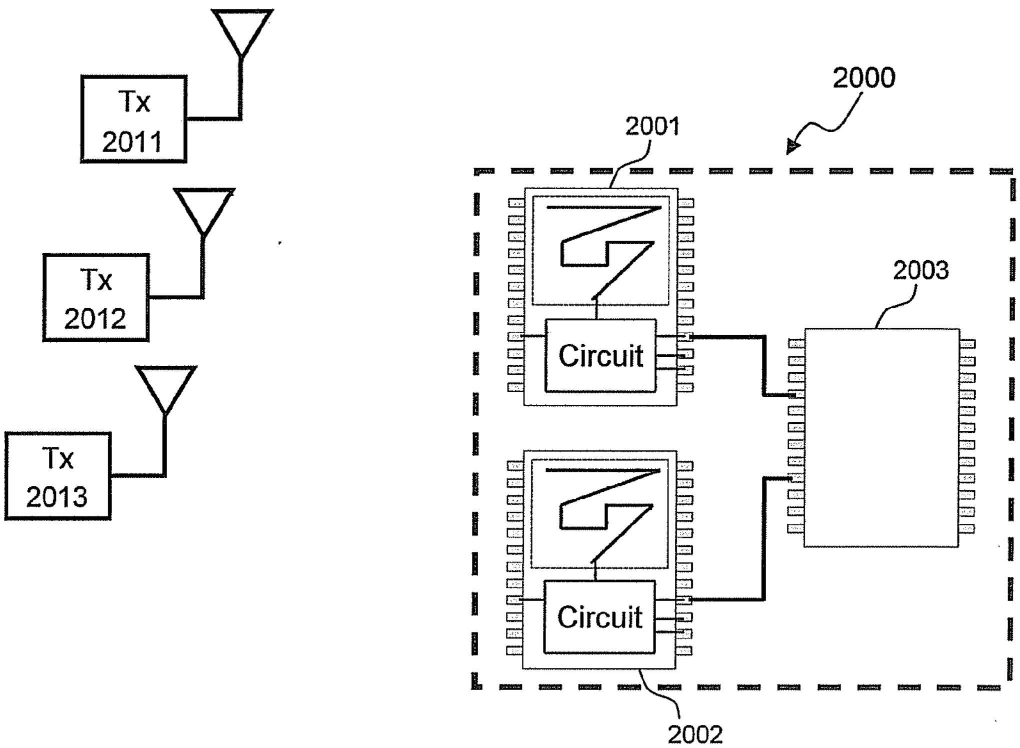


FIG. 20

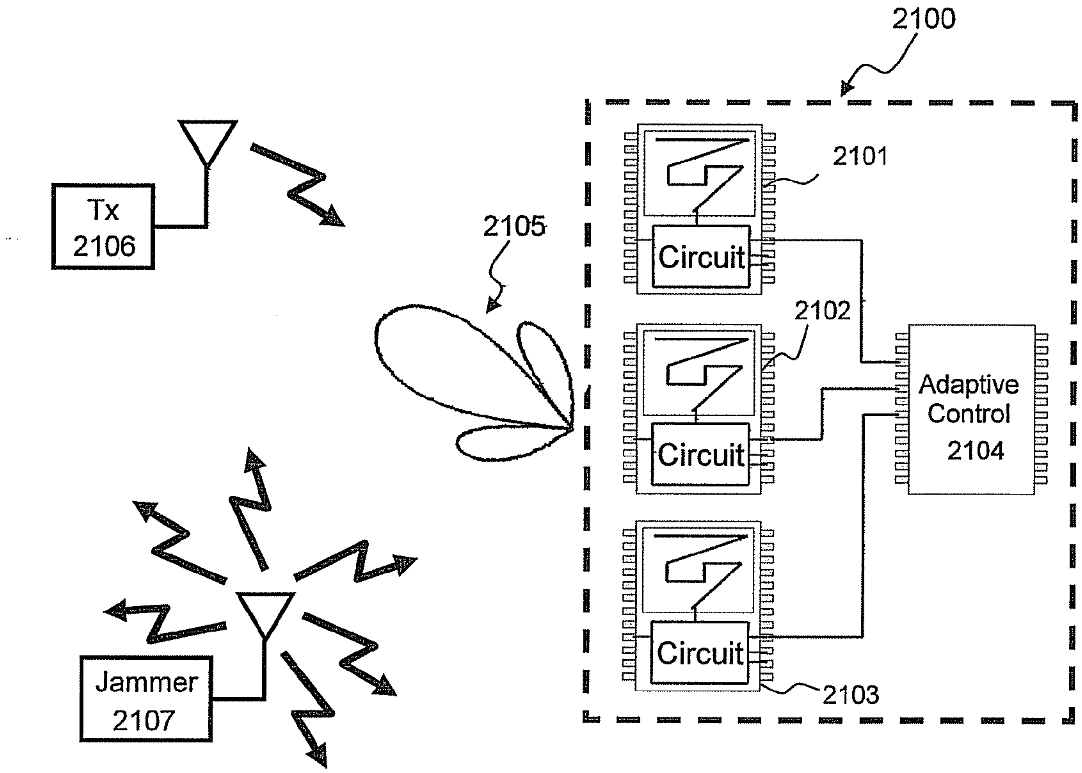

2100
2101
2105
Tx
2106
Circuit
2102
Adaptive
Control
2104
Circuit
Circuit
2103
Jammer
2107

FIG. 21

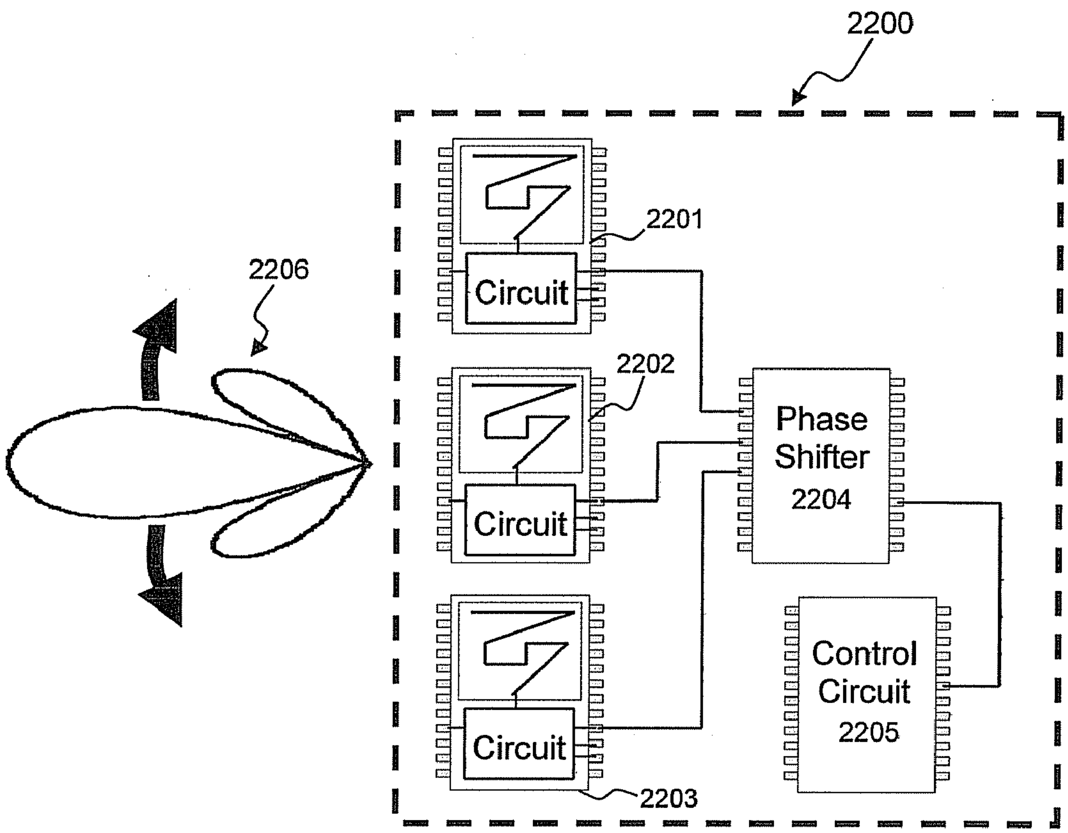

2200
2201
2202
2203
2206
Circuit
Circuit
Circuit
Phase
Shifter
2204
Control
Circuit
2205

