(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 November 2012 (15.11.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/152618 A1

(51) International Patent Classification:
G01R 33/3415 (2006.01) *G01R 33/561* (2006.01)

(21) International Application Number:
PCT/EP2012/057990

(22) International Filing Date:
2 May 2012 (02.05.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11165140.2 6 May 2011 (06.05.2011) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: ANTENNA ASSEMBLY FOR ULTRA-HIGH FIELD MRI

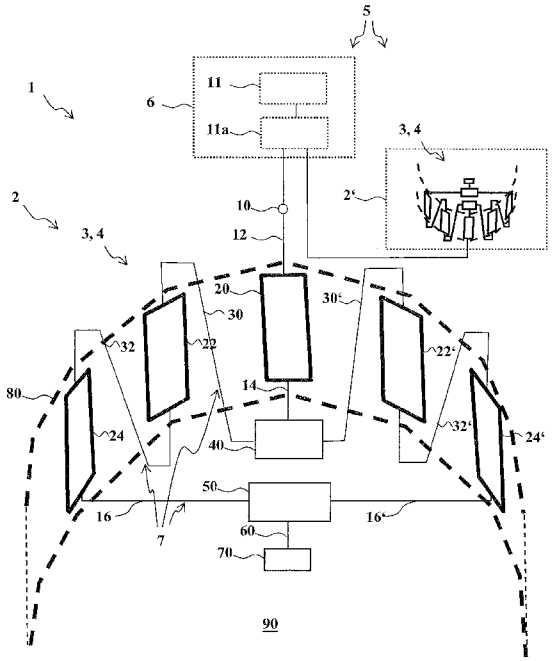

Fig. 1

(57) **Abstract**: The invention relates to an antenna assembly (1) comprising at least one input port (10) and a plurality of antenna elements (20 - 24'). The plurality of antenna elements (20 - 24') is supplied by the at least one input port (10) via a circuitry (7). The antenna elements (20 - 24') are arranged along a circumference around an inner area (90) of the antenna assembly (1). At least two of the antenna elements (20 - 24') have distinct characteristic impedances. According to the invention, the impedance of an antenna element is varied with respect to that of another antenna element in order to achieve the desired spatial rf field distribution. The invention further relates to a radio transmitter (5) comprising at least one of the inventive antenna assemblies (1) as well as a RF source (11). In addition, the invention relates to a method for operating the inventive antenna assembly (1).

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Antenna assembly for ultra-high field MRI

Prior Art

In particular in the field of MRI (magnet resonance imaging), it is desired to provide a RF excitation signal with a desired RF (radio frequency) magnetic field strength distribution in a volume, preferably a homogenous intensity distribution in an inner volume of an MRI apparatus.

For generating such a desired, homogenous distribution, it is known to use a so called birdcage structure. Such a structure is shown in Figure 1 of "An Efficient, Highly Homogeneous Radiofrequency Coil for Whole-Body NMR Imaging at 1.5 T" by Cecil E. Hayes, William A. Edelstein, John F. Schenck, Otward M. Mueller and Matthew Eash, Journal of Magnetic Resonance 63, 622-628 (1985). A birdcage structure comprises circumferentially distributed rods as antenna elements, which in its low-pass version are connected with conducting rings by an equal number of capacitors resulting in a cylindrical structure such that a resonator is provided. When applying a RF signal, two waves are generated traveling circumferentially in opposite directions from rod to rod, according to the electrical connection provided by the conductive rings. This results in a homogeneous RF magnetic field strength in the inner area of the birdcage structure, as far as the frequency of the RF signal is matched to the dimensions of the rods and the rings and capacitors, and as far as the rings properly propagate the RF signal along the circumference. In this way, the resonant birdcage structure defines the radio frequency magnetic field strength distribution in its inner volume by the appropriately chosen resonant mode which causes a current distribution between individual rods inherent to the arrangement and properties of rods, the capacitors and the rings.

Since the dimensions of the birdcage structure is inherently related to the frequency of the RF signal exciting the birdcage structure, the size of the birdcage structure is limited by this frequency. Further, for frequencies above 100 – 150 MHz, the conducting rings do not properly define the current distribution among the rods and capacitive / inductive coupling among the rods impairs the current distribution and, therefore, impairs the desired distribution of the magnetic RF field.

However, since higher static magnetic fields in MRI devices above 3 Tesla or above 5 Tesla inherently require higher exciting frequencies, a birdcage structure does not provide the desired precision regarding the desired field strength distribution and, in addition, does not allow a size appropriate for imaging a human body.

Another approach is shown in Figure 1c of "Travelling-wave nuclear magnetic resonance" by David O. Brunner, Nicola De Zanche, Jürg Fröhlich, Jan Paska & Klaas P. Pruessmann, Nature Vol. 457, 19 February 2009, pages 994 – 998. The depicted structure refers to a travelling wave resonator, wherein an antenna emits a RF wave into one end of the cylindrical bore of an MRI apparatus, which is used as waveguide. A human body within the bore absorbs a high amount of the RF wave near the antenna, in particular in case of frequencies above 150 MHz. Thus, when imaging a part of the human body remote to the antenna requiring a certain field strength at this part, RF waves with high power have to be emitted into the bore, thereby easily exceeding a maximum SAR (Specific Absorption Rate) level at the body parts next to the antenna. This problem aggravates with increasing static magnetic field strength of the MRI apparatus and aggravates with increasing radio frequency. In addition, undesired additional spatial modes occur at higher radio frequencies, in particular due to the distortion of the radio frequency wave distribution by the human body within the bore. Therefore, also travelling wave resonators do not allow to provide a desired radio wave distribution at higher frequencies adapted for MRI devices with higher static magnetic field strengths above 3 or 5 Tesla.

Further, it is known to use TEM (transversal electromagnetic mode) resonators for high field MRI, eg. as shown in "High frequency volume coils for clinical NMR imaging and spectroscopy" by J.T. Vaughan, H.P. Hetherington, J.O. Otu, J.W. Pan, G.M. Pohost,. Mag. Reson. Med. 32 (1994), pages 206-218 and in "Whole-Body Imaging at 7T: Preliminary Results" J. Thomas Vaughan, Carl J. Snyder, Lance J. DelaBarre, Patrick J. Bolan, Jinfeng Tian, Lizann Bolinger, Gregor Adriany, Peter Andersen, John Strupp and Kamil Ugurbil, Magnetic Resonance in Medicine 61:244-248 (2009). As shown in these documents, the desired distribution of the radio frequency magnetic field strength (a homogeneous cross section) cannot be achieved in all volume, so the application of TEM resonators has restrictions for imaging a whole human body at 7T and above. For example in Fig. 2a of "Whole-Body Imaging at 7T: Preliminary Results" as referenced above showing a cross sectional B1-map, strongly varying magnetic field strengths within the cross section are observed.

Summarized, known concepts for providing a radio frequency excitation to a volume do not allow for a desired (homogeneous) distribution of the radio frequency field strength with sufficient precision, in particular for frequencies above 125 MHz, which are required

for MRI with static magnetic field strength above 3 or 5 Tesla. The known concepts suffer from small antenna volumes not capable to receive a human body, from substantial deviations from a desired distribution of the radio frequency excitation and from undesired, additional spatial modes of the RF magnetic field.

In US 20090192382 A1, a magnetic resonance system obtaining magnetic resonance exposures of an examination subject is disclosed. The magnetic resonance system has an examination tunnel and a whole-body antenna with two connection terminals. The whole-body antenna cylindrically extends around the examination tunnel along a longitudinal axis. The system has a radio-frequency supply device in order to respectively supply the whole-body antenna with radio-frequency signals for emission of a radio-frequency field in the examination tunnel. The radio-frequency supply device has a radio-frequency generator for generation of a radio-frequency signal, a signal splitter that divides a radio-frequency signal coming from the radio-frequency generator into two partial signals that are phase-shifted by 90° relative to one another. Two radio-frequency feed lines are connected with the two connection terminals of the whole-body antenna. Via these radio-frequency feed lines, the two partial signals are fed into the whole-body antenna. The whole-body antenna has an intrinsic transmission characteristic such that a radio-frequency field is emitted that is elliptically polarized in a defined manner in a plane lying perpendicular to the longitudinal axis, at least in the unloaded state of the examination tunnel.

In US 20060181279 A1, a magnetic resonance imaging apparatus is disclosed. The magnetic resonance imaging apparatus acquires magnetic resonance signals by the PI method using an RF coil unit having basic coils serving as surface coils which are arrayed with at least two coils along a static magnetic field direction (Z direction) and at least two coils along each of two orthogonal x, y directions. The coils are divided into an upper unit and a lower unit. The upper unit and lower unit are fixed by a band or the like to allow them to be mounted on an object to be examined. The signals detected by the respective surface coils are sent to a data processing system through independent receiver unit and formed into a magnetic resonance image.

It is therefore an object of the invention to provide an antenna structure or a mode of operation therefore, which allows providing a desired radio frequency magnetic field strength distribution within an area of sufficient size.

Disclosure of the Invention

This problem is solved by the subject matter of the independent claims. In particular, this problem is solved by an antenna assembly comprising at least one input port and a plurality

of antenna elements. The plurality of antenna elements is supplied by the at least one input port via a circuitry. The antenna elements are arranged along a circumference around an inner area of the antenna assembly. At least two of the antenna elements have distinct characteristic impedances. In particular, antenna elements positioned at distinct angular distances with regard to an input port (or with regard to an antenna element directly connected thereto) have distinct characteristic impedances.

The antenna elements are preferably so called nonsymmetrical transmission lines, which are open to the inner area or volume of the subject to be examined by MRI. Their characteristic impedance is defined by geometric dimensions and physical properties of their dielectric parts. The plurality of antenna elements preferably forms a transmission array and more preferably a transmission coil array. As used herein, the term transmission array refers to an array of antennas, which are adapted to generate a specific field distribution and/or field strength distribution in a specific volume, such as in an inner area or volume partially or fully surrounded by the antennas. Further, as used herein, the term transmission coil array refers to a transmission array, wherein the antennas of the transmission array fully or partially are designed as coils. However, other types of embodiments of the plurality of antenna elements are possible, such as other types of arrangements and/or other embodiments of the antenna elements. Preferably, the antenna assembly is adapted such that the impedance, preferably the characteristic impedance, of at least one of the antenna elements may be varied with respect to the impedance, preferably the characteristic impedance, of at least one other antenna element, in order to achieve a desired spatial field strength distribution.

