Title: MULTIBAND ANTENNA SYSTEM

Abstract: An antenna system internal to a radio device, the system comprising separate antennas and having separate operating bands. The system is implemented as de-centralized in a way that each antenna is typically based on a small-sized chip component (310; 320; 330; 340; 350; 360; 610), which are located at suitable places on the circuit board (PCB) and possibly on also another internal surface in the device. The chip component comprises a ceramic substrate and at least one radiating element. The operating band of an individual antenna covers e.g. the frequency range used by a radio system or only the transmitting or receiving band in that range. At least one antenna is connected to an adjusting circuit with a switch, by which the antenna's operating band can be displaced in a desired way. In this case the operating band covers at a time a part of the frequency range used by one or two radio systems. The antennas can be made small-sized, because a relatively small bandwidth is sufficient for an individual antenna, when there is a plurality of antennas. When the bandwidth is small, a material with higher permittivity can be chosen for the antenna than for an antenna having a wider band, in which case the antenna dimensions can be made correspondingly smaller. In addition, a good matching of the antenna is achieved on the whole width of each radio system, because the matching of a separate antenna having a relatively narrow band is easier to arrange than that of a combined multiband antenna.
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Multiband antenna system

The invention relates to an internal antenna system of a radio device with separate operating bands. The system is intended for use especially in small-sized mobile stations.

In small-sized, mobile radio devices the antenna is preferably placed inside the casing of the device for convenience. This makes the design of the antenna a more demanding task compared to an external antenna. Extra difficulties in the design is caused when the radio device has to function in a plurality of frequency ranges, the more the wider these ranges or one of them are.

Internal antennas most often have a planar structure, in which case they have a radiating plane and a parallel ground plane at a certain distance from it. The radiating plane is provided with a short-circuit and feed point of the antenna. The short-circuit conductor belonging to the structure extends from the short-circuit point to the ground plane, and the feed conductor of the antenna extends from the feed point to the antenna port of the device. For increasing the number of operating bands of the antenna, the radiating plane can be divided into two or more branches of different length as seen from the short-circuit point. The number of bands can also be increased by a parasitic auxiliary element. As an alternative, a parasitic element can be used for widening an operating band by arranging the resonance frequency corresponding to it relatively close to the resonance frequency corresponding to a branch of the radiating plane.

In this description and the claims, the terms "radiating plane", "radiating element" and "radiator" mean an antenna element, which can function as a part transmitting radio-frequency electromagnetic waves, as a part receiving them or as a part which both transmits and receives them. Correspondingly, "feed conductor" means a conductor which can also function as a receiving conductor.

The antennas of the kind described above have the drawback that their characteristics are insufficient when the number of radio systems in accordance with which the radio device must function increases. The insufficiency appears e.g. from that the matching of the antenna is poor in the band used by one of the radio systems or in a part of at least one of such bands. In addition, it is difficult to make sufficient isolation between the antenna parts corresponding to different bands. The drawbacks are emphasized when the antenna size has to be compromised because of the lack of space. The size is reduced by shortening the distance between the ra-
diating plane and the ground plane or by using dielectric material between them, for example.

It is also possible to arrange two radiators in the antenna structure so that they both have a feed conductor of their own. This comes into question when the radio device has a separate transmitter and receiver for some radio system. Fig. 1 shows an example of such an antenna structure known from the publication WO 02/078123. It comprises a ground plane 101, a radiating plane 110, a parasitic element 113 of the radiating plane and a segregated radiator 107. The radiating plane has a feed conductor 102 and a short-circuit conductor, and it thus forms a PIFA (Planar Inverted F-Antenna) together with the ground plane. The PIFA has two bands, because the radiating plane is divided into a first 111 and a second 112 branch as seen from the short-circuit and feed point. The first branch functions as a radiator in the frequency range of the GSM900 (Global System for Mobile communications) and the second branch in the range of the DCS (Digital Cellular Standard) system. The parasitic element 113 is connected to the ground plane and it functions as a radiator in the range of the PCS (Personal Communication Service) system. The segregated radiator 107 has its own feed conductor 103 and short-circuit conductor. Together with the ground plane it forms an IFA, which functions as a Bluetooth antenna. The segregated radiator is located near the radiating plane and its parasitic element so that the short-circuit and feed conductors of the radiating plane, the short-circuit conductor of the parasitic element and the short-circuit and feed conductors of the segregated radiator are in a row in a relatively small area compared to the dimensions of the antenna structure. The support structure of the antenna elements is not visible in the drawing.