FIG. 22

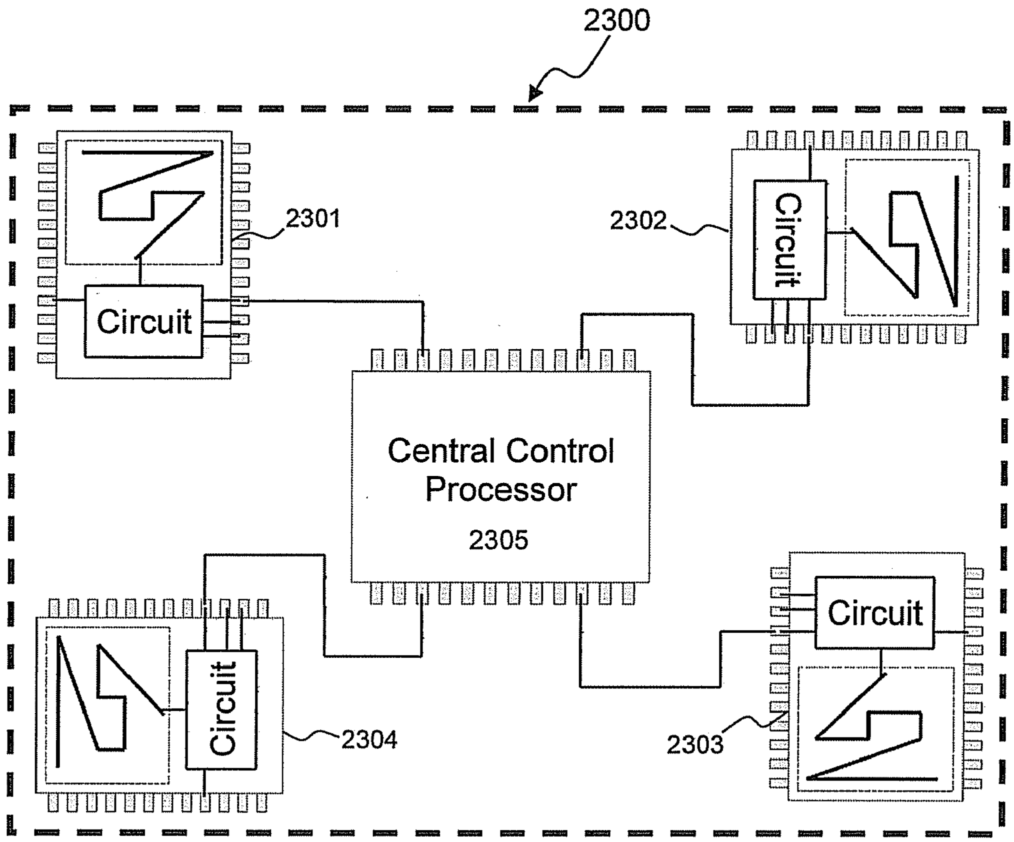

2300
2301
2302
2303
2304
Circuit
Circuit
Circuit
Circuit
Central Control Processor
2305

FIG. 23

RADIO-FREQUENCY SYSTEM IN PACKAGE INCLUDING ANTENNA

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation application of U.S. application Ser. No. 11/556,455, filed on Nov. 3, 2006, which claims the benefit of priority afforded by patent application PCT/EP2004/004851, entitled "Radio-Frequency System In Package Including Antenna," filed on May 6, 2004 and is a continuation-in-part of patent application Ser. No. 11/488,107 (filed Jul. 17, 2006), which is a continuation of application Ser. No. 11/040,622, now U.S. Pat. No. 7,095, 372, filed on Jan. 21, 2005, which is a continuation of application no. PCT/EP2002/012427, filed on Nov. 7, 2002.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to novel integrated circuit packages that include a new family of miniature antennas in the package.

[0003] There is a trend in the semiconductor industry towards the so-called System on Chip (SoC) and System on Package (SoP) concepts. The full integration of systems or subsystems into a single chip, package or module provides many advantages in terms of cost, size, weight, consumption, performance and product design complexity. Several electronic components for consumer applications, such as handsets, wireless devices, personal digital assistants (PDAs) or personal computers (PCs) are becoming more and more integrated into SoP/SoC products.

[0004] The concept of integrating a miniature antenna into a package or module is especially attractive owing to the tremendous growth and success of cellular and wireless systems. In particular, there is a new generation of short/medium range wireless applications such as Bluetooth™, Hyperlan, IEEE802.11 and ultra wide band (UWB), Wimax and Zig Bee systems where the progressive system integration into a single, compact product is becoming a key success factor (see for instance, S. Harris and H. Johnston, "Handset Industry Debate Bluetooth™ Chip Options", *WirelessEurope*, May 2002).

[0005] This concept of integrating a miniature antenna into a package or module is especially attractive as well in GSM, UMTS, PCS 1900, KPCS, CDMA, WCDMA, and GPS.

[0006] There have been reported several attempts to integrate an antenna in a package or module. These designs feature two important limitations: first the operating frequency must be large enough to allow a conventional antenna to fit inside the chip; second the antenna performance is poor in terms of gain, mainly due to the losses in the semiconductor material. According to D. Singh, et al., the smallest frequency in which an antenna has been integrated together with an electronic system inside the same was 5.98 GHz. Typical gains that have been achieved with such designs are around −10 dBi.

[0007] In general, there is a trade-off between antenna performance and miniaturization. The fundamental limits on small antennas were theoretically established by H. Wheeler and L. J. Chu in the middle 1940's. They stated that a small antenna has a high quality factor (Q), because of the large reactive energy stored in the antenna vicinity compared to the radiated power. Such a high quality factor yields a narrow bandwidth; in fact, the fundamental derived in such theory imposes a maximum bandwidth given a specific size of a small antenna. Related to this phenomenon, it is also known that a small antenna features a large input reactance (either capacitive or inductive) that usually has to be compensated with an external matching/loading circuit or structure. It also means that it is difficult to pack a resonant antenna into a space which is small in terms of the wavelength at resonance. Other characteristics of a small antenna are its small radiating resistance and its low efficiency (see, R. C. Hansen, Fundamental Limitations on Antennas, Proc. IEEE, vol. 69, no. 2, February 1981).