The distinct characteristic impedances of the individual antenna elements allow controlling the resulting field contribution of this antenna element to the overall distribution within the structure. Herein, the term field distribution denotes the spatial distribution of the RF (radio frequency) electromagnetic field, in particular the magnetic field strength thereof, and relates to the RF magnetic field strength distribution, if not explicitly noted otherwise. The field distribution within a volume or inner area is the result of the magnetic fields provided by the respective antenna elements irradiating into the volume or inner area.

In contrast to the above mentioned known concepts, the invention generates the required overall current distribution by well defined characteristic impedances of the individual antenna elements. According to the invention, a desired overall current distribution and a desired resulting spatial field strength distribution is defined by characteristic impedances of the antennas. The characteristic impedances of at least one of the antenna elements is varied with regard to at least another antenna element in order to achieve the desired overall current distribution and the desired resulting spatial field strength distribution. The

characteristic impedances are varied according to the desired overall current distribution and the desired resulting spatial field strength distribution. In particular, the characteristic impedances of the antenna elements are adapted to the desired overall current distribution and a desired resulting spatial field strength distribution. In particular, the RF field distribution is not predefined by a resonant mode nor by inter-element coupling or by wave propagation via end rings but can be arbitrarily selected (e.g. according to a desired inner are size or volume), while the impedances of the antennas are adapted to provide a desired field distribution. A further advantage of the invention is the use of traveling waves in contrast to standing waves of a resonating structure as given by the prior art. In this way, undesired resonant modes, which are the inherent result of a resonating structure and an object within the structure, do not occur and/or may be suppressed. Additionally or alternatively, undesired inhomogeneities may be mitigated or suppressed. Specifically, by using non-resonant structures, inhomogeneities in the field may be suppressed at a large extent, since regions in which partial waves may positively or negatively interfere are not fixed in space. Contrarily, these regions of interference may move along the direction of the static magnetic field, which is typically referred to as the z-direction. Consequently, maxima and minima of interference may move, as opposed to a typical situation in a resonator in which these maxima and minima of the fields typically remain fixed in space. Specifically, in a bird-cage setup, partial waves may move in opposing directions, such as in opposing azimuthal directions around the z-axis. Wherever the partial waves meet, however, a static pattern of field distribution may occur, which may remain fixed in space and fixed inside the object such as the human body. Consequently, specifically at high frequencies, stationary interference patterns may occur.

In this regard, the magnetic field strength provided by each antenna element directly depends on the impedance of the respective antenna element since the magnetic field strength provided by an antenna element is proportional to the current it carries.

According to the invention, the antenna impedances are varied in order to provide the desired current at the respective antenna elements, the resulting individual magnetic field strengths produced by the respective antenna elements and, in consequence, to provide the desired overall magnetic field strength distribution within the inner area or the interior of the inventive antenna assembly or at least one of these desired parameters. By contrast, in a birdcage structure, the respective field strengths are predefined by the current distribution pattern existing on the rods. The rings of a birdcage structure forward RF power from one antenna element to the subsequent antenna elements in form of two waves, traveling in opposite directions along the rings and so cause a standing current pattern by mutual interference and/or by mutual inductance, which depends on the geometrical properties of the ring with regard to the wavelength. Thus, the geometry in a birdcage structure is given

by electrical constraints rather than by application requirements. Thus, the invention allows more flexible arrangements since the impedance of the antenna elements is used to define the field strength provided by the respective antenna elements, independent from their geometrical arrangement.

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According to the invention, the antenna elements are oriented towards an inner area encompassed by the antenna elements. The antenna elements are arranged along a circumference, which preferably is a circumference encompassing the inner area. The circumference corresponds to an outer boundary of the inner area. The inner area is
10 preferably a volume, which is encompassed by the antenna elements. At least two or preferably all of the antenna elements extend along the same direction. In particular, the antenna elements extend along a longitudinal direction of the inner area, preferably corresponding to a longitudinal axis of the inventive antenna assembly. The field distribution provided by the antenna elements preferably relates to a cross section, which is
15 substantially perpendicular to the longitudinal direction of the inner area. In an example, the antenna elements are distributed along a circumference of a cylinder, preferably an oval or circular cylinder (having an oval or circular cross section). Generally, the cylinder may have an arbitrary cross-section, such as a circular, a round, an oval or a polygonal cross-section. Particularly, the antenna elements are mutually aligned in circumferential direction
20 of the antenna assembly. The antenna elements extend transverse to the cross sectional area of the antenna assembly, in particular perpendicular thereto. The antenna elements are arranged in parallel to each other, and, in particular, parallel to a longitudinal axis of the antenna assembly.

25 According to a further aspect of the invention, the antenna elements are of the same electrical length, in particular corresponding to a half wavelength or an integer multiple thereof. In this way, no reflections occur despite distinct characteristic impedances of connected antenna elements.

30 The at least one input port is adapted to receive a RF signal and is further adapted to forward this signal to one of the antenna elements or to a subgroup of antenna elements. Each antenna element comprises two taps, which are located at opposite sides of a respective antenna element. The input port is connected to a tap of one of the antenna elements. Alternatively, each of the input ports is connected to a tap of an antenna element,
35 wherein each antenna element is connected to one input port only at most.

As used herein, the term circuitry may refer to an arbitrary element or combination of elements which is adapted to supply antenna elements with appropriate high-frequency or rapid frequency signals by the input port. Thus, the at least one circuitry may comprise one

or more connections interconnecting the antenna elements and/or one or more lines connecting one or more of the antenna elements with at least one further element, such as with an RF source adapted to generate RF signals and/or with a splitter adapted to split one or more RF signals and/or with one or more power splitters. Generally, the term "supply" may imply an arbitrary type of providing RF signals to the antenna elements, such as guiding the RF signals via appropriate conductor elements.

Preferably, the antenna assembly is designed such that at least two, preferably more than two or even all of the antenna elements are connected serially. Thus, as the skilled person will recognize, a circuitry may be provided in which the antenna elements, preferably all of the antenna elements, are switched in line. The serial connection of the at least two antenna elements preferably may refer to the fact that a RF signal is transmitted from the input port such that the RF signal reaches the antenna elements in a sequential order, such as by firstly reaching a first one of the antenna elements and, thereafter, leaving the first one of the antenna elements reaching the other one of the antenna elements.

A power splitter can be provided downstream or upstream the input port or downstream of an antenna element, which is supplied by the input port. Thus, the circuitry can comprise a power splitter and/or connections serially connecting antenna elements. In an example, a power splitter can be connected between an input port and two antenna elements supplied by the power splitter in order to distribute the power supplied to the power splitter among two or more antenna elements (or among two or more groups of mutually - preferably serially - connected antenna elements). Further, a power splitter can be provided between a first antenna element connected to the input port and two second antenna elements, which are supplied by the power splitter. In the latter case, the power splitter is connected to the first antenna element in order to be supplied by the first antenna element. Such a power splitter distributes the power received from the first antenna element on two second antenna elements. The first antenna element is supplied by the input port.

In accordance to a preferred embodiment, the circuitry comprises connections, in particular one or more connections. The connection serially connects (at least) two of the antenna elements. If more than one connection is provided, the connections successively connect more than two antenna elements in series. The connections can further connect a plurality of outputs (preferably two outputs) with two or more antenna elements. Thereby, each connection connects an output with a respective antenna element. Such an output can be the output of a power splitter. The at least one connection provides a phase shift of approximately n1 x 180°, n1 being an integer number ≥ 1, in particular being 1, 2, 3, 4, 5 or more. Preferably, n1 is an odd integer number ≥ 1, in particular being 1, 3, 5 or more. This phase shift relates to the phase difference between an output of one or more of the

antenna elements and an input of a subsequent element. Thus, as used throughout the present invention, the term phase shift of a specific element, such as a specific antenna element, relates to a phase difference of the specific element as compared to one or more neighboring elements, such as to the preceding element of the same time and/or the subsequent element of the same type. Thus, when referring to the connection providing a phase shift of a specific amount, as the skilled person immediately will understand, the term phase shift refers to the fact that the connection is interposed in between a first element and a second element, wherein the connection is adapted to provide a phase difference by the specific amount in the second element as compared to the first element or vice versa. Further, as used herein, the term approximately when used in connection with a specific phase shift refers to the fact that the phase shift preferably exactly is the specific phase shift, wherein, optionally, specific tolerances may be provided, preferably tolerances of no more than $\pi/10$, more preferably tolerances of no more than $\pi/20$ and, most preferably, tolerances of no more than $\pi/40$.

The at least one connection may provide approximately an equivalent electrical length of the product of an integer number of the wavelength and/or an odd integer number of half the wavelength, wherein a half wavelength or an integer multiple thereof may be added to the product. Preferably, the connection, e.g. a connection between the end of an antenna element and the beginning of the following, preferably serially connected, antenna element, may provide a phase shift of an odd integer number of half the wavelength, in particular for achieving currents in these two, preferably next to each other arranged, antenna elements having the same phases. The beginning of an antenna element may be arranged closer to the input port than the end of the antenna element. This phase shift of an odd integer number of half the wavelength may be picked up in the connection, e.g. in at least one coaxial cable and/or at least one coaxial connection, which may be isolated and/or hidden from an environment. Preferably, this phase shift of an odd integer number of half the wavelength caused by the connector may not have any effect on the environment, preferably on the electromagnetic field in the inner area. The connection to the following antenna element, e.g. a reverse guiding of the coaxial connection, thus may provide refeeding and/or a phase delay of the refeeded wave of n1 x 180°, wherein n1 preferably may be 1, 3, 5, 7 or more. A phase shift of approximately (n1 x 180°) corresponds to a phase shift of (n1 x 180°) ± 5 % of 180°, (n1 x 180°) ± 10 % of 180°, (n1 x 180°) ± 15 % of 180°, or (n1 x 180°) ± 20 % of 180°. Therefore, the term approximately in this context includes a deviation of 5 %, 10 %, 15 % or 20 % at maximum of 180°, i.e. of a half wavelength. The at least one connection is in particular at least one serial connection.

The phase shift of (n1 x 180°) of the – at least one – connection is provided by its length. Alternatively, the phase shift and, therewith, the equivalent electrical length, is provided by discrete capacitors or coils connected to the connection, thereby forming a part of the connection. In particular, the phase shift is provided by the combination of a connection length of the connection and discrete capacitors or coils connected in series or in parallel. For n1 = 1, the connections can be provided with small dimensions.

The impedance of the at least one connection is preferably matched to an impedance at the input port and/or to the impedance at an output of a power splitter.