The segregated radiator mentioned above, provided with its own feed, is thus for the Bluetooth system. Such a radiator can similarly be e.g. for the WCDMA (Wideband Code Division Multiple Access) system. In general, the use of a segregated radiator provided with its own feed reduces the drawbacks mentioned above to such an extent that the matching can be made good at least in the frequency range of the radio system for which the segregated radiator is provided.

The use of dielectric material for reducing the physical size of the antenna was mentioned above. Fig. 2 shows an example of such a known antenna. This comprises a dielectric substrate 211, a radiator 212 and its feed element 213. The radiator and the feed element are conductor strips on the surface of the substrate. All three together form an antenna component, which is mounted on the circuit board PCB of a radio device.
The object of the invention is to reduce the above-mentioned drawbacks of the prior art. The arrangement according to the invention is characterized in what is set forth in the independent claim 1. Some preferred embodiments of the invention are set forth in the other claims.

The basic idea of the invention is the following: The antenna system of a multiband radio device is implemented as internal and decentralized in such a way that the device has a plurality of separate antennas. Each antenna is typically based on a small-sized chip component with a ceramic substrate and at least one radiating element. The chip components are located at suitable places on the circuit board and possibly on also another internal surface of the device. The operating band of an individual antenna covers the frequency range used by one radio system or only the transmitting or receiving band of that range. At least one antenna is connected to an adjusting circuit provided with a switch, by means of which circuit the antenna operating band can be displaced in a desired way. In this case the operating band covers at a time a part of the frequency range used by one or two radio systems.

The invention has the advantage that the size of the antennas can be made small. This is due to that when there is a plurality of antennas, a relatively small bandwidth is sufficient for an individual antenna. When the bandwidth is small, a material with higher permittivity can be chosen for the antenna than for an antenna having a wider band, in which case the antenna dimensions can be made correspondingly smaller. In addition, the invention has the advantage that a good matching is achieved on the whole width of the band of each radio system. This is due to that the matching of a separate antenna having a relatively narrow band is easier to arrange than the matching of a combined multiband antenna. The invention further has the advantage that the number of the necessary antennas can be decreased without compromising the matching. For example, when the time division duplex is used, the separate transmitting and receiving antennas can be replaced with an antenna equipped with said adjusting circuit. The operating band of this antenna is displaced from the transmitting band to the receiving band and vice versa, as needed. The matching and also the efficiency are in part improved by the fact that in a decentralized system the antennas can each be located in a place which is advantageous with regard to its function. The invention further has the advantage that the isolation between the antennas is good. This is due to the sensible decentralization of the antennas and the fact that a substrate with a relatively high permittivity collapses the near field of the antenna.
In the following, the invention will be described in detail. Reference will be made to the accompanying drawings, in which

Fig. 1 shows an example of a known multiband antenna,

Fig. 2 shows an example of a known antenna component using a dielectric substrate,

Fig. 3 shows an example of the placement of the antennas in an antenna system according to the invention,

Figs. 4a-e show examples of the composition of an antenna system according to the invention,

Fig. 5 shows an example of an adjusting circuit, by which the operating band of an antenna can be displaced,

Fig. 6a shows an example of an individual antenna and its connection to the adjusting circuit,

Fig. 6b shows an example of the adjusting circuit of the antenna in Fig. 6a,

Fig. 7 shows an example of displacement of the operating band of an antenna suitable for the adjustable antenna in Fig. 4e,

Fig. 8 shows an example of the matching of a pair of antennas in the antenna system according to Fig. 3,

Fig. 9 shows an example of the efficiency of a pair of antennas in the antenna system according to Fig. 3, and

Fig. 10 shows another example of an arrangement, by which the operating band of an antenna can be displaced.