[0008] Some antenna miniaturization techniques rely basically on the antenna geometry to achieve a substantial resonant frequency reduction while keeping efficient radiation. For instance, patent application WO 01/54225 A1 discloses a set of space-filling antenna geometries (SFC) that are suitable for this purpose. Another advantage of such SFC geometries is that in some cases they feature a multiband response.

[0009] The dimension (D) is a commonly used parameter to mathematically describe the complexity of some convoluted curves. There exist many different mathematical definitions of dimension but in the present document the box-counting dimension (which is well-known to those skilled in advanced mathematics theory) is used to characterize some embodiments (see discussion on the mathematical concept of dimension in W. E. Caswell and J. A. Yorke, "Invisible Errors in Dimension Calculations: Geometric and Systematic Effects", *Dimensions and Entropies in Chaotic Systems*, G. Mayer-Kress, editor, Springer-Verlag, Berlin 1989, second edition, pp. 123-136 or K. Judd, A. I. Mees, "Estimating Dimensions with Confidence", *International Journal of Bifurcation and Chaos,* 1, 2 (1991) 467-470).

[0010] So-called chip-antennas are described in H. Tanidokoro, N. Konishi, E. Hirose, Y. Shinohara, H. Arai, N. Goto, "1-Wavelength Loop Type Dielectric Chip Antennas", Antennas and Propagation Society International Symposium, 1998, *IEEE*, vol. 4, 1998 ("Tanidokoro, et al.") or H. Matsushima, E. Hirose, Y. Shinohara, H. Arai, N. Golo, "Electromagnetically Coupled Dielectric Chip Antenna", Antennas and Propagation Society International Symposium, *IEEE*, vol. 4, 1998. Those are typically single component antenna products that integrate only the antenna inside a surface-mount device. To achieve the necessary wavelength compression, those antennas are mainly constructed using high permittivity materials such as ceramics. The drawbacks of using such high permittivity materials are that the antenna has a very narrow bandwidth, the material introduces significant losses, and the manufacturing procedure and materials are not compatible with most package manufacturing techniques; therefore they do not currently include other components or electronics besides the antenna, and they are not suitable for a FWSoC or FWSoP.

[0011] There have been recently disclosed some RF SoP configurations that also include antennas on the package. Again, most of these designs rely on a conventional microstrip, shorted patch or PIFA antenna that is suitable for large frequencies (and therefore small wavelengths) and feature a reduced gain. In K. Lim, S. Pinel, M. Davis, A. Sutono, C. Lee, D. Heo, A. Obatoynbo, J. Laskar, E. Tantzeris, R. Tummala, "RF-System-On-Package (SOP) for Wireless Communications", *IEEE Microwave Magazine*, vol. 3, no. 1, March 2002 ("Lim, et al."), a SoP including an RF front-end with an integrated antenna is described. The antenna comprises a microstrip patch backed by a cavity which is made with shorting pins and operates at 5.8 GHz. As mentioned in Lim, et al., it is difficult to extend those designs in the 1-6 GHz frequency range where most current wireless and cellular services are located, mainly due to the size of conventional antennas at such large wavelengths. Another design for an antenna on a package is disclosed in Y. P. Zhang, W. B. Li, "Integration of a Planar Inverted F Antenna on a Cavity-Down Ceramic Ball Grid Array Package", IEEE Symp. on Antennas and Propagation, June 2002. Although the antenna operates at the Bluetooth™ band (2.4 GHz), the IC package is substantially large (15×15 mm) and the antenna performance is poor (gain is below −9 dBi).

[0012] Patent application EP1126522 describes a particular double S-shaped antenna design that is mounted on a BGA package. Although no precise data is given on the package size in the application, typically, S-shaped slot antennas resonate at a wavelength on the order of twice the unfolded length of the S-shaped pattern. Again, this makes the whole package too large for typical wireless applications where the wavelength is above 120 mm. Also, this design requires a combination with high permittivity materials that in turn, reduce the antenna bandwidth, increase its cost and decreases the overall antenna efficiency.

[0013] Regarding the package construction and architecture, there are several standard configurations depending mainly on the application. Some basic architectures are: single-in-line (SIL), dual-in-line (DIL), dual-in-line with surface mount technology DIL-SMT, quad-flat-package (QFP), pin grid array (PGA) and ball grid array (BGA) and small outline packages. Other derivatives are for instance: plastic ball grid array (PBGA), ceramic ball grid array (CBGA), tape ball grid array (TBGA), super ball grid array (SBGA), micro ball grid array BOA® and leadframe packages or modules. A description of several standard packaging architectures can be found on the websites of several package manufacturers, e.g.: www.amkor.com (see also L. Halbo, P. Ohickers, *Electronic Components, Packaging and Production*, ISBN: 82-992193-2-9).

[0014] In PCT/EP02/12427 (filed as well by the applicant, but not published when this current application was filed), attempts have been made in order to incorporate a miniature antenna to a package together with a semiconductor die.

[0015] Although this arrangement is suitable for certain applications it involves some disadvantages. More components in the package leads to a bigger size of the system.

[0016] Another reason not to have a fully integrated solution is that some manufacturers incorporate their own processors onto the printed circuit board (PCB) and prefer to incorporate a package or module antenna rather than a fully integrated package. Moreover, having a circuit in the same package or module as the die itself, can increase the amount of heat to be dissipated and might lead to an increase of temperature of the whole system causing a malfunction of the die. Besides, interference between the antenna and the die might occur. This could lead to a decrease in the performance of the system.

[0017] In the last few years, several improvements in packaging technology have appeared mainly due to the development of Multichip Module (MCM) applications (see, for instance, N. Sherwani, Q. Yu, S. Badida, *Introduction to Multi Chip Modules*, John Wiley & Sons, 1995). Those consist of an integrated circuit package that typically contains several chips (i.e., several semiconductor dies) and discrete miniature components (biasing capacitors, resistors, inductors). Depending on the materials and manufacturing technologies, MCM packages are classified in three main categories: laminated (MCM-L), ceramic (MCM-C) and deposited (MCM-D). Some combinations thereof are possible as well, such as e.g. MCM-L/D and other derivations such as Matsushita ALIVH. These MCM packaging techniques cover a wide range of materials for the substrate (for instance E-glass/epoxy, E-glass/polyimide, woven Kevlar/epoxy, s-glass/cyanate ester, quartz/polymide, thermount/HiT^{a} epoxy, thermount/polyimide, thermount/cyanate ester, PTFE, RT-Duroid 5880, Rogers RO3000® and RO4000®, polyiolefin, alumina, sapphire, quartz glass, Corning glass, beryllium oxide and even intrinsic GaAs and silicon) and manufacturing processes (thick film, thin film, silicon thin film, polymer thin film, LTCC, HTCC).

SUMMARY OF THE INVENTION

[0018] The objective technical problem to be solved by the invention is to provide a system with improved characteristics in view of the prior art, said device being applicable in various ways.

[0019] This problem is solved by the features of the independent claims. Further embodiments of this invention result from the dependent claims.