In a further embodiment of the inventive antenna assembly, at least two of the antenna elements are serially connected by the connections. Two antenna elements are connected by one of these connections, preferably in a direct way. Antenna elements are preferably directly connected in series by one of the connections. In particular, such antenna elements are successive antenna elements as regards their geometric arrangement along the circumference. Antenna elements, which are neighboring each other along the circumference, are successive antenna elements. Preferably, successive antenna elements are connected directly by a connection as given above.

Particularly, at least one of the antenna elements or preferably all antenna elements of the assembly provide a phase shift of an angle phi, wherein phi may be approximately n2 x 180°. In this regard, n2 may be an integer number ≥ 1. Thus, n2 may be 1, 2, 3, 4, 5 or more. Preferably, at least one of the antenna elements, or preferably all antenna elements of the assembly, may provide a phase shift of an angle phi being approximately 180°. Preferably, all antenna elements may be about half of the wavelength, e.g. lambda/2, long. E.g. each antenna element may generate a phase shift of 180°.

Preferably, each antenna element may have at most a phase shift of 180°, corresponding to a length of the antenna element of half the wavelength. An antenna assembly having longer antenna elements, e.g. antenna elements being longer than half the wavelength, may generate a RF electromagnetic field having at every point in the inner area and/or in the volume to be examined at a certain point in time positive field components, e.g. generated by a first half wave in the antenna element, as well as negative field components, e.g. generated by the excess length. The most inappropriate case may be an antenna element being exactly one wavelength long, e.g. as for the same point in time on a first freely radiating half of the antenna element a positive field may be generated and on a also freely radiating second half of the antenna element a negative field may be generated, or vice versa.

A antenna element having a length of about, preferably exactly, half a wavelength may generate at every point in space, preferably at every point in the inner area, a at most positive field, wherein an oppositely polarized half wave may be hidden in the coaxial connection and/or may be isolated from the environment inside the connection. In a later and/or former point in time, preferably a quarter of a period later, a positive quarter wave and a negative quarter wave, e.g. with a zero crossing in between, may be present on the freely radiating antenna element. Preferably, it should be like this, and later at a distant point in space the resulting field may vanish and a short time after that a at most negative field may be present, and so on. Preferably, this may happen simultaneously on at least two antenna elements, preferably on all antenna elements of the upper unit and/or simultaneously on all antenna elements of the lower unit, preferably with an opposite phase.

In the case one antenna element being smaller than half the wavelength, at least one point in space, e.g. at least one point in the inner area, preferably at least one point somewhere in the volume to be examined, may never show the maximally achievable field strength, e.g. because a part of the half wave always may be hidden inside the coaxial connector and/or may be isolated from the environment by the connection, and e.g. not may be used, e.g. for generating the RF electromagnetic field.

In a particular example further given below, n2 is equal to 1 for one of the antenna elements, for a subgroup of the antenna elements or for all antenna elements.

For n2 = 1, the antenna elements can be provided with small dimensions. Each antenna element may provide a phase shift of an angle phi, phi being approximately n2 x 180°, wherein n2 may be an integer number ≥ 1. The term approximately in this context includes a deviation of 5 %, 10 %, 15 % or 20 % at maximum of the given value, preferably of 180°. The equivalent electrical length of the antenna elements is approximately a half wavelength or an integer multiple thereof. Preferably, the maximal length of the antenna element may not significantly excess and/or deviate half of the wavelength. The term “not significantly” in this context may include a deviation and/or an excess of 5 %, 10 %, 15 % or 20 % of half the wavelength.

The phase shift of n2 x 180° of the antenna elements is provided by the respective geometrical length of the antenna elements. Alternatively, the phase shift and, therewith, the equivalent electrical length, is provided by discrete capacitors or coils connected to the antenna element, thereby forming a part of the antenna element. In particular, the phase shift is provided by the combination of an antenna length of the respective antenna element and discrete capacitors or coils connected in series or in parallel. The antenna elements are

preferably linear antennas. The antenna elements can be half-wave antennas, in particular half-wave dipoles, for example linear half-wave dipoles, wherein the antennas e.g. may be provided with the RF signal in the middle, e.g. in the middle of the half-wave dipole, preferably serially. Additionally or alternatively, other embodiments of the antenna elements are possible, such as arrangements allowing for an easier serial arrangement of the antenna elements. Thus, the antenna elements may be or may comprise generally arbitrary forms of waveguides and/or antennae, such as monopoles or multipoles.

According to an additional aspect of the invention, the impedance of the antenna elements, or of a subgroup thereof, strictly may increase with the angular distance from the input port. In this regard, the input port directly or indirectly may supply the antenna elements. Preferably, all antenna elements of the subgroup may be supplied directly or indirectly by the input port based on which the angular distance is counted. In an alternative, the impedance strictly may increase with the angular distance from the antenna element, which is closest to the input port. In this regard, the antenna element closest to the input port may be the antenna element with the least angular distance to input port and/or with fewest electrical components connected between input port and antenna element.

Alternatively, both outside lying antenna elements, preferably the antenna elements with the highest impedance, may be provided by the two outputs of the input port, e.g. a power splitter, e.g. directly, and at least one element with a lower impedance, e.g. with the lowest impedance, may act as outlet, e.g. as collective outlet. In general, at least one antenna element may be provided by at least one output of the input port, e.g. directly, and at least one antenna element may act and/or may lead to at least one outlet, e.g. to at least one collective outlet.

The impedances of the antenna elements, e.g. the characteristic impedances of at least two neighboring antenna elements, may be varied with regard to each other in a strictly decreasing or strictly increasing or monotonically decreasing or monotonically increasing order, e.g. for the whole antenna assembly and/or for the upper unit and/or for the lower unit. Preferably, an order of the characteristic impedances may deviate from a strictly decreasing or strictly increasing order. At least for one antenna element of the antenna assembly and/or of the upper unit and/or of the lower unit may deviate from a strictly decreasing or strictly increasing order, e.g. the antenna element before the power splitter and/or next to the input source, e.g. an antenna element, preferably directly, followed by at least two elements, e.g. at least two antenna elements, and/or an antenna element providing at least two antenna elements. As antenna elements after the splitter only may be supported with half of the power, e.g. half of the power of an RF signal, preferably for generating the RF electromagnetic field and/or a component for the RF electromagnetic field, an order of

the impedances of the antenna elements may not strictly decrease or strictly increase or monotonically decrease or monotonically increase. Further, an order and/or a dimensioning of the characteristic impedances of the antenna elements, e.g. all the antenna elements of the antenna assembly and/or of the upper unit and/or of the lower unit, may fulfill at least one further requirement, e.g. that the impedances may lead to a decreasing current, e.g. to a decreasing amplitude of the current, preferably to a at least partially decreasing amplitude of the current, preferably at least partially according to at least one trigonometric function, e.g. a cosine, preferably cos(alpha), as explained in detail below.

An antenna element at an angle alpha = 0 may be the first antenna element being provided with the RF signal, wherein the power of the RF signal may be split after this first antenna element, e.g. into two halves, which may causes in this case that the impedance preferably may not strictly increase with the angular distance from the antenna element, as the current in every antenna element may be only a, preferably well-defined, part of the current in the antenna element at alpha = 0. E.g., an antenna element positioned at an angle of 30° may preferably be provided by cos 30° = 0.8667 times the current of the antenna element at alpha = 0. The impedance of the first antenna element may be 75 Ohm and the impedance of the antenna element at the position alpha = 30° may be 50 Ohm, thus smaller than the impedance of the first antenna. The impedance preferably may increase with the angular distance to the antenna element at alpha = 0, wherein the increase may start preferably after an antenna element following a power splitter.

As used herein and as the skilled person immediately will recognize, the term angular distance refers to a specific polar angle in a polar coordinate system characterizing the geometric setup of the assembly. Thus, the antenna elements may be arranged in a plane, such as in a plane perpendicular to an axis of an inner area surrounded by the antenna elements. Thus, the inner area may have a cylindrical shape, having an arbitrary cross-section, such as a cylindrical, an oval or a polygonal cross-section, wherein the antenna elements may be arranged in a plane perpendicular to an axis of the cylindrical shape. The coordinate system may be chosen such that the center of the coordinate system is located in the plane and on the axis. Thus, each element of the antenna assembly may be defined by polar coordinates in the plane, i.e. by a specific polar angle and a distance from the center of the coordinate system. The angular distance of two elements, such as the angular distance of two antenna elements, may be defined by the difference of the polar coordinates of these elements.

According to a further aspect, the characteristic impedances of the antenna elements vary according to a predefined angular function depending on an angle alpha. Therein, the angle alpha preferably may be a polar angle of the antenna elements in an arbitrary polar

coordinate system, such as the polar coordinate system discussed above. This polar angle is also referred to as a geometrical angle. A virtual line connecting the antenna elements and delimiting the inner area fully or partially surrounded by the antenna elements may be referred to as a "circumference" of the antenna assembly. The inner area may be the geometric area delimited by the circumference.

The angular function is preferably a strictly increasing function, at least for angular sections spanning an angle interval of 90°. The angular function is preferably strictly increasing for an angle alpha from 0° to 90° and/or from 180° to 270°. Further, the angular function can be an angular function strictly decreasing for an angle alpha from 90° to 180° and/or from 270° to 360°. Angle alpha is the geometrical angle along the circumference. The origin of angle alpha (alpha = 0) is an orientation corresponding to the position of the input port or the position of an antenna element directly connected to the input port. According to this angular function, the magnetic field strength distribution within the inner area is provided. At least one of two antenna elements of the antenna assembly and/or of the upper unit and/or of the lower unit may be arranged symmetrically to alpha = 0, wherein at least one of these antenna elements and/or at least one of these symmetrical pairs of antenna elements, e.g. the antenna elements arranged at the third position counted from alpha = 0, may act and/or serve as an input port and/or the position of this antenna elements may directly be connected to the input port. An antenna element arranged at or next to alpha = 0, e.g. in the upper unit and/or in the lower unit, may act and/or serve as an output port, e.g. may be connected directly with a power combiner and/or with a termination.

By varying the characteristic impedances, the desired currents at the respective antenna elements varying according to the angular position of the antenna elements are provided. In particular, the antenna elements are fed with an electrical power (common to a plurality or to all antenna elements) such that the varying characteristic impedances directly define the currents at the respective antenna elements and the resulting (individual) field strength provided by the respective antenna elements.