Figs. 1 and 2 were already described in connection with the prior art.

Fig. 3 shows an example of an antenna system according to the invention as a layout drawing. There is a radio device 300 with a circuit board PCB, plastic frame FRM and casing CAS in the drawing. A large part of the surface of the circuit board on the side visible in the drawing consists of a conductive ground plane GND. In this example the antenna system includes six antennas. Each one of these comprises an elongated antenna component with a ceramic substrate and two radiating elements. The ground plane around the antenna component is also considered to be a part of the antenna here. In this example, the radiating elements of each antenna component are of the same size so that they resonate on
the same, relatively narrow frequency range. The feed conductor of an antenna is connected to one element, and the other element is parasitic.

The first 310, the second 320, the third 330, the fourth 340 and the fifth 350 antenna component are mounted on the same side of the circuit board PCB, visible in the drawing. The first antenna component 310 is located in the middle of the first end of the circuit board, parallel with the end. The second antenna component 320 is located in a corner defined by the second end and the first long side of the circuit board, parallel with the end. The third antenna component 330 is located near the corner defined by the second end and the second long side of the circuit board, parallel with the long side. The fourth antenna component 340 is located beside the first long side of the circuit board parallel with it, slightly closer to the first than the second end. The fifth antenna component 350 is located beside the second long side of the circuit board parallel with it, opposite to the fourth antenna component. The sixth antenna component 360 is mounted on the side surface of the frame FRM, which surface is perpendicular to the plane of the circuit board. The antenna components are located at places which are advantageous with regard to the other RF parts and so that they do not much interfere with each other.

Fig. 3 also shows an example of the ground arrangement of the antennas. The ground plane of the surface of the circuit board has been removed from below and beside the first antenna component 310 to a certain distance. However, a narrow part of the ground plane extends to one or more points of the radiators. In practice, the system has mainly antenna-dedicated ground planes because of the decentralization of the antenna components. This becomes evident from the fact that the distance along the ground plane between two radiators belonging to different antennas is at least the combined length of these radiators.

The antennas according to Fig. 3 can be designed e.g. as follows:
- the antenna based on the component 310 is an antenna for the GSM850 system;
- the antenna based on the component 320 is an antenna for the GSM900 system;
- the antenna based on the component 330 is an antenna for the GSM1800 system;
- the antenna based on the component 340 is a transmitting antenna for the WCDMA system;
- the antenna based on the component 350 is a receiving antenna for the WCDMA system;
the antenna based on the component 360 is an antenna for the GSM1 900 system.

Figs. 4a-4e show examples of the composition of the antenna system according to the invention as schematic diagrams. In Fig. 4a there are three antennas. One of them is shared between the GSM850 and GSM900 systems, the second is shared between the GSM1 800 and GSM1 900 systems, and the third is for the WCDMA system. In Fig. 4b, there are six antennas for the same bands as above in the example mentioned in the description of Fig. 3. So, one of them is for the GSM850 system, the second for the GSM900, the third for the GSM1 800, the fourth for the GSM1 900, the fifth for the transmitting side of the WCDMA system, and the sixth for the receiving side of the WCDMA system, listed in the order of Fig. 4b. In Fig. 4c there are twelve antennas. One of them is for the transmitting side of the GSM850 system, and the second and the third for the receiving side of the GSM850 system. The latter two are used to implement the space diversity in the receiving. There is a corresponding group of three antennas for the GSM900, GSM1 800 and GSM1 900 system as well. In Fig. 4d there is a separate antenna for both the GSM850 and GSM900 system, like in Fig. 4b. However, in this case the antennas are connected to the same feed line. After the separation of the transfer directions, the antennas then become connected to the shared transmitter and the shared receiver of these systems. In the same way also other antennas, the operating bands of which are close to each other, can be connected to a shared feed line.