[0020] The present invention generally relates to novel integrated circuit packages, modules or systems comprising a new family of miniature antennas according to the any independent claim. Also, the invention relates to several novel ways of arranging the materials and components of the package to include the antenna. Particularly, main advantages of the invention are as follows:

- **[0021]** the small size of the antenna, which allows the use of very small packages (such as for instance chip scale packages ("CSP")) at typical wireless wavelengths;
- **[0022]** the antenna geometry that enables such a miniaturization;
- **[0023]** the arrangement of the antenna in the package;
- **[0024]** the compatibility of the antenna design with virtually any state of the art packaging architecture;
- **[0025]** scaled and distributed devices can be put together in an economical and efficient way;
- **[0026]** the heating-up effect of the package can be dissipated to an external component or an additional package, reducing the risk of malfunction of the device;
- **[0027]** several packages can be combined/put together, e.g. packages of RF circuits and/or antennas to be e.g. maintained by a processor to combine signals to be used in a multiple input multiple output (MIMO) environment. This might lead to a scalability of the packages according to the demands of the respective environment or system.

[0028] In contrast to the chip-antennas as described in Tanidokoro, et al., the present invention relies on the specific novel design of the antenna geometry and its ability to use the materials that are currently being used for integrated circuit package construction, so that the cost is minimized while allowing a smooth integration with the rest of the system.

[0029] The objective problem is solved by a system comprising at least one antenna and a circuit, wherein the circuit is at least in part not a silicon chip or a die. The at least one antenna and the circuit are arranged on a package.

[0030] The problem is also solved by a system comprising at least one antenna and at least one circuit, wherein the at least one antenna and the at least one circuit are arranged on a package, wherein the at least one circuit performs a base-band and/or a digital functionality.

[0031] This base-band functionality comprises e.g.:

- **[0032]** Conversion from a digital bitstream to a sequence of symbols in transmission, or symbol acquisition and digital data regeneration in reception;
- **[0033]** Clock recovery and symbol synchronization;
- **[0034]** Automatic gain control;
- **[0035]** Error correction algorithms;
- **[0036]** Data encryption/decryption;
- **[0037]** Channel estimation for adaptive detection;
- **[0038]** Memory blocks (for example for temporary data storage, for programming other digital blocks, etc.);
- **[0039]** Transmission/Reception buffers for storage of received packets and packets to be transmitted; or
- **[0040]** Microprocessors and/or microcontrollers to carry out data processing, control tasks (like data handshaking with other chips), implement communication ports protocols (like USB) or audio features (like an audio CODEC).

[0041] In an embodiment of the invention the (at least one) circuit comprises a radio-frequency circuit (RF-circuit). In particular, the coupling between the at least one antenna and the radio-frequency circuit can be a reactive coupling, in particular a capacitive or inductive coupling.

[0042] In another embodiment, the radio-frequency circuit is connected to or located on a ground plane.

[0043] Yet another embodiment is directed to at least some of the connections of the radio-frequency circuit being balanced.

[0044] In another embodiment, a radio-frequency component is arranged outside the package. In particular, this radio-frequency component could be a matching network. As a further option, the radio-frequency component can be a matching network, a bypass or a through-connection.

[0045] Optionally, the radio-frequency circuit on the package can be a matching network, a bypass or a through-connection.

[0046] It is to be noted that the radio-frequency component arranged outside the package could be an external circuit as well as an external sub-circuit, the latter e.g. being part of a larger circuit. This external circuit or sub-circuit can be or comprise a radio-frequency circuit, respectively.

[0047] Furthermore, the radio-frequency component outside the package as well as the radio-frequency circuit on the package can be a power amplifier, respectively.

[0048] Some other possibilities of components that could be part of the radio-frequency circuit (internal) or radio-frequency component (external to the package) are:

- **[0049]** Power amplifier;
- **[0050]** Low noise amplifier;
- **[0051]** Filters;
- **[0052]** Diplexer;
- **[0053]** Local oscillators (like a quartz crystal oscillator);
- **[0054]** Modulator/demodulator;
- **[0055]** Switch;
- **[0056]** Mixer;
- **[0057]** (Signal) Detector;
- **[0058]** Phase shifter; or
- **[0059]** balun.

[0060] In yet another embodiment the at least one antenna is connected to the radio-frequency circuit and at least in part the radio-frequency circuit is connected to the radio-frequency component outside the package.

[0061] In an additional embodiment, the at least one antenna is connected to the radio-frequency component outside the package directly.

[0062] Furthermore, the radio-frequency circuit can comprise a balun. Preferably, this balun can be incorporated as a printed circuit or as a discrete component. Additionally, the balun can be placed inside the package or outside of the package.

[0063] In another embodiment, the ground plane is not located underneath or on top of the at least one antenna. In particular, the projection of the antenna should not be on a ground plane.

[0064] In particular, the package can be an integrated circuit package (IC package).

[0065] Another embodiment is directed to a system, wherein the radio-frequency circuit or the radio-frequency component includes at least one filter. Preferably, this filter is or comprises a band-pass characteristic. Additionally, other filter types as high-pass or low-pass filters or combinations thereof can be provided.

[0066] A next embodiment is directed to the at least one antenna being connected to an input/output connector of the package and at least a part of the circuit being connected to an input/output connector of the package. Said connectors can be the same or different ones.

[0067] In another embodiment the at least one antenna is a space filling antenna. Preferably, the space filling antenna has a dimension bigger than 1.

[0068] In fact, there exist several definitions of the dimension, e.g. a box counting dimension and a grid dimension. Preferably, these dimensions amount to numbers between 1 and 2, respectively, in particular the dimensions amount to 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0. The respective value depends on the miniaturization of the packet size.

[0069] In particular, space filling is directed to the ability of filling the space where the curve is located. This space could be an approximated surface or some sort of three-dimensional volume.

[0070] In general, increasing the number of segments, reducing the size of the segments, narrowing the angles between the segments and increasing the dimension of the curve will lead to further miniaturization, respectively.

[0071] As a subsequent embodiment, the antenna can comprise a conducting pattern at least a portion of which includes a curve, wherein said curve comprises at least five segments. Each of the at least five segments forming a pair of angles with each adjacent segment in said curve and at least three of said segments are shorter than 1/10 of the longest free-space operating wavelength of said at least one antenna.

[0072] In particular, the smaller angle of the pair of angles between adjacent segments is less than 180° and at least two of said smaller angles between adjacent section segments are less than 115°, wherein at least two of the angles, which are on the same side of the curve and are formed from adjacent segments of the group of said at least five segments, are different.

[0073] As a subsequent option, said conducting pattern fits inside a rectangular area, the longest side of said rectangular area being shorter than 1/5 of the longest free-space operating wavelength of said at least one antenna.

[0074] The number of "at least five" segments can as well be in particular seven, nine, eleven, fifteen, twenty or twenty-five segments.

[0075] In another embodiment, at least the at least one antenna and/or the radio frequency circuit comprise(s) a connection with a radio-frequency input/output connector. In addition, the radio-frequency component outside the package can as well comprise such a connection with a radio-frequency input/output connector.

[0076] In particular, the at least one antenna can be a modular or a discrete component. As an option, the modular or discrete component can be a surface mount technique component (SMT component).

[0077] In a further embodiment, both ends of the at least one antenna can be connected to the package, in particular to Input/Output connectors of the package. In a particular embodiment, both ends of the antenna are connected to Input/Output connectors of the package.

[0078] Another embodiment is directed to the at least one antenna being a parasitic element. This parasitic element can be incorporated inside the package or, as an alternative, outside the package.

[0079] In yet another embodiment the system comprises at least one external antenna.

[0080] In addition, the system can comprise a switch. This switch can be placed outside or on the package. As a next embodiment, the switch can be used to commute between the at least one (internal) antenna and the at least one external antenna.