In case that a first antenna element is connected to at least two subsequent antenna elements (ie. second antenna elements) via a power splitter, the characteristic impedance of the first antenna element on the basis of which the impedance of subsequent antenna elements is provided according to the function given herein is the factual characteristic impedance of the first antenna element, i.e. the characteristic input of an antenna element if taken alone multiplied by the number of subsequent second antenna elements. Since the first antenna element is connected to more than one subsequent antenna elements, the characteristic impedance of the first antenna element as seen from one of the second

antenna elements is the factual characteristic impedance of the first antenna divided by the number of second antenna elements connected to the first antenna element. In this regard, it should be considered that the power forwarded through the first antenna element is divided among the subsequent antenna elements or branches of serially connected antenna elements connected thereto. In other words, the power supplied to each of the subsequent second antenna elements is the power forwarded through the first antenna element divided by the number of second antenna element. Thus, the characteristic impedance of the first antenna element as seen from one of the second antenna elements differs from the factual characteristic impedance of the first antenna element according to the division provided by the partitioning of the RF power provided by the power splitter. The factual characteristic impedance is the characteristic impedance of the (first) antenna element if taken alone. The function, according to which the characteristic impedance is varied, refers to the characteristic impedance of an antenna element as seen from a subsequent antenna element.

In order to achieve a homogeneous distribution, the currents carried by each antenna element vary according to an angular function cos(alpha). Preferably, antenna elements at an angle of alpha = ± 90° (with regard to the position of the input port) are omitted. While the function can be a continuous function of angle alpha, the current and the characteristic impedances of the antennas are discrete values corresponding to the values of the continuous function for particular angles at which the particular antennas are positioned. Angle alpha is the angle between a position of an antenna, for which the current and the characteristic impedance is provided, and the position of the input port (or the first antenna element connected to the input port) along the circumference. The currents carried by each antenna element vary according to the angular function cos(alpha), which is the direct result of the inventive variation of the impedances of the antenna elements. Thus, the characteristic impedances of the antenna elements vary according to an angular function $1 / \cos(\text{alpha})^2$, wherein the angular function of the currents is given by these impedances and a given power provided to the antenna elements.

Further, the antenna elements are serially connected. Thus, opposite ends of antenna elements of the plurality of antenna elements are connected to distinct antenna elements, in particular to a previous and a subsequent antenna element. A previous – or first – antenna element is connected upstream, towards the input port, and a subsequent antenna element is connected downstream, away from the input port. Specifically, all antenna elements of the antenna assembly are connected in N branches, N being an integer number, preferably being 1, 2, 4 or more. Particularly, each branch has the same number of antenna elements. All antenna elements of each branch are connected in series. Two or more branches can be connected to a power splitter, wherein the each branch is connected to one of the output

ports of the power splitter. A phase difference can be provided by the outputs of the power splitter according to the geometrical angle between the antenna elements, which are most closely connected to the respective output, for example a phase difference of approximately 180°.

The antenna elements can be evenly distributed along the circumference. In particular, the antenna elements of each branch are evenly distributed along the circumference. Further, the circumference is preferably circular and planar, according to the circumference of a cross section of a cylinder. The circumference is a closed line. Preferably, the circumference comprises one, two or more symmetry axes. In case of two or more symmetry axes, at least two of them are mutually perpendicular.

According to the invention, the antenna elements are connected in series. At least a subgroup of the antenna elements of the antenna assembly or all antenna elements of the antenna assembly are connected in series. The antenna assembly preferably comprises a non-reflecting termination. The termination is connected to at least one of the antenna elements, which is not connected to a successive antenna element. Further, the termination is connected to the last antenna of the serial connection provided by the antenna elements. In addition, the termination is connected to the last antenna of a branch. Preferably, each last antenna of each branch of the antenna assembly is connected to the termination. The connection to the termination is a direct connection. The termination is provided by a load with matched impedance and is adapted to convert the received RF power into heat. In a particular embodiment, the two last antennas of two branches are connected to a termination via a power combiner.

Further, an antenna assembly according to the invention is provided, in which the antenna elements are connected in series. The input port is connected to an antenna element between the two outmost antenna elements of the serial connection provided by the antenna elements. The input port is connected to two branches of antenna elements, wherein the two branches are connected to each other at the antenna element, which is connected to the input port. Branches, which are connected with each other, e.g. by a common power splitter supplied by the input port, have the same number of antenna elements. This preferably also applies to branches, which are not connected or supplied by the same input port.

According to a further aspect of the invention, the antenna element connected to the input port is connected to a power splitter. The power splitter is connected downstream the antenna element connected to the input port. Two branches provided by the antenna elements are connected downstream the power splitter. These two branches are connected

to two output ports of the power splitter. Preferably, the output ports of a power splitter supplying two neighboring branches have the same phase. In other words, the power splitter connected between a first (or previous) antenna element and subsequent, second antenna elements does not provide a phase shift. The antenna element upstream the power splitter forwards the complete RF power provided by the input port supplying this antenna element. The power splitter downstream this antenna element can be adapted to split the RF power into two parts of the same amount of power. Preferably, any power splitter distributes the power delivered thereto into parts of the same amount of power, preferably into two parts. The power splitter is connected to the subsequent antenna elements such that both antenna elements are supplied with the same phase. Any potential phase shift of the power splitter is compensated by complementary phase shifts of connections between outputs of the power splitter and the subsequent antenna elements.

The antenna elements each comprises a linear conductor to which a current and a voltage according to the supplied RF power is applied. The characteristic impedance of the antenna elements depends on geometrical and material properties, in particular of the linear conductor and other conducting and/or isolating components of the antenna elements as given below.

The characteristic impedances of the antenna elements are varied along the circumference by providing antenna elements having distinct characteristic impedances with distinct geometrical and/or material properties. The geometrical properties comprise at least one of a conductor width, a conductor thickness, an insulator thickness, a distance between an irradiating conductor and a conductor shield. The material properties comprise at least one of a permittivity of an insulator and a specific conductivity of an insulator. All geometrical properties and material properties pertain to components of the antenna elements. The antenna elements of distinct characteristic impedance preferably have distinct distances between the conductor, which adapted to emit the irradiation, and a shield opposite to the inner area in view of the irradiating conductor. In addition or alternatively, the antenna elements of distinct characteristic impedance have preferably distinct conductor widths, i.e. have conductors adapted to emit the irradiation with distinct widths. In general, the antenna elements of distinct characteristic impedance can have conductors adapted to emit the irradiation having distinct cross sectional areas as regards shape and surface area. Further, in addition or alternatively to distinct geometrical and/or material properties, antenna elements of distinct characteristic impedance can comprise distinct additional discrete electrical components, i.e. coils or capacitors in order to provide distinct impedances.

In a particular embodiment, each of the antenna elements comprises a conductor shield and an irradiating conductor being directed towards the inner area. The irradiating conductor is

adapted to irradiate RF radiation. The conductor shield and the irradiating conductor are in an asymmetric configuration. Therefore, the magnetic (and electrostatic) field between the conducting shield and the irradiating conductor is not in a balanced configuration such that a propagating wave is emitted by the irradiating conductor is a direction opposite to the conductor shield. Preferably, the cross section of the irradiating conductor is smaller than the conductor shield in a direction along the circumference leading to a propagating wave. The conductor shield and the irradiating conductor are arranged perpendicular to the circumference and, preferably perpendicular to the cross sectional area encircled by the circumference.

At least one of the antenna elements is formed by a microstripline. The microstripline comprises an insulating substrate, preferably planar, on which the conductor shield, also preferably planar, is arranged. The irradiating conductor is provided as a linear conductor mechanically attached to the substrate and/or the conductor shield on the side of the substrate opposite to the conductor shield. The irradiating conductor can be in direct contact with the substrate. However, in order to provide distinct characteristic impedances, the irradiating conductor can be attached to the substrate at a certain distance to the substrate. Distinct characteristic impedances can be provided by distinct cross sections of the irradiating conductor, in particular distinct widths, by distinct distances between irradiating conductor and conductor shield or between irradiating conductor and insulating substrate, or by distinct widths of the substrate, or by any combination thereof. Further, distinct materials with distinct permittivity can be used for the isolating substrate. A holder attaching the irradiating conductor to the substrate or to the conductor shield can be provided. The holder is preferably electrically insulating. Further, the holder can comprise a mechanism adapted to vary the distance between the irradiating conductor and the substrate or the distance between the irradiating conductor and the conductor shield. The mechanism can comprise a thread or a spindle mechanism. As a particular aspect, conductive outer rims can be provided, which are in electrical (and physical) contact with the conductor shield and which are arranged at outer edges of the conductor shields. The outer rims extend in parallel to the irradiating conductor.

The antenna elements comprise nonsymmetrical striplines providing an irradiating conductor. The ground planes thereof provide the conductor shields and the conductive paths thereof provide the irradiating conductors. The substrate of the striplines forms the insulator or insulating substrate. The irradiating conductors are facing the inner area of the antenna assembly. The field generated by the irradiating conductors extends through the inner area. The field, in particular the magnetic field, provided by the irradiating conductors is arranged to excite the nuclear spins. The field generated by the irradiating conductors extends through an object within the inner area, e.g. a patient. The

characteristic impedance of the antenna elements is particularly defined by the geometric dimensions of the antenna elements like the width of the irradiating conductors, the distance between irradiating conductors and respective conductor shields and the kind, material and thickness of the dielectric medium (i.e. the insulator) between irradiating conductors and respective conductor shields. The irradiating conductors can be provided in the shape of a strip or a tube. The cross section of the irradiating conductors can be round, circular, elliptic, polygonal, etc. The irradiating conductors can be arranged as conductors floating with regard to the substrate or on the conductor shields or can be supported by the isolator or substrate.

The invention further relates to a radio transmitter comprising at least one of the inventive antenna assemblies. The radio transmitter further comprises at least one RF signal source connected to the at least one input port. In case of a plurality of input ports, at least one power splitter can be provided as a part of the radio transmitter, wherein the input ports are connected downstream the power splitter and the RF signal source is connected to an input of the at least one power splitter. The power splitter can provide a phase shift between its outputs to which the input ports are connected, wherein the phase shift corresponds to the geometrical angle between the input ports or the antenna elements directly connected to (or closest to) the input ports. The radio transmitter further comprises a frame structure, on which the antenna elements are mounted. The frame structure is preferably of electrically insulating material. Further, the antenna elements are connected only by the defined connections. In particular, the conductor shields of distinct antennas are not in direct electrical contact. This avoids eddy current losses. The frame structure arranges the antenna elements without direct electrical contact (except for the connections).