In Fig. 4e there are two antennas, existing for the GSM850 and GSM900 system, connected to the same feed line, like in Fig. 4d. In this case the operating band of one antenna covers only the transmitting band of the GSM850 system. The other antenna is adjustable so that its operating band can be set to cover either the receiving band of the GSM850 system, the transmitting band of the GSM900 system or the receiving band of the GSM900 system. These three bands are successive so that there are only relatively narrow unused frequency ranges between them.

Compared with Fig. 4d, no saving regarding the number of the antennas is achieved by the arrangement of Fig. 4e, but it has the advantage that both antennas have a narrower band.

Fig. 5 presents as block diagram an example of an adjusting circuit, by which the operating band of an antenna can be set to different places. The number of the places is three in this example. The adjusting circuit 580 is connected to an antenna component 510 and the ground plane. Seen from the antenna, the adjusting
circuit includes first a filter FIL. Its object is here to attenuate the harmonic frequency components developing in the switch and to function as an ESD (Electrostatic Discharge) protector of the switch. The filter type is for example high-pass or bandpass one. The second port of the filter is connected to the input of the switch SW, which has three alternative outputs. Each output is coupled to the ground through a different reactive circuit, the reactances $X_1$, $X_2$ and $X_3$ of these circuits deviating from each other. Thus the radiator(s) in the antenna component can be coupled to the ground through three alternative reactances. In a simple case the reactive circuit is a short-circuit with short conductors (very high reactance).

Changing the reactance by controlling the switch changes the resonance frequency/frequencies of the antenna and in that way the place of its operating band. The switch is controlled by the signal C.

Fig. 6a shows an example of an individual antenna and its connection to the adjusting circuit. A part of the circuit board PCB of a radio device, on which board there is mounted an antenna component 610, is seen in the figure. The antenna component comprises a substrate 611, a first radiating element 612 fed by the feed conductor 602 and a parasitic radiating element 613. The radiating elements are located symmetrically so that each of them covers a part of the upper surface of the substrate and one of the opposite end surfaces. A relatively narrow slot is left over between the elements, which slot extends diagonally from a corner to the opposite corner of the substrate's upper surface. Also in this example, as already mentioned in the description of Fig. 3, the ground plane of the surface of the circuit board has been removed from below and beside the antenna component 610 to a certain distance. Such an arrangement increases the electric size of the antenna compared to that the ground plane would continue as wide to the area under the component. In that case for example the height of an antenna component functioning in a certain frequency range can be correspondingly reduced. However, the ground plane extends both to the first radiator 612 and the parasitic radiator 613 at the ends of the antenna component.

For the antenna adjusting, the antenna component further comprises a strip conductor 614 extending along a side surface of the substrate from the first radiator 612 to the surface of the circuit board PCB. That strip conductor is then galvanically connected to the first radiator in a control point CP. The galvanic connection continues in this example through a via to the opposite side of the circuit board, where the adjusting circuit of the antenna in question is located.
Fig. 6b shows an example of the adjusting circuit of the antenna in Fig. 6a. A part of the circuit board PCB of Fig. 6a is seen from the reverse side in the drawing. The adjusting circuit comprises a switch and three transmission lines. The conductor coming from the control point CP is connected to the input port of the switch SW through a blocking capacitor BC, by which the direct current circuit from the switch control to the ground through the switch input is broken. The switch has three alternative outputs, each of them being coupled to a transmission line. The transmission lines are in this example planar lines on the surface of the circuit board PCB. Each line comprises a middle conductor and a ground conductor on its both sides. The first transmission line 681 is short-circuited at its tail end, the second transmission line 682 is open and the third transmission line 683 is short-circuited. At the head end of each short-circuited line there is a similar blocking capacitor as also on the input side of the switch. The lengths of the transmission lines are respectively 32 mm, 25 mm and 11 mm, for instance. The transmission lines have then the length less than a quarter wave at the frequencies of order of one GHz. This means that the first and third transmission lines represent capacitive reactances with different values, and the second transmission line represents an inductive reactance with a certain value. When the transmission line connected to the switch input is replaced by controlling the switch, the resonance frequency of the antenna and the place of its operating band are changed.