[0081] The switch can be a jumper or a bypass, or any mechanical switch with several positions to select manually a distinct antenna from several available antennas. The switch can also be an electromechanical switch (like a relay), or an electronic switch like a transistor, FET, FLIP-FLOP or the like.

[0082] The use of a switch to select between the at least one (internal) antenna and the at least one external antenna could be used to implement an antenna diversity system. The technique of antenna diversity consists of providing several antennas to the receiver as a way to protect the receiver from signal fading in the communication channel. The antennas must be arranged so that there is little, or no, correlation between the signals received by each one of them.

[0083] In an alternative embodiment, the at least one antenna is not physically connected to any other component. This might as well apply to the external antenna mentioned above.

[0084] Furthermore, the at least one antenna could be a balanced or an unbalanced antenna.

[0085] In addition, the at least one antenna can be loaded with discrete reactive components, e.g. capacitors and/or inductors.

[0086] As another embodiment, the antenna can be loaded with external loads.

[0087] Another embodiment comprises several systems as described above, wherein the antennas are forming a multiple antenna communication system.

[0088] This multiple antenna communication system can be a multiple-input-multiple-output system, a smart antenna system, a phased array system or a sensor network.

[0089] For certain applications it is advantageous as well to separate the radio frequency band from the base band, because of interference problems between both parts. Higher quality components, which might need more space could be used if one part of the signal processing circuit is placed outside the package.

[0090] The technique of having a separate outside part of the (functional) circuit systematically opens the possibility to use existing components outside the package, such as e.g. clocks, oscillators or filters.

BRIEF DESCRIPTION OF THE DRAWINGS

[0091] Embodiments of the invention will be illustrated and explained hereinafter on the basis of the drawings:

[0092] FIG. **1** shows an embodiment of a package including an antenna and a circuit;

[0093] FIG. **2** shows an embodiment of a package including an antenna and a circuit composed by a base band circuit;

[0094] FIG. **3** shows an embodiment of a package including a dipole antenna and a radio-frequency circuit together with an additional circuit outside the package;

[0095] FIG. **4** shows an embodiment of a package including a monopole antenna and a circuit, both connected to a matching network outside the package;

[0096] FIG. **5** shows an embodiment of a package including a balanced antenna and a radio-frequency circuit together with an additional circuit outside the package;

[0097] FIG. **6** shows an embodiment of a package including a balanced antenna with a reactive loading;

[0098] FIG. **7** shows examples of space filling curves;

[0099] FIG. **8** (FIG. **8**A to FIG. **8**D) shows an example of how the grid counting dimension is calculated;

[0100] FIG. **9** (FIG. **9**A and FIG. **9**B) shows an example of how the box counting dimension is calculated.

[0101] FIG. **10** shows an embodiment of a package including an antenna and a circuit.

[0102] FIG. **11** shows an embodiment of a package with a matching network.

[0103] FIG. **12** shows an embodiment of a package with radio-frequency component outside the package.

[0104] FIG. **13** shows an embodiment of a package with a power amplifier.

[0105] FIG. **14** shows an embodiment of a package with an antenna and a circuit.

[0106] FIG. **15** shows an embodiment of a package including an antenna, a circuit, and a parasitic element.

[0107] FIG. **16** shows an embodiment of a package with a second antenna external to the package.

[0108] FIG. **17** (FIGS. **17**A, **17**B and **17**C) show embodiments of a system with an antenna and an electrical circuit enclosed in a common package housing.

[0109] FIG. **18** shows an embodiment of a system with an antenna and an electrical circuit enclosed in a common package housing.

[0110] FIG. **19** (FIGS. **19**A and **19**B) show embodiments of a package with a balun.

[0111] FIG. **20** shows an embodiment of a multiple-antenna communication system that forms a MIMO system.

[0112] FIG. **21** shows an embodiment of a multiple-antenna communication system that forms a smart antenna system.

[0113] FIG. **22** shows an embodiment of a multiple-antenna communication system that forms a phased array system.

[0114] FIG. 23 shows an embodiment of a multiple-antenna communication system that forms a sensor network.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0115] FIG. 1 shows an embodiment of a package 1 including an antenna 100 in an area 101 and a circuit 130. Both, the antenna 100 and the circuit 130 are arranged on a substrate 102. Preferably, there is no ground plane underneath the antenna 100, i.e. the area 101 is free of any conductive material, at least in 50% of the surface above or below area 101. Particularly, the only metal that is placed below or above the antenna pattern are the connectors (such as for instance wire bonds or metal strips).

[0116] The antenna 100 is a monopole antenna with a single radiating arm comprising seven segments 111 through 117. Preferably, the side length of the rectangular area 101 is the longest operating wavelength for the antenna divided by five. The antenna 100 forms at least two angles such as angle 121 and angle 122 being less than 115°. Although not required, it is preferred that at least two of the angles that are less than 180° are defined in the clock-wise and counter clock-wise directions at the opposite sides of the curve (right side for 121, left for 122). The antenna curve 100 is fed through a connection 105 to a pad on the circuit 130, such a connection including, but not limited to, a wire bond.

[0117] The circuit 130 preferably is embodied as a radio-frequency circuit (RF circuit). The antenna 100 is connected to the RF circuit 130, transferring the unbalanced signal of the antenna 100 to the RF circuit 130. The RF circuit 130 can be connected to the ground plane of the antenna 100. The RF circuit provides some RF functionality needed in an RF front-end, like e.g. antenna impedance matching, unbalanced-to-balanced transformation, power amplifying, filtering, mixing, frequency conversion, etc.

[0118] The output connection of the RF circuit 130, as represented in the embodiment can be a balanced device. Optionally, the RF circuit 130 comprises a connection to a "0" level reference.

[0119] Alternatively, the output connection of the RF circuit 130 can be unbalanced. In such a case the common ground "GND" is an input signal for the RF circuit 130.

[0120] The RF circuit 130 is connected to the monopole antenna 100 and comprises optional connections to terminals like common ground "GND", 108 "0", 107 "+" and/or 109 "–".

[0121] FIG. 2 shows an embodiment of a package 2 including the antenna 100 in an area 201 and a radio-frequency circuit (RF circuit) 230 together with a base band component 240 arranged on a substrate 202.

[0122] The antenna 100 has been described in FIG. 1 above. It comprises seven segments 111 through 117 and forms at least two angles 121 and 122 being less than 115°. The antenna 100 is connected to the RF circuit 230 by a connection 205.

[0123] The RE circuit 230 and the base band component 240 are connected to the ground connector GND. The base band component 240 is connected to the terminals "+" 207, "0" 208 and "–" 209.

[0124] The base band component 240 provides at least some of the base band functionality required in the system, like for example conversion from a digital bitstream to a sequence of symbols, symbol acquisition, digital data regeneration, clock recovery, symbol synchronization, automatic gain control, error correction algorithms, data encryption and/or decryption, channel estimation for adaptive detection, analog-to-digital conversion, etc.

[0125] The RF circuit 230 performs at least some of the RF functionality needed in an RF front-end, like for example antenna impedance matching, balanced-to-unbalanced transformation, power amplifying, filtering, mixing, frequency conversion, etc.