The radio transmitter is adapted to be introduced into a bore, i.e. into an inner volume, of a MRI apparatus, in particular of a coil of a MRI apparatus providing the static magnetic field. Preferably, the inner area spanned by the antenna assembly or assemblies has a diameter greater than 30 cm or 50 cm or 70 cm in order to allow a whole body scan. In case of more than one antenna assembly, the antenna assemblies are sequenced along the circumference such that each antenna assembly spans an individual angle interval. Preferably, two antenna assemblies are provided, each for an angle interval of 180°. Antenna elements of the two antenna assemblies for ± 90° are omitted. In other words, the antenna elements at the positions at which the angle intervals spanned by the antenna assemblies abut to each other, are omitted. The omitted antenna element can be regarded as virtual or imaginary antenna element when regarding the even circumferential distribution of the antenna elements. Even though the antenna elements are omitted, the pertaining antenna assembly spans the full angle of 180° since the omitted antenna elements do not contribute to the field distribution within the inner area. Each of the antenna assemblies

spanning 180° comprises two branches, each branch having the same number of antenna elements. The branches of each antenna assembly are preferably symmetrical to each other.

Further, the invention relates to an MRI coil comprising at least one inventive radio transmitter or at least one inventive antenna assembly. In addition, the invention relates to an MRI apparatus comprising an inventive MRI coil, at least one inventive radio transmitter or at least one inventive antenna assembly.

According to a further aspect of the invention, a method is given for providing an adapted intensity distribution of a RF radiation within an inner area enclosed by a plurality of antenna elements according to a desired intensity distribution. The antenna elements are provided with distinct characteristic impedances and the antenna elements are supplied with a RF signal. Distinct field strengths are generated by the antenna elements having distinct characteristic impedances. The distinct field strengths resulting from the distinct characteristic impedances adapt the intensity distribution generated by the antenna elements to the desired intensity distribution.

The method preferably uses the antenna assembly and/or the radio transmitter according to the present invention. However, other embodiments are possible. Thus, with regard to preferred embodiments of the method, reference may be made to the embodiments of the antenna assembly and/or the radio transmitter or vice versa.

As discussed above, the plurality of antenna elements preferably forms a transmission array and more preferably a transmission coil array. Preferably, the characteristic impedance of at least one of the antenna elements is varied with respect to the impedance of at least one other antenna element in order to achieve a desired spatial field strength distribution and/or field distribution.

Thus, instead of defining the field strength of the individual antenna elements by a resonant mode of a fixed connection as given by the rings and rods of a birdcage structure, the invention provides to adapt the characteristic impedances of the antenna elements in order to define the currents and, consequently, the individual magnetic field strengths of the antenna elements. This provides a substantial flexibility as regards the geometrical arrangement of the antenna elements, in particular in view of the size if the inner area spanned by the antenna elements.

According to the inventive method, supplying the antenna elements comprises forwarding a RF signal (radio frequency signal) from one of the antenna elements to another antenna element (of the antenna elements) having distinct characteristic impedances. The RF signal

is forwarded via a connection. Preferably, this connection adds a phase shift of approximately (n1 x 180°) to the forwarded RF signal. In this context, n1 is an integer number ≥ 1, preferably an odd integer number ≥ 1. Further, the RF signal is forwarded through one or more of the antenna elements. The plurality of or all of the antenna elements provide a phase shift of an angle phi, phi being approximately n2 x 180°, wherein n2 is an integer number ≥ 1, preferably n2 may be approximately 180°. E.g., this may relate to more than one connection and/or antenna element, preferably to all connections and/or all antenna elements. In particular, the phase shift or the phase shifts are provided by a length of the connection and/or by the geometrical length of the antenna element, e.g. the phase shift may only be provided by the geometrical length of the antenna element. Further, the phase shift, preferably of 180°, provided by forwarding the radio frequency signal, may be provided by a length of a pertaining connection only. By such a phase shift of n1 x phi, n1 being preferably an odd integer, reflections due to distinct characteristic impedances of interconnected antenna elements may be avoided. In the case n1 being even, reflections may vanish, but a phase difference between neighboring antenna elements may deviate from 0°. Preferably n1 and/or n2 may be chosen in such a way that reflections may vanish and/or the phase difference between neighboring antenna elements may be 0° or 360° or multiples thereof.

The RF signal is forwarded from one of the antenna elements to another antenna element. At least two of the antenna elements are connected in series and the RF signal is forwarded from one of these antenna elements to another. In addition, the RF signal is forwarded through at least one of the antenna elements.

According to a further aspect of the invention, the RF signal is forwarded from one of the antenna elements to a subsequent antenna element. The subsequent antenna element receives the RF signal directly from the one of the antenna elements via a connection as given above. Further, the RF signal is forwarded through at least one of the antenna elements between which the RF signal is forwarded. In particular, the RF signal is forwarded through the subsequent antenna element. At least one of the antenna elements or all antenna elements through which the radio frequency signal is forwarded adds a phase shift of an angle phi to radio frequency signal. Angle phi is approximately n2 x 180°, wherein n2 may be an integer number ≥ 1, preferably phi may be approximately 180°. At least one of the antenna elements or all antenna elements transform the impedance at one of their ends to the opposite end thereof without substantial changes to the impedance and does not provide a reflection for the RF signal delivered thereto.

The RF signal is forwarded successively through the antenna elements. At least two of the antenna elements are connected in series. The RF signal can be forwarded successively

through at least two groups of antenna elements in parallel. The at least two groups of antenna elements form at least two branches of antenna elements connected in series. The RF signal is split and is supplied to the two branches. The RF signal is split into two or more parts of the RF signal, the parts having the same power. Splitting the RF signal can comprise to add distinct phase shifts to the resulting split parts of the radio frequency signal, wherein the split parts can have a mutual phase shift of 180° (or a integer multiple thereof). Further, splitting the signal can be provided by dividing the RF signal into parts of the same amount of power without imposing a phase shift between the parts of the RF signal. The RF signal can be forwarded from one antenna element to at least two antenna elements by splitting the RF signal, wherein the step of splitting does not introduce a phase shift. In particular, splitting and forwarding the split RF signals does not introduce a phase shift. Further, the RF signal can be forwarded from an RF source to at least two antenna elements, wherein the step of splitting introduces a phase shift, the angle of which may correspond to a geometrical angle between the antenna elements. Preferably, a phase difference, e.g. of the current, preferably of the RF signal, between at least two of the antenna elements, most preferably between all of the antenna elements, e.g. of at least the upper unit and/or of the lower unit, e.g. of at least one half of the coils and/or of the antenna elements, may be 0°or 360° or multiples thereof. In particular, the RF signal can be split into two parts.

According to an embodiment of the inventive method, the radio frequency signal is forwarded to a termination absorbing the RF signal after being forwarded through at least one, two or more of the antenna elements. In particular, the radio frequency signal forwarded through all antenna elements of a serially connected group of antenna elements, i.e. of a branch, is absorbed by the termination preferably without reflection. Particularly, the radio frequency signal of two or more of branches of serially connected group of antenna elements can be combined and the combined signal is absorbed by the termination.

In an aspect of the invention, the radio frequency signal has a frequency of approximately 100 – 600 MHz, 200 – 450 MHz or 250 - 350 MHz, wherein a particular example provides a frequency of approx. 300 MHz. However, also lower or higher frequencies can be used within the invention. Preferably, if used for magnet resonance imaging with a static magnetic field B_{stat}, the radio frequency signal has a frequency of approximately $f = B_{stat}$ x 42 MHz / Tesla. The radio frequency signal is a sinus signal and comprises a dominating frequency component of the frequency mentioned above or substantially contains only this frequency component.

According to a further aspect of the invention, at least two of the inventive antenna assemblies are arranged successively. The inventive antenna assemblies are arranged along

the same longitudinal axis and are provided at distinct heights as regards the longitudinal axis. At least two of the inventive antenna assemblies, which are arranged successively, provide an inventive antenna system the length of which can be adapted by successively arranging at least two of the inventive antenna assemblies. This allows to span lengths greater than a length of a single inventive antenna assembly. Preferably, successively arranged antenna assemblies are supplied by the same RF signal source, in particular via a power splitter the outputs of which are individually connected to the respective antenna assemblies. The RF signals respectively supplied to successively arranged antenna assemblies may have a phase shift of 180° or an integer multiple thereof, preferably an odd integer multiple. This phase shift relates to the RF signals as supplied to the antenna assemblies. Further, this phase shift can be increased by the angular equivalent of a gap length between the successively arranged antenna assemblies. In total, the phase shift between multiple successively arranged antenna assemblies may be preferably approximately 0° or approximately 360° or multiples thereof, e.g. for constructively adding simultaneously generated magnetic fields, e.g. to generate the RF electromagnetic field at least partially by constructive interference.

Preferably, between the currents and/or the RF signals of different antenna elements, preferably of all antenna elements of the upper unit and/or the lower unit, e.g. of at least one half of the coils and/or of the antenna elements, no phase difference may be present, at least no phase difference besides about 0° or 360° or multiples thereof. E.g, the phase shifts provided between at least two antenna elements may be about 0° or 360° or multiples thereof, preferably the phase shift of the connection, preferably n1 x 180°, n1 being an odd integer number ≥ 1, and the phase shift of the respective antenna element, preferably 180°, and optionally additionally at least one phase shift provided by the splitter and/or by the power splitter and/or by at least one other element may result, e.g. by adding, in a phase shift and/or in a phase difference and/or in a total phase shift and/or in a total phase difference of about 0° or 360° or multiples thereof, preferably for generating a constructive interference of the RF electromagnetic fields generated by each of the antenna elements. The term "about" may include deviations of the mentioned phase shifts and/or phase differences and/or angles of less than 360°, e.g. of less than 90°, preferably of less than 10°, most preferably of less than 1°.

Summarizing the findings of the present invention, the following embodiments are specifically preferred:

Embodiment 1: Antenna assembly comprising at least one input port and a plurality of antenna elements, wherein the plurality of antenna elements is supplied by the at least one input port via a circuitry, wherein the antenna elements are arranged along a circumference

around an inner area of the antenna assembly, wherein at least two of the antenna elements have distinct characteristic impedances.

Embodiment 2: Antenna assembly according to the preceding embodiment, wherein a desired overall current distribution and a desired resulting spatial field strength distribution is definable by characteristic impedances of the antenna elements, wherein the antenna assembly is adapted to vary characteristic impedances of at least one of the antenna elements with regard to at least another antenna element in order to achieve the desired overall current distribution and the desired resulting spatial field strength distribution.