There is no filter between the switch and the antenna component in the example of Fig. 6b. If desired, such a filter is obtained for example by adding a coil between the ground and the conductor coming from the control point CP. In this case the coil together with the capacitor BC forms a high-pass filter for the ESD protection of the switch.

Fig. 7 shows an example of displacement of the operating band of an antenna suitable for the adjustable antenna in Fig. 4e. So the antenna has three alternative operating bands, and they are implemented by a structure according to Figs. 6a and 6b. Curve 71 shows the reflection coefficient S11 as a function of frequency, when the antenna is intended to function as the receiving antenna in the GSM850 system, the receiving band B1 of which is 869-894 MHz. It is seen from the curve that the reflection coefficient is -7 dB or better at this setting of the adjusting circuit. Thus the antenna’s operating band covers well the required range. Curve 72 shows the reflection coefficient as a function of frequency, when the antenna is intended to function as the transmitting antenna in the GSM900 system, the transmitting band B2 of which is 890-915 MHz. It is seen from the curve that the reflec-
tion coefficient is -7 dB or better also at this setting of the adjusting circuit. Thus
the antenna's operating band covers well the required range. Curve 73 shows the
reflection coefficient as a function of frequency, when the antenna is intended to
function as the receiving antenna in the GSM900 system, the receiving band B3 of
which is 935-960 MHz. It is seen from the curve that the reflection coefficient is
about -8 dB or better at this setting of the adjusting circuit. Thus the antenna's op-
erating band covers well the required range.

Fig. 8 shows an example of the matching of the antenna system according to Fig.
3 for the antennas corresponding to the fourth 340 and the fifth 350 antenna com-
ponent, when these are designed to function as the transmitting and receiving an-
tennas of the WCDMA system. The substrate of the antenna components is of a
ceramics, and its dimensions are 10-3-2 mm³ (length, width, height). The matching
appears from the curve of the reflection coefficient S11 as a function of frequency.
It is seen from the curve that the reflection coefficient is -10 dB or better in the
range of both the transmitting and the receiving band. The matching of the an-
tenna pair is then good.

Fig. 9 shows a curve of the efficiency of the same antenna pair to which Fig. 8 ap-
pplies as a function of frequency. It is seen that the efficiency is approx. 0.76 on an
average in the transmitting band and approx. 0.72 on the receiving band. The effi-
ciency of the antenna pair is then excellent considering the small size of the an-
tenna components. The maximum gain of the transmitting antenna is approx. 1.3
dB and the maximum gain of the receiving antenna approx. 2.3 dB on an average
as measured in free space.

Fig. 10 shows another example of an arrangement, by which the operating band
of an antenna can be displaced. A part of the circuit board PCB of a radio device,
on which board there is mounted an antenna component A10, is seen in the figure.
The antenna component comprises also in this example a substrate A11, a radia-
tor A12 fed via the feed conductor A02 and a parasitic radiator A13. The radiators
are located symmetrically so that each of them covers a part of the upper surface
of the substrate and one of the opposite end surfaces. In addition, the antenna
component comprises a second parasitic element A14, which is located on one
side surface of the substrate so that it has an electromagnetic coupling of equal
strength to both radiators. The second parasitic element is connected by a con-
ductive strip to the adjusting circuit A80 on the circuit board PCB, which adjusting
circuit is presented as an integrated component in the figure. So the coupling of
the adjusting circuit to the radiators is electromagnetic in this example. The control of the adjusting circuit takes place e.g. through a via in the circuit board, the control being invisible in the figure.