[0126] FIG. 3 shows an embodiment of a package 3 including a dipole antenna 300 and a radio-frequency circuit 330. An external circuit 350 is located outside the package 3. The dipole antenna 300 comprises two radiating arms 303 and 304 and is fed by a differential input/output terminal 305, which is provided by a couple of close connectors such as for instance two wire bonds. Other suitable feeding means could include two conducting strips placed on the same layer as the antenna, the two strips reaching directly or by means of a via hole, the solder balls of a flip-chip, or the pad connection region of a flip-chip connected by means of tape automatic bonding (TAB).

[0127] A substrate 302 can be embodied as a single layer or a multilayer, but in any case it leaves a clearance with no conducting material of at least 50% of the area 301 where the antenna is enclosed, in any of the layers above or below the layer on which the antenna is lying.

[0128] The antenna 300 is connected to the RF circuit 330, transferring the balanced signal to the RF circuit 330. The RF circuit 330 can be connected to ground. The RF circuit 330 performs at least some of the RF functionality needed in an RF front-end, like for example antenna impedance matching, balanced-to-unbalanced transformation, power amplifying, filtering, mixing, frequency conversion, etc.

[0129] The output signal 331 of the RF circuit 330 is unbalanced, and afterwards connected to an external circuit 350, which can be an external chip.

[0130] Alternatively, the output connection 331 of the RF circuit 330 can be balanced. In such case, two connections to different pins (two pins instead of one pin 331) of the package, preferably labeled as "+" and "–" are necessary, with the option of the presence of a third pin being the "0" level reference.

[0131] FIG. 4 shows an embodiment of a package 4 including a (unbalanced) monopole antenna 100 (as described in FIG. 1) and an RF circuit 430, both connected to an external RF circuit 450, which is located outside the package 4.

[0132] A substrate 402 can be arranged as a single layer or a multilayer, but in any case it to leaves a clearance with no conducting material of at least 50% of the area 401 where the antenna is enclosed, in any of the layers above or below the layer on which the antenna is lying.

[0133] The antenna 100 and the RF circuit 430 are connected to at least one Input/Output connector (which can be a pin) of the package 4, respectively, i.e. pin 431 for the antenna 100 and pin 432 for the RF circuit 430. An interconnection between the antenna 100 and the RF circuit 430 is provided by the external RF circuit 450, which is preferably another RF (sub-)circuit external to the package. Preferably, the external RF circuit 450 can be a matching network, a bypass or a through-connection.

[0134] The RF circuit 430 could also be connected to the antenna 100, hence performing at least some RF functionality needed in an RF front-end. The external RF circuit 450 provides additional RF functionality, e.g. it could be a short circuit that establishes direct electrical contact between antenna **100** and RF circuit **430**.

[0135] As indicated by FIG. **4**, the output between the RF circuit **430** and the external RF circuit **450** (e.g. matching network) is unbalanced, but it could also be balanced instead.

[0136] As an alternative, the antenna **100** could be directly connected to the RF circuit **430**, which is connected to the external RF circuit **450**, which can optionally be a matching network.

[0137] FIG. **5** shows an embodiment of a package **5** including a balanced antenna **300** (as described in FIG. **3**) and a radio-frequency circuit **530** (RF circuit). An additional circuit **550** is placed outside the package **5**.

[0138] A substrate **502** can be arranged as a single layer or a multilayer, but in any case it leaves a clearance with no conducting material of at least 50% of the area **501** where the antenna is enclosed, in any of the layers above or below the layer on which the antenna is lying.

[0139] Both anus **303** and **304** of the antenna **300** are connected to a respective terminal of the package **5**, i.e. arm **303** is connected to terminal **551** and arm **304** is connected to terminal **552**. These terminals **551** and **552** of the package **5** are connected to the external circuit **550**. Via terminals **531** and **532** the RF circuit **530** of the package **5** is connected to the circuit **550**, whereas the RF circuit **530** is further connected to terminals **533** and **534** of the package **5**. These terminals **533** and **534** are the input/output connectors to which an external RF front-end (not shown) can be connected.

[0140] This embodiment is similar to what has been described with FIG. **3**, but the antenna **100** being balanced. Preferably, all connections shown in FIG. **5** are balanced, although at least some of them could be unbalanced as well.

[0141] This embodiment is advantageous to be applied for an external power amplifier (PA), because this amplifier typically is differential (i.e. balanced) in order to enable noise suppression and in order to minimize unnecessary heating-up of the amplifier.

[0142] FIG. **6** shows an embodiment of a package **6** including a balanced antenna **300** with a reactive loading **610** and **620**. The antenna **300** has been described in FIG. **3** above. The arm **303** is connected to a load **610** and the arm **304** is connected to a load **620**. The antenna **300** is connected via connection **606** (for arm **303**) and connection **605** (for arm **304**) with an RF circuit **630**, which is also attached to the package **6** onto the substrate **602**. The RF circuit **630** is connected to a terminal **632** of the package **6** to which also a chip **650** is attached. Furthermore, the RF circuit **630** is connected to a terminal **631**.

[0143] The reactive loads **610** and/or **620** could be placed at the beginning of the conductive pattern of the antenna or, alternatively, at the end of it. Optionally, the loads **610** and/or **620** can be placed to any intermediate point. Moreover, the reactive loads **610** and/or **620** can be placed outside the package if the necessary connections via terminals of the package **6** arc provided.

[0144] This scheme of reactive loading is advantageous for further miniaturization purposes of the antenna.

[0145] FIG. **7** shows examples of space filling curves. Filling curves **701** through **714** are examples of prior art space filling curves for antenna designs. Other types of multiband antennas that also feature a reduced size are multilevel antennas as disclosed in WO 01/22528, which herewith is incorporated by reference.

[0146] FIG. **8** (FIG. **8**A to FIG. **8**D) shows an example of how the grid dimension is calculated.

[0147] The grid dimension of a curve may be calculated as follows: A first grid having square cells of length LI is positioned over the geometry of the curve, such that the grid completely covers the curve. The number of cells (N**1**) in the first grid that enclose at least a portion of the curve are counted. Next, a second grid having square cells of length L**2** is similarly positioned to completely cover the geometry of the curve, and the number of cells (N**2**) in the second grid that enclose at least a portion of the curve are counted. In addition, the first and second grids should be positioned within a minimum rectangular area enclosing the curve, such that no entire row or column on the perimeter of one of the grids fails to enclose at least a portion of the curve. The first grid preferably includes at least twenty-five cells, and the second grid preferably includes four times the number of cells as the first grid. Thus, the length (L**2**) of each square cell in the second grid should be one-half the length (L**1**) of each square cell in the first grid. The grid dimension (D_g) may then be calculated with the following equation:

$$D_g = -\frac{\log(N2) - \log(N1)}{\log(L2) - \log(L1)}.$$

[0148] For the purposes of this application, the term grid dimension curve is used to describe a curve geometry having a grid dimension that is greater than one (1). The larger the grid dimension, the higher the degree of miniaturization that may be achieved by the grid dimension curve in terms of an antenna operating at a specific frequency or wavelength. In addition, a grid dimension curve may, in some cases, also meet the requirements of a space-filling curve, as defined above. Therefore, for the purposes of this application a space-filling curve is one type of grid dimension curve.

[0149] FIG. **8**A shows an example two-dimensional antenna **800** forming a grid dimension curve with a grid dimension of approximately two (2). FIG. **8**B shows the antenna **800** of FIG. **8**A enclosed in a first grid **801** having thirty-two (32) square cells, each with a length L**1**. FIG. **8**C shows the same antenna **800** enclosed in a second grid **802** having one hundred twenty-eight (128) square cells, each with a length L**2**.