Embodiment 3: Antenna assembly according to one of the preceding embodiments, wherein the antenna assembly forms a transmission array, preferably a transmission coil array.

Embodiment 4: Antenna assembly according to one of the preceding embodiments, wherein the circuitry comprises connections, which serially connect at least two of the antenna elements, wherein the connections provide a phase shift of approximately (n1 x 180°), n1 being an integer number ≥ 0, wherein the phase shift preferably is defined as the difference of phases of the RF signal between the end of one antenna element and the beginning a following antenna element, preferably as the difference of phases between the two ends of the connections.

Embodiment 5: Antenna assembly according to one of the preceding embodiments, wherein at least two of the antenna elements are serially connected by at least one connection, and wherein each antenna element provides a phase shift of an angle phi, phi being approximately n2 x 180°, wherein n2 is an integer number ≥ 1, preferably phi being approximately 180°, wherein the phase shift preferably is defined as the difference of phases between the two ends of the antenna elements.

Embodiment 6: Antenna assembly according to one of the preceding embodiments, wherein the impedance of the antenna elements strictly increases, preferably starting with second antenna elements, with an angular distance from the input port or from the antenna element, which is closest to the input port at least for angular sections spanning an angle interval of 90°.

Embodiment 7: Antenna assembly according to one of the preceding embodiments, wherein the characteristic impedances of the antenna elements vary, preferably starting with second antenna elements (22 – 24'), according to a predefined angular function depending on an angle alpha, wherein alpha is the geometrical angle along the

circumference, and preferably according to the angular function 1 / cos(alpha)^2, and wherein antenna elements at an angle of alpha = ± 90° are omitted.

Embodiment 8: Antenna assembly according to one of the preceding embodiments, wherein the antenna elements are serially connected and evenly distributed along the circumference, wherein the circumference is circular and planar.

Embodiment 9: Antenna assembly according to one of the preceding embodiments, wherein the antenna elements are connected in series and wherein the antenna assembly comprises a non-reflecting termination connected to the last antenna of the serial connection provided by the antenna elements.

Embodiment 10: Antenna assembly according to one of the preceding embodiments, wherein the antenna elements are connected in series and wherein the input port is connected to an antenna element between the two outmost antenna elements of the serial connection provided by the antenna elements, and wherein the antenna element connected to the input port is connected to a power splitter downstream the antenna element connected to the input port, and wherein two branches provided by the antenna elements are connected downstream the power splitter.

Embodiment 11: Antenna assembly according to one of the preceding embodiments, wherein the characteristic impedances of the antenna elements are varied along the circumference by providing antenna elements having distinct characteristic impedances with distinct geometrical and/or material properties, wherein the geometrical properties comprise at least one of a conductor width, a conductor thickness, an insulator thickness, a distance between an irradiating conductor and a conductor shield, and wherein the material properties comprise at least one of a permittivity of an insulator and a specific conductivity of an insulator, all geometrical properties and material properties pertaining to components of the antenna elements.

Embodiment 12: Antenna assembly according to the preceding embodiment, wherein each of the antenna elements comprises a conductor shield and an irradiating conductor being directed towards the inner area and being smaller than the conductor shield in a direction along the circumference, wherein conductor shield and irradiating conductor are arranged perpendicular to the circumference, wherein at least one of the antenna elements is formed by a microstripline.

Embodiment 13: Radio transmitter comprising at least one antenna assembly according to one of the preceding embodiments, further comprising at least one radio frequency signal source connected to the at least one input port.

Embodiment 14: Radio transmitter according to the preceding embodiment, further comprising at least one frame structure, on which the antenna elements are mounted.

Embodiment 15: Radio transmitter according to one of the two preceding embodiments, wherein the radio transmitter further comprises at least one control unit.

Embodiment 16: Radio transmitter according to the preceding embodiment, wherein the frequency signal source is part of the control unit.

Embodiment 17: Method for providing an adapted intensity distribution of a radio frequency radiation within an inner area enclosed by a plurality of antenna elements according to a desired intensity distribution, the method preferably using an antenna assembly and/or a radio transmitter according to one of the preceding embodiments, the method comprising: providing the antenna elements with distinct characteristic impedances and supplying the antenna elements with a radio frequency signal, thereby generating distinct field strengths by the antenna elements having distinct characteristic impedances, wherein the distinct field strengths adapt the intensity distribution generated by the antenna elements to the desired intensity distribution.

Embodiment 18: Method according to the preceding embodiment, wherein supplying the antenna elements comprises: forwarding the radio frequency signal from one of the antenna elements to another antenna element having a distinct characteristic impedance, and wherein the radio frequency signal is forwarded via a connection, which adds a phase shift of approximately (n1 x 180°) to the forwarded radio frequency signal, n1 being an integer number ≥ 1, preferably an odd integer number ≥ 1.

Embodiment 19: Method according to one of the two preceding embodiments, wherein the radio frequency signal is forwarded from one of the antenna elements to a subsequent antenna element as well as through the subsequent antenna element itself, wherein at least one of the antenna elements between which the radio frequency signal is forwarded adds a phase shift of an angle phi to the radio frequency signal, phi being approximately n2 x 180°, wherein n2 is an integer number ≥ 1, preferably equal to 1.

Embodiment 20: Method according to one of the preceding embodiments referring to a method, wherein the radio frequency signal is forwarded to a termination absorbing the

radio frequency signal, after being forwarded through at least one, two or more of the antenna elements.

Potential embodiments of the invention are depicted in the Figures as described and represented in the following.

Brief Description of the Drawings

Figure 1 shows an antenna assembly according to a preferred embodiment of the invention in symbolic representation and

Figure 2a – 2c shows cross sections of antenna elements.

Detailed Description of the Drawings

In Figure 1, an inventive antenna assembly is shown. In this embodiment, the antenna assembly is denoted by reference number 1. The antenna assembly 1 may comprise one or more arrangements of antenna elements, which will be explained in more detail in the following and which are denoted by reference numbers 20 ,22, 22', 24, 24', … In the specific embodiment depicted in Figure 1, the antenna assembly 1 comprises two arrangements 2, 2', wherein only arrangement 2 is depicted in detail. However, other embodiments of the antenna assembly 1 are possible, such as embodiments comprising only one arrangement of antenna elements and/or embodiments comprising more than two arrangements of antenna elements. As an example, the antenna assembly 1 and/or the arrangement of antenna elements may form or may comprise at least one transmission array 3 comprising the plurality of antenna elements, preferably in a predetermined arrangement, wherein the antenna elements are adapted to generate a specific field distribution and/or a specific field strength distribution in a predetermined area, such as in an inner area or volume fully or partially surrounded by the antenna elements. In Figure 1, the inner area fully or partially surrounded by the antenna elements of the arrangements 2, 2' is denoted by reference number 90. Since, as outlined in detail elsewhere, antenna elements 20, 22, 22', 24, 24', … preferably are designed as coils, transmission array 3 preferably may be designed to form a transmission coil array denoted by reference number 4.

The antenna assembly 1 comprises an input port 10, which is connected via a line 12 to a first antenna element 20. Further, the antenna assembly comprises second antenna elements 22 and 22' as well as third antenna elements 24 and 24'. The first, second and third antenna elements 20 – 24' are depicted in a perspective view and enclose an inner

area 90. The first, second and third antenna elements 20 – 24' are arranged along a circular circumference delimiting the inner area 90. The inner area 90 has a cylindrical shape. The first, second and third antenna elements 20 – 24' partly encircle an upper half of the inner area 90 and provide the radio frequency magnetic field for the upper half of the inner area 90. Another arrangement 2 (which is represented schematically) is provided according an inventive antenna assembly is described below, wherein the arrangement 2 is dedicated to the lower half of the inner area 90.

The first antenna element is supplied via line 12 and receives a radio frequency signal applied to input port 10. Line 12 provides a certain phase shift, which in relation to the line leading to arrangement 2 provides a phase shift of q1 x 180°, q1 = 1, 3, 5... . This phase shift relates to RF signals as supplied to the antenna assemblies and is provided by the power splitter, the connections between power splitter and assemblies, or by a combination thereof. In a first alternative, splitter 11a provides two parts of the RF signal supplied by a RF source 11, which have the same phase (or have a phase shift, which is a multiple integer of 360°). In this alternative, the connection between the splitter 11a and the antenna element 20 has a length with regard the connection between the splitter 11a and arrangement 2, which introduces a phase shift of q1 x 180°, q1 being a positive, odd integer number. In a second alternative both connections have the same length or provide a phase shift of q2 x 180, q2 being a positive, even integer number. In the second alternative, the splitter 11a provides two parts of the RF signal supplied by the RF source 11 having a phase shift of q1 x 180°, q1 being a positive, odd integer number.

A line 12 forwards the radio frequency signal to a first end of the first antenna element 20. The first end is located at a rear side of the antenna assembly. The opposite end of the first antenna element 20 positioned at a front side of the antenna assembly is connected via line 14 to a power splitter 40. The power splitter 40 divides the radio frequency signal received from the first antenna element 20 in two signals of the same strength and of the same phase. The divided or split signals are forwarded via a connection 30 to one of the second antenna elements 22, 22', i.e. to second antenna element 22, and are forwarded via a connection 30' to the other of the second antenna elements 22, 22', i.e. to second antenna element 22'. Between the second antenna element 22, 22' and the first antenna element 20, a geometric angle of 30° is provided. The geometric angle is measured along the circumference with regard to the inner area 90.

Connections 30 and 30' each provide a phase shift of approx. n1 x 180°, n1 = 1, 3, 5... In particular, connections 30 and 30' have an electrical length of 180°, i.e. of a half wavelength of the RF signal provided by the RF source 11. The first antenna 20 has an electrical length of a half wavelength corresponding to a phase shift of approx. 180°. The

impedance of the first antenna is 75 Ohm. So, an RF power of 75 W delivered from the input port 10 to the input of the first element 20 generates a current of 1 A on this element.

The first antenna element 20 is connected to a power splitter 40, wherein the power splitter 40 is located downstream the first antenna element 20. In contrast thereto, the power splitter 11a as given above is located upstream the first antenna element 20. Power splitter 40, located downstream the first antenna element 20, provides parts of the RF signal supplied thereto, which are of the same amount and phase. The power splitter 40 does not introduce a phase shift. In particular, the combination of the power splitter and its direct outgoing or subsequent connections does not introduce a phase shift.

Preferably, a combination of the power splitter 40 and the respective connection 30, 30' may generate a phase shift of 180° or odd multiples thereof. Most preferably a phase shift may be provided in a way such that the currents of the first antenna element 20 and of the second antenna elements 22, 22' may be in phase.

The power splitter 40 is connected to antenna elements 22 and 22', which can be denoted as subsequent or second antenna elements. Antenna elements 22 and 22' are elements of two branches, which both are supplied by the first antenna element 20 via the splitter 40. Connections 30 and 30' have the same length. The power splitter 40 and the connections 30, 30'are adapted to provide the RF signal forwarded by the first antenna 20 to the second antenna elements 22, 22', with the same phase and amount. Thus, antenna elements 22 and 22' are supplied with the same phase and amount of power.

The antenna elements 20 – 24' extend from a front side to a rear side of the arrangement 90 and each have an end at both sides. At the ends located at the rear side, the antenna elements receive the RF signal. At the ends located at the rear side, the antenna elements are connected to a RF source or to an antenna element located upstream. This connection is a direct connection or involves a power splitter. At the ends located at the front side, the antenna elements deliver the RF signal. At the ends located at the front side, the antenna elements are connected to at least one subsequent antenna element or to a termination. This connection is a direct connection or involves a power splitter 40 (in case of antenna element 20) or a power combiner 50 (in case of antenna elements 24, 24').

Each of the second antenna elements 22, 22' has an equivalent electrical length of a half wavelength and, consequently, provides a phase shift of 180°. The line 14 connects the end of the first antenna 20, which is located at the front side, with the input of an equal amplitude equal phase power splitter 40. The connections 30, 30' connect the output of the

power splitter 40 with the respective receiving ends of the second antenna elements 22, 22' at the opposite side, i.e. at the rear side.

In an example, the power delivered to each input of the second elements 22, 22' is 75W/2 = 37.5 W which is only half the power delivered from first antenna element 20 to the power splitter 40. In order to generate currents on the antenna elements 22, 22' located at 30° with the size of I = cos(alpha) = 0.8667A, the characteristic impedance of the second elements 22, 22' (for each of the second antenna elements) must be $37.5W/(\cos(30°))^2$ = 50 Ohms. Alpha is the geometrical angle between the first antenna element 20 and the subsequent antenna elements 22, 22', i.e. 30°.

In general, the characteristic impedance of the antenna elements 22, 22' subsequent to a preceding antenna element 20 supplying more than one subsequent antenna element 22, 22', is (Z/m) / $\cos(alpha)^2$, with Z being the characteristic impedance of the preceding antenna element 20 if taken alone, ie. the factual characteristic impedance of the preceding antenna element 20, m being the number of subsequent antenna elements 22, 22' supplied by the preceding antenna element 20 via the power splitter 40, and alpha being the geometrical angle between preceding antenna element 20 and subsequent antenna elements 22, 22'. Further, m is the number of outputs of the power splitter 40. The subsequent antenna elements 22, 22' are referred to as second antenna elements and the preceding antenna element 20 is referred to as first antenna element.

Each of the second antenna elements 22, 22' is connected to one of the third antenna elements 24, 24'. In particular, the front ends of the second antenna elements (which are the ends opposite to the ends connected with the upstream antenna element 20, i.e. the first antenna element), are connected to the rear ends of the third antenna elements 24, 24'. The connections between the second antenna elements 22, 22' and the third antenna elements 24, 24' are connections 32 providing a phase shift of n1 x 180°, n1 = 1, 2, 3,..., preferably n1 = 1, 3, 5,.... Preferably, the third antenna elements provide a phase shift of 180° corresponding to an electrical length of a half wave length of the RF signal. The phase shifts provided by the second and third antenna elements are, as with the first antenna element, 180° or integer multiples thereof, preferably odd integer multiples thereof, most preferably 180°.

In order to generate currents on elements 24, 24' the size of I = cos(alpha) = 0.5A wherein alpha is the geometrical angle between the first antenna element 20 and the third antenna elements 24, 24', i.e. 60°, the characteristic impedance of the third elements 24, 24' (for each of the third antenna elements) is $37.5W/(\cos(60°))^2$ = 150 Ohms. The currents referred to in this Figure description follow the function of cos(alpha).

Thus, the first, second and third antenna elements may have a characteristic impedance following a $1/\cos(\text{alpha})^2$ – function of the angle (alpha) at which they are located. Most preferably, the second and third antenna elements may have a characteristic impedance following a $1/\cos(\text{alpha})^2$ – function of the angle (alpha) at which they are located. The impedance of the first antenna element 20 may deviate from the mentioned rule, preferably from the mentioned $1/\cos(\text{alpha})^2$ – function.

The front ends of the third antenna elements 24, 24', i.e. the ends of the antenna elements located most remotely to the input port (in electrical view), which are opposite to the ends at which these antenna elements receive the radio frequency signal, are connected to a power combiner 50. The third antenna elements 24, 24' are connected to the power combiner via lines 16, 16', which may not have a particular phase shift, but may be of equal electrical length. The power combiner 50 combines the radio frequency signal received by the third antenna elements 24, 24'. The power combiner 50 provides the combined signal to a non-reflecting termination 70 via line 60 connecting the output of the power combiner 50 and the termination 70.

The impedances of the lines 12, 14, 16 and 60 as well as the connections 30, 30', 32 and 32' have a wave impedance matched to the components directly connected upstream or downstream the pertaining line or connection. Connections 30, 30', 32, 32' form part of a circuitry 7 via which antenna elements 20, 22, 22', 24, 24', ... may be supplied with appropriate rapid-frequency or high-frequency signals by the input port 10. Further, optionally, one or more of lines 12, 14 and 16 may form part of the circuitry 7.

Imaginary forth antenna elements subsequent to the third antenna elements 24, 24' would be arranged at a geometrical angle alpha of 90° with regard to the first antenna element. The respective impedance would be $Z \times 1/\cos(90°)^2$, wherein Z is the impedance of the first antenna element. This would result in infinitive impedance, corresponding to a current of zero, equivalent to a magnetic field strength provided by these forth antenna elements of zero. Therefore, the forth antenna elements at 90° are omitted. Nevertheless the first, second and third antenna elements 20 – 24' support an angle interval of -90° to 90° with respective magnetic field strengths and radio frequency irradiation, even though the forth antenna elements are omitted. The magnetic field strengths provided by the first, second and third antenna elements 20 – 24' and the current through these antenna elements follows the function cos(alpha), alpha being the geometrical angle with regard to the first antenna element 20. Such a magnetic field distribution inherently leads to a homogenous radio frequency magnetic field distribution within the inner area 90.

In order to complete the circumference, an additional antenna assembly 2 symmetrical to the antenna assembly described above can be provided, wherein both antenna assemblies are sequenced along the circumference in order to cover an angle of 360°.

A unit or entity comprising at least one antenna assembly 1, each antenna assembly 1 comprising one, two or more arrangements 2, 2' of antenna elements 20, 22, 22', 24, 24' and/or comprising one, two or more transmission arrays 3 and/or one, two or more transmission coil arrays 4, may form a radio transmitter 5 or part of a radio transmitter 5, as depicted in Figure 1. Further, the radio transmitter 5 may comprise one or more other elements, such as one or more control units 6. The at least one control unit 6 may be adapted to control the at least one radio transmitter 5 in such a way that a specific field distribution and/or a specific field strength distribution in a specific volume, preferably in the inner area 90 fully or partially surrounded by the antenna elements 20, 22, 22', 24, 24', ... is generated, such as by providing appropriate RF signals. Thus, preferably, the radio frequency source 11 may be part of the control unit 6 and/or may form the control unit 6. Further, optionally, the control unit 6 may comprise one or more additional elements, such as the at least one splitter 11a. Additionally and optionally, other elements may be comprised, such as one or more data processing units, such as one or more processors.

In Figure 1, without restricting other potential embodiments, the radio transmitter 5 comprises an antenna assembly 1 having two arrangements 2, 2', and, further, the radio frequency source 11. The radio transmitter 5 further comprises at least one mechanical frame structure 80 (for illustrative purposes depicted for arrangement 2 only). A mechanical frame structure 80 may be provided for each arrangement 2, 2'. The mechanical frame structure 80 may be adapted to hold the antenna elements 20, 22, 22', 24, 24', ... of each arrangement 2, 2' in a predetermined position and/or orientation. The radio transmitter 5 further may include power splitter 11a, which divides the radio frequency signal supplied by the radio frequency source 11 into two signal components with a mutual phase difference of 180°. This phase difference can be given by the power splitter, by the connection connecting the power splitter and the respective antenna assembly, or by a combination thereof. Thus, the lower antenna assembly 2 is provided with a radio frequency signal, which a phase difference of 180° with regard to the radio frequency signal provided to the upper antenna assembly. The power splitter 11a comprises an input connected to the output of the radio frequency source 11 and further comprises two outputs with a phase difference of 180° (at the input ports of the antenna assembly), which are connected to two antenna assemblies, in particular to two input ports thereof.

For the sake of clarity, only one antenna assembly is depicted in detail in Figure 1, while the additional (lower) antenna assembly 2 is given symbolically only. In the same way, the frame structure 80 is shown for the upper antenna assembly only. When realizing the invention, the frame structure 80 encompasses a complete circumference of 360°. Further, the antenna elements of all antenna assemblies are attached to this frame structure 80.

Since the frame structure 80 may be regarded as an optional feature of an inventive antenna assembly (since it typically does not have a substantial influence on the field distribution), it is drawn in dashed lines. Further, the lower antenna assembly 2 as well as the power splitter 11a and the radio frequency signal source 11 are drawn for the sake of completeness and for explaining the inventive radio transmitter and are considered as optional features with regard to the explanation of the (upper) antenna assembly drawn in detail. Thus, these components are given in dotted and dashed lines.

In Figure 1, the physical representation of antenna elements 20 – 24' and of the frame structure 80 is given in a symbolic, perspective view drawn in thick lines. The electrical connections provided by the lines and the connections as well as power splitter 11a, 40, power combiner 50 and termination 70 of the embodiment shown in Figure 1 are represented schematically in the sense of a circuit diagram. Thus, these electrical components are given in thin lines and are not drawn perspectively.

Embodiments of the antenna elements 20 – 24' are given in further detail in Figures 2a-c as cross sections.

An embodiment alternative to the embodiment shown in Figure 1 comprises antenna elements 20 – 24' and connections 30 – 32' as given above. However, in place of a termination 70, a RF signal source like source 11 as given above is provided, which is connected to a power splitter via a line like line 60 as given above. Such a power splitter may split the RF signal provided by the signal source into two parts having the same amount of power and a mutual phase shift of 180° or 0°, preferably 0°. These parts are supplied to the antenna elements 24, 24' via lines like lines 16, 16' as given above. The RF signal parts are forwarded through the antenna elements 20 – 24' and the connections 30 – 32. In place of power splitter 40, a power combiner is provided, which is connected to receive the RF signal parts from the lines 30, 30' and is connected to output the combined RF signal to line 14. Instead of an input port 10, a termination like termination 70 as given above is connected via a connection similar to connection 12 as given above. The impedance of the termination is matched to the impedance of the signal source (which is also the case for other embodiments of the invention). In general, any phase shift, phase difference or identity of phases is provided by a power splitter, by connections attached to

the power splitter, or a combination thereof. The lower antenna assembly may be driven likewise, but with a relative phase of 180° referred to the upper antenna assembly 1.

The antenna element shown in Figure 2a comprises an irradiating conductor 100 and a conductor shield 104 as well as an insulator 102 provided as a substrate. These components form a microstripline. The irradiating conductor 100 and the conductor shield 104 are provided as a conductive layer, preferably of copper, silver, an alloy or a structural, preferably layered combination thereof. The insulator is provided as epoxy material or another isolating material. In an alternative, the insulator comprises fiber fabric, in particular of glass. The antenna element shown in Figure 2a can be provided by a structures circuit board, preferably of material FR4 or FR5. The irradiating conductor 100 can be provided as strip line of a circuit board.

The impedance of the antenna element shown in Figure 2a significantly depends on the distance between irradiating conductor 100 and conductor shield 104, the width of the conductor 100 (and the conductor shield 104), and the relative electrical permittivity of the insulator, i.e. the substrate. The antenna element shown in Figure 2a can be provided by opposite conductive layers of a circuit board providing the irradiating conductor 100 and the conductor shield 104, wherein the insulating material of the circuit board provides the insulator 102.

Irradiating conductor 100, conductor shield 104 as well as the insulator 102 are plane and extend in mutually parallel planes. However, the conductor shield can also be provided by a curved conducting surface, partially encircling the irradiating conductor.

The antenna element shown in Figure 2b also comprises an irradiating conductor 110 and a conductor shield 114 as well as an insulator 112 provided as an insulating substrate. The insulator supports the conductor shield 114. The irradiating conductor 110 is attached to the conductor shield 114 and/or to the insulator 112 with a fixed distance. The distance between irradiating conductor 110 and conductor shield 114 of the antenna element of Figure 2b is smaller than the distance between the conductor shield 104 and the irradiating conductor 100 of Figure 2a (defined by the thickness of the insulator 102). Thus, the characteristic impedance of the antenna element of Figure 2b is distinct to the characteristic impedance of the antenna element of Figure 2a.

Figures 2a-2c are not drawn to scale. In common realizations, the distance between irradiating conductor and conductor shield provided by a circuit board is usually smaller than the distance between these components in case of an embodiment as depicted in Figure 2b.

Between irradiating conductor 110 and conductor shield 114, no insulator is given in the embodiment of Figure 2b, while the insulator 102 of the embodiment of Figure 2a is located between irradiating conductor 100 and conductor shield 104. In this way, the characteristic impedances of the embodiments of Figures 2a and 2b are distinct by this difference, i.e. by the presence of an insulator between irradiating conductor and conductor shield.

Optionally, the embodiment of Figure 2b further comprises support elements connected to the insulator 112 and/or the conductor shield 114. Such support elements physically connect the antenna element and a frame structure, e.g. the frame structure 80 shown in Figure 1.

In Figure 2c, an embodiment of an antenna element is depicted comprising an irradiating conductor 120 and a conductor shield 124. An optional insulator can be provided, which supports the conductor shield. In this case, the conductor shield and the insulator can be provided by a circuit board, the insulating substrate of which provides the insulator and the conductive surface layer of which provides the conductor shield.

The embodiment shown in Figure 2c further comprises outer rims 116, 116' directly abutting to the edges of the conductor shield 124. The outer rims are conductive and are electrically connected to the conductor shield 124. Further, the embodiment shown therein comprises an optional holder 118, which is an electrical insulator. The structure and/or the material of the optional holder 118 provide that the holder does not electrically connect the conductor shield 124 and the irradiating conductor 120. The holder can comprise a thread mechanism, which is adapted to vary the distance between the conductor shield 124 and the irradiating conductor 120. The irradiating conductor 120 can be provided by a rod, preferably extending in parallel to the irradiating conductor 120 and to the outer rims 116, 116'. The irradiating conductor 120 can have a hollow cross section or can have completely filled cross section. The irradiating conductor 120 is of a conductive material, preferably of copper, silver, an alloy thereof or a structure comprising copper and silver, preferably a layered structure having an outer layer of silver.

Preferably, the conductor shield is supported by an optional insulating substrate. The optional holder 118 can be attached to the insulating substrate. Preferably, at each end of the antenna element (rear side and front side), a holder is provided.

Antenna elements at distinct angle orientations with regard to the input port have distinct impedances. The impedances are distinguished by distinct dimensions or other geometrical

features of the antenna elements, in particular of the irradiating conductor and the conductor shield. Further, the impedances are distinguished by distinct substrates, wherein the substrates are of distinct thickness as regards the insulator. In particular, the antenna impedances are distinguished by the distance between irradiating conductor and conductor shield and/or are distinguished by the width and/or the cross section of the irradiating conductor. The width of the irradiating conductor is measured along the circumference of the antenna assembly.

The antenna elements are layered structures with a constant cross sectional structure along a transverse axis of the antenna assembly. The transverse axis of the antenna assembly extends perpendicular to the plane in which the circumference extends. The antenna elements extend parallel to the transverse axis or are slightly inclined to the transverse axis towards the circumferential direction of the antenna assembly.

List of reference numbers

1	Antenna assembly
2, 2'	Arrangement
3	Transmission array
4	Transmission coil array
5	Radio transmitter
6	Control unit
7	Circuitry
10	Input port
11	RF source
11a	Splitter
12	Line
14	Line
16, 16'	Line
20	First antenna element
22, 22'	Second antenna elements
24, 24'	Third antenna elements
30, 30'	Connection
32, 32'	Connection
40	Power splitter
50	Power combiner
60	Line
70	Termination
80	Mechanical frame structure
90	Inner area
100, 110, 120	Irradiating conductor
102, 112,	Insulator
104, 114, 124	Conductor shield
116, 116'	Outer rim
118	Holder

Claims

1. Antenna assembly (1) comprising at least one input port (10) and a plurality of antenna elements (20 – 24'), wherein the plurality of antenna elements (20 – 24') is supplied by the at least one input port (10) via a circuitry (7), wherein the antenna elements (20 – 24') are arranged along a circumference around an inner area (90) of the antenna assembly (1), wherein at least two of the antenna elements (20, 22, 24) have distinct characteristic impedances.

2. Antenna assembly (1) according to claim 1, wherein the circuitry (7) comprises connections (30 – 32'), which serially connect at least two of the antenna elements (20 – 24'), wherein the connections (30 – 32') provide a phase shift of approximately (n1 x 180°), n1 being an integer number ≥ 0.

3. Antenna assembly (1) according to claim 1 or 2, wherein at least two of the antenna elements (20 – 24') are serially connected by at least one connection (30, 32), and wherein each antenna element (20 – 24') provides a phase shift of an angle phi, phi being approximately n2 x 180°, wherein n2 is an integer number ≥ 1, preferably phi being approximately 180°.

4. Antenna assembly (1) according to one of the preceding claims, wherein the impedance of the antenna elements (20 – 24') strictly increases, preferably starting with second antenna elements (22 – 24'), with an angular distance from the input port (10) or from the antenna element (20), which is closest to the input port (10) at least for angular sections spanning an angle interval of 90°.

5. Antenna assembly (1) according to one of the preceding claims, wherein the characteristic impedances of the antenna elements (20 – 24') vary, preferably starting with second antenna elements (22 – 24'), according to a predefined angular function depending on an angle alpha, wherein alpha is the geometrical angle along the circumference, and preferably according to the angular function $1 / \cos(\text{alpha})^2$, and wherein antenna elements at an angle of alpha = ± 90° are omitted.

6. Antenna assembly (1) according to one of the preceding claims, wherein the antenna elements (20 – 24) are serially connected and evenly distributed along the circumference, wherein the circumference is circular and planar.

7. Antenna assembly (1) according to one of the preceding claims, wherein the antenna elements (20 – 24') are connected in series and wherein the antenna assembly (1) comprises a non-reflecting termination (70) connected to the last antenna (24, 24') of the serial connection (20 – 24; 20 – 24') provided by the antenna elements (20 – 24').

8. Antenna assembly (1) according to one of the preceding claims, wherein the antenna elements (20 – 24') are connected in series and wherein the input port (10) is connected to an antenna element (20) between the two outmost antenna elements (24, 24') of the serial connection provided by the antenna elements, and wherein the antenna element (20) connected to the input port (10) is connected to a power splitter (40) downstream the antenna element (20) connected to the input port (10), and wherein two branches (22, 24; 22', 24') provided by the antenna elements (20 – 24') are connected downstream the power splitter (40).

9. Antenna assembly (1) according to one of the preceding claims, wherein the characteristic impedances of the antenna elements (20 – 24') are varied along the circumference by providing antenna elements (20 – 24') having distinct characteristic impedances with distinct geometrical and/or material properties, wherein the geometrical properties comprise at least one of a conductor width, a conductor thickness, an insulator thickness, a distance between an irradiating conductor and a conductor shield, and wherein the material properties comprise at least one of a permittivity of an insulator and a specific conductivity of an insulator, all geometrical properties and material properties pertaining to components of the antenna elements (20 – 24').

10. Antenna assembly (1) according to claim 9, wherein each of the antenna elements (20 – 24') comprises a conductor shield (104) and an irradiating conductor (100) being directed towards the inner area and being smaller than the conductor shield (104) in a direction along the circumference, wherein conductor shield (104) and irradiating conductor (100) are arranged perpendicular to the circumference, wherein at least one of the antenna elements (20 – 24') is formed by a microstripline.

11. Radio transmitter (5) comprising at least one antenna assembly (1) according to one of the preceding claims, further comprising at least one radio frequency signal source (11) connected to the at least one input port (10).

12. Radio transmitter (5) according to the preceding claim, further comprising at least one frame structure (80), on which the antenna elements (20 – 24') are mounted.

13. Method for providing an adapted intensity distribution