A decentralized antenna system according to the invention has been described above. As appears from the examples described, the number and the location of the antennas can vary greatly. An individual antenna can include also only one radiating element. Some or all of the reactances of the adjusting circuit can be naturally implemented by discrete components, too. The adjusting circuit can also be based on the use of capacitance diodes, in which case the adjustment can be continuous instead of the step-wise one. The band of an adjustable antenna can also cover only a part of the transmitting or receiving band of a system using a large frequency range. The invention does not limit the method of manufacture of individual antenna components. The manufacture can take place for example by coating a piece of ceramics partly with conductive material or by growing a metal layer on the surface e.g. of silicon and removing a part of it by the technique used in the manufacture of semiconductor components. An individual substrate can also be a part of the outer casing of a radio device. The inventive idea can be applied in different ways within the scope defined by the independent claim 1.
Claims

1. An internal antenna system of a radio device, which system comprises a ground plane (GND) and at least two antennas, each radiating element (612, 613; A12, A13) of which is a conductor on a surface of a dielectric substrate (611; A11), characterized in that:
   - a distance along said ground plane between two radiating elements belonging to different antennas is at least the combined length of these radiators, and
   - at least one antenna is connected to an adjusting circuit (528; A28), by which its operating band can be displaced.

5 2. An antenna system according to Claim 1, characterized in that the substrate (611; A11) of an individual antenna and the at least one radiating element on surface of the substrate constitute a unitary, chip-type antenna component (A0; A0; 320; 330; 340; 350; 360; 610; A10).

10 3. An antenna system according to Claim 2, characterized in that at least one (A0; 320; 330; 340; 350) of the antenna components is located on a circuit board (PCB) of the radio device.

15 4. An antenna system according to Claim 2, characterized in that at least one (360) of the antenna components is on a surface of an internal frame (FRM) of the radio device.

20 5. An antenna system according to Claim 1, characterized in that an operating band of an antenna belonging to the antenna system covers a frequency range used by at least one radio system.

25 6. An antenna system according to Claim 1, characterized in that an operating band of an antenna belonging to the antenna system covers a transmitting band (Tx) in the frequency range used by a radio system, and an operating band of another antenna belonging to the antenna system covers a receiving band (Rx) of the same frequency range.

30 7. An antenna system according to Claim 6, characterized in that it further comprises an antenna, an operating band of which likewise covers the receiving band of the frequency range used by the radio system in question to implement the space diversity in the receiving.
8. An antenna system according to Claim 1, characterized in that said adjusting circuit (528) comprises a switch (SW) and alternative reactive circuits (X₁, X₂, X₃) to change a resonance frequency of the antenna and to displace in that way an operating band of the antenna.

9. An antenna system according to Claim 8, characterized in that said reactive circuits are implemented by planar transmission lines (681, 682, 683).

10. An antenna system according to Claim 8, characterized in that the operating band of the antenna covers at a time only a part of the transmitting or receiving band of a radio system.

11. An antenna system according to Claim 1, characterized in that said adjusting circuit is connected galvanically to a radiating element (612) of the antenna.

12. An antenna system according to Claim 2, characterized in that said substrate is of a ceramics.

13. An antenna system according to Claim 1, characterized in that the substrate of an individual antenna is a part of an outer casing (CAS) of the radio device.
Fig. 1  PRIOR ART

Fig. 2  PRIOR ART
Fig. 9

Fig. 10
# International Search Report

**International application No**

PCT/FI2006/050402

## A. Classification of Subject Matter

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

## B. Fields Searched

Minimum documentation searched (classification system followed by classification symbols)

IPC8: H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI, IEEExplore

## C. Documents Considered to be Relevant

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