[0150] The length (L**1**) of each square cell in the first grid **801** is twice the length (L**2**) of each square cell in the second grid **802** (L**2**=2×L**1**). An examination of FIG. **8**A and FIG. **8**B reveal that at least a portion of the antenna **800** is enclosed within every square cell in both the first and second grids **801**, **802**. Therefore, the value of N**1** in the above grid dimension (D_g) equation is thirty-two (32) (i.e., the total number of cells in the first grid **801**), and the value of N**2** is one hundred twenty-eight (128) (i.e., the total number of cells in the second grid **802**). Using the above equation, the grid dimension of the antenna **800** may be calculated as follows:

$$D_g = -\frac{\log(128) - \log(32)}{\log(2 \times L1) - \log(L1)} = 2$$

[0151] For a more accurate calculation of the grid dimension, the number of square cells may be increased up to a maximum amount. The maximum number of cells in a grid is dependant upon the resolution of the curve. As the number of cells approaches the maximum, the grid dimension calculation becomes more accurate. If a grid having more than the maximum number of cells is selected, however, then the accuracy of the grid dimension calculation begins to decrease. Typically, the maximum number of cells in a grid is one thousand (1000).

[0152] For example, FIG. **8**D shows the same antenna **800** enclosed in a third grid **803** with five hundred twelve (512) square cells, each having a length L**3**. The length (L**3**) of the cells in the third grid **803** is one half the length (L**2**) of the cells in the second grid **802**, shown in FIG. **8**C. As noted above, a portion of the antenna **800** is enclosed within every square cell in the second grid **802**, thus the value of N for the second grid **802** is one hundred twenty-eight (128). An examination of FIG. **8**D, however, reveals that the antenna **800** is enclosed within only five hundred nine (509) of the five hundred twelve (512) cells of the third grid **803**. Therefore, the value of N for the third grid **803** is five hundred nine (509). Using FIG. **8**C and FIG. **8**D, a more accurate value for the grid dimension (D_g) of the antenna **800** may be calculated as follows:

$$D_g = -\frac{\log(509) - \log(128)}{\log(2 \times L2) - \log(L2)} \approx 1.9915$$

[0153] FIG. **9** (FIG. **9**A and FIG. **9**B) shows an alternative example of how the box counting dimension is calculated.

[0154] The antenna comprises a conducting pattern, at least a portion of which includes a curve, and the curve comprises at least five segments, each of the at least five segments forming an angle with each adjacent segment in the curve, at least three of the segments being shorter than one-tenth of the longest free-space operating wavelength of the antenna. Each angle between adjacent segments is less than 180° and at least two of the angles between adjacent sections are less than 115°, and wherein at least two of the angles are not equal. The curve fits inside a rectangular area, the longest side of the rectangular area being shorter than one-fifth of the longest free-space operating wavelength of the antenna.

[0155] One of the advantages of the package arrangements of the present invention is that they allow a high package density including the antenna. In some embodiments the antenna can be fitted in a rectangular area, the longest edge of which is shorter than one-twentieth of the longest free-space operating wavelength of the antenna. Alternatively, the arrangement of the package in terms of layout, antenna and chip arrangement allows the whole package to be smaller than one-twentieth of the free-space operating wavelength.

[0156] One aspect of the present invention is the box-counting dimension of the curve that forms at least a portion of the antenna. For a given geometry lying on a surface, the box-counting dimension is computed in the following way: First a grid with boxes of size L**1** is placed over the geometry, such that the grid completely covers the geometry, and the number of boxes N**1** that include at least a point of the geometry are counted; secondly a grid with boxes of size L**2** (L**2** being smaller than LI) is also placed over the geometry, such that the grid completely covers the geometry, and the number of boxes N**2** that include at least a point of the geometry are counted again. The box-counting dimension D is then computed as:

$$D = -\frac{\log(N2) - \log(N1)}{\log(L2) - \log(L1)}$$

[0157] In terms of the present invention, the box-counting dimension is computed by placing the first and second grids inside the minimum rectangular area enclosing the curve of the antenna and applying the above algorithm.

[0158] The first grid should be chosen such that the rectangular area is meshed in an array of at least 5×5 boxes or cells, and the second grid is chosen such that L**2**=½ L and such that the second grid includes at least 10×10 boxes. By the minimum rectangular area it will be understood such area wherein there is not an entire row or column on the perimeter of the grid that does not contain any piece of the curve. Thus, some of the embodiments of the present invention will feature a box-counting dimension larger than 1.17, and in those applications where the required degree of miniaturization is higher, the designs will feature a box-counting dimension ranging from 1.5 up to 3, inclusive. For some embodiments, a curve having a box-counting dimension of about 2 is preferred. For very small antennas, that fit for example in a rectangle of maximum size equal to one-twentieth of the longest free-space operating wavelength of the antenna, the box-counting dimension will be necessarily computed with a finer grid. In those cases, the first grid will be taken as a mesh of 10×10 equal cells, while the second grid will be taken as a mesh of 20×20 equal cells, and then D is computed according to the equation above. In the case of small packages with of planar designs, i.e., designs where the antenna is arranged in a single layer on a package substrate, it is preferred that the dimension of the curve included in the antenna geometry have a value close to D=2.

[0159] In general, for a given resonant frequency of the antenna, the larger the box-counting dimension the higher the degree of miniaturization that will be achieved by the antenna. One way of enhancing the miniaturization capabilities of the antenna according to the present invention is to arrange the several segments of the curve of the antenna pattern in such a way that the curve intersects at least one point of at least 14 boxes of the first grid with 5×5 boxes or cells enclosing the curve. Also, in other embodiments where a high degree of miniaturization is required, the curve crosses at least one of the boxes twice within the 5×5 grid, that is, the curve includes two non-adjacent portions inside at least one of the cells or boxes of the grid.

[0160] An example of how the box-counting dimension is computed according to the present invention is shown in FIG. **9**A and FIG. **9**B. An example of a curve **900** according to the present invention is placed under a 5×5 grid **901** and under a 10×10 grid **902**. As seen in the graph, the curve **900** touches N1=25 boxes in grid **901** while it touches N2=78 boxes in grid **902**. In this case the size of the boxes in grid **901** is twice the size of the boxes in **902**. By applying the equation above it is found that the box-counting dimension of curve **902** is, according to the present invention, equal to D=1.6415. This example also meets some other characteristic aspects of some preferred embodiments within the present invention. The curve **900** crosses more than 14 of the 25 boxes in grid **901**, and also the curve crosses at least one box twice, that is, at least one box contains two non adjacent segments of the curve. In fact, **900** is an example where such a double crossing occurs in 13 boxes out of the 25 in **901**.

[0161] The package arrangements in which the antenna is built on a single layer of a package substrate are very convenient in teims of cost because a single mask can be used for processing the antenna pattern on such a layer. In some embodiments the antenna is arranged in a single layer and fed in one tip of the curve, such that no conductor crossing over the curve is required. Although not required, a further simplification and cost reduction is achieved by means of those embodiments in the present invention wherein the antenna and the chip are mounted on the same layer of a package substrate.

[0162] It is noted that, according to the present invention, the antenna structure is not limited to a planar structure, because the package can include several portions or parts of the antenna in multiple layers or components of the package.

[0163] In the case of non-planar, multi-layer or volumetric structures for the antenna pattern within the package, the box-counting algorithm can be computed by means of a three-dimensional grid, using parallelepiped cells instead of rectangular and meshes with 5×5×5 cells and 10×10×10 or 20×20×20 cells, respectively. In those cases, such a curve can take a dimension larger than two and in some cases, up to three.

[0164] FIG. **10** shows an alternative embodiment of the package **2**, which has already been described in FIG. **2**, mounted on a ground plane **1000**. In the figure, it is only represented a portion of the ground plane **1000** in the vicinity of the package **2**.

[0165] The ground connector GND of the package **2** is connected to the ground plane **1000** by means of connection **1002**. The ground plane **1000** is located with respect to the package **2** so as not to be underneath or above the at least one antenna **100**.

[0166] In this embodiment the antenna **100** comprises a parasitic element **1001** that is located outside the package **2**. The parasitic element **1001** is also connected to the ground plane **1000** by means of connection **1003**.

[0167] FIG. **11** shows an alternative embodiment of the package **4** of FIG. **4**, in which the radio-frequency component **450** outside the package **4** is a matching network **1100**.

[0168] FIG. **12** shows another embodiment of the package **4** of FIG. **4**, in which the radio-frequency component **450** outside the package **4** is a bypass or through-connection **1200**. Furthermore, in this embodiment the RF circuit **430** comprises a filter **1201**.

[0169] FIG. **13** shows a further embodiment of the package **4** of FIG. **4**, in which the radio-frequency component **450** outside the package **4** comprises a power amplifier **1300**.

[0170] FIG. **14** shows an alternative embodiment of the package **1** of FIG. **1**, in which the antenna **100** is a modular or discrete component **1400**. In particular, said modular or discrete component **1400** is a surface mount technique (SMT) component.

[0171] FIG. **15** shows an embodiment of a package **15** similar to the one already described in connection with FIG. **1**, but in which an antenna **1500** has a parasitic element **1501** located inside the package **15**.

[0172] FIG. **16** shows an embodiment of a system comprising the package **4** of FIG. **4** and a second antenna **1600** external to the package **4**. The radio-frequency component **450** outside the package **4** comprises a switch **1601** that makes it possible to commute between the antenna **100** arranged in the package **4** and the second antenna **1600**, providing antenna diversity.

[0173] FIG. **17**A shows an embodiment of a system comprising an antenna **1701** and an electrical circuit **1702** enclosed in a common package housing **1710** having a form factor of an in-line package for integrated circuit packages.

[0174] FIG. **17**B shows an embodiment of a system comprising an antenna **1701** and an electrical circuit **1702** enclosed in a common package housing **1720** having a form factor of a surface mount package for integrated circuit packages.

[0175] FIG. **17**C shows an embodiment of a system comprising an antenna **1701** and an electrical circuit **1702** enclosed in a common package housing **1730** having a form factor of a ball grid array package for integrated circuit packages.

[0176] FIG. **18** shows an embodiment of a system comprising an antenna **1801** and an electrical circuit **1802** enclosed in a common package housing **18** having a form factor of a leadframe package for integrated circuit packages. The package housing **18** comprises a metal layer **1803** on which the antenna **1801** has been created and on which the electrical circuit **1802** is mounted.

[0177] FIG. **19**A shows an alternative embodiment of the package **3** of FIG. **3**, in which the radio-frequency circuit **330** comprises a balun **1901**, the balun **1901** being a discrete component.

[0178] FIG. **19**B shows a further embodiment of the package **3** of FIG. **3**, in which the radio-frequency circuit **330** comprises a balun **1902**, the balun **1902** being a printed circuit.

[0179] FIG. **20** shows an embodiment of multiple-antenna communication system **2000** that forms a multiple-input-multiple-output (MIMO) system. The multiple-antenna communication system **2000** comprises two packages **2001** and **2002** (such as the one in FIG. **1**) mutually connected through a control circuit **2003**. The MIMO system **2000** receives signals from three remote transmitters (**2011**, **2012** and **2013**)

[0180] FIG. **21** shows an embodiment of multiple-antenna communication system **2100** that forms a smart antenna system. The multiple-antenna communication system **2100** comprises three packages **2101**, **2102** and **2103** (such as the one in FIG. **1**) mutually connected through an adaptive control circuit **2104**. The adaptive control circuit **2104** combines the radiation patterns of the antennas included in the packages **2101-2103** so that a resulting radiation pattern **2105** can be selectively directed towards a remote transmitter **2106** and away from a jamming source **2107** optimizing the signal-to-interference ratio of the system.

[0181] FIG. **22** shows an embodiment of multiple-antenna communication system **2200** that forms a phased array system. The multiple-antenna communication system **2200** comprises three packages **2201**, **2202** and **2203** (such as the one in FIG. **1**) mutually connected through a phase shifter **2204**. The antennas included in the packages **2201-2203** form an array, each antenna being fed with a phase determined by the phase shifter **2204**. By modifying the phases applied to the antennas, the tilt angle of the radiation pattern **2206** of the array can be varied. The multiple-antenna communication system **2200** further comprises a control circuit **2205** to determine the sequence in which the phases are varied to define a scanning path.

[0182] FIG. **23** shows an embodiment of multiple-antenna communication system **2300** that forms a sensor network. The multiple-antenna communication system **2300** comprises four packages **2301**, **2302**, **2303** and **2304** (such as the one in FIG. **1**) mutually connected through a central control processor **2305**.

1. System comprising:

an antenna and

an electrical circuit,

wherein the antenna and the circuit are arranged in a package having a form factor for integrated circuit packages.

2. System of claim **1**, wherein the circuit performs a baseband functionality.

3. System of claim **1**, wherein the circuit performs a digital functionality.

4. System according to claim **1**, wherein the circuit comprises a radio-frequency circuit.

5. System according to claim **4**, wherein a coupling between the antenna and the radio-frequency circuit is a reactive coupling.

6. System according to claim **4**, wherein the radio-frequency circuit is connected to a ground plane.

7. System according to claim **4**, wherein at least some of the connections of the radio-frequency circuit are balanced.

8. System according to claim **1**, comprising a radio frequency component outside the package.

9. System according to claim **8**, wherein the radio-frequency component outside the package is a matching network.

10. System according to claim **8**, wherein radio-frequency component outside the package is a bypass or a through-connection.

11. System according to claim **8**, wherein the radio-frequency component outside the package comprises a power amplifier.

12. System according to claim **4**, wherein the antenna is connected to the radio-frequency circuit and at least a part of the radio-frequency circuit is connected to the radio-frequency component outside the package.

13. System according to claim **4**, wherein the antenna is connected to the radio-frequency component outside the package.

14. System according to claim **4**, wherein the radio-frequency circuit comprises a balun.

15. System according to claim **14**, wherein the balun is a printed circuit.

16. System according to claim **14**, wherein the balun is a discrete component.

17. System according to claim **6**, wherein the ground plane is located with respect to the package so as not to be underneath or on top of the at least one antenna.

18. System according to claim **1**, wherein the antenna is connected to an input/output connector of the package and at least a part of the circuit is connected to an input/output connector of the package.

19. System according to claim **1**, wherein the antenna is a space filling antenna.

20. System according to claim **19**, wherein the space-filling antenna has a dimension larger than 1 when computed as a grid dimension calculation.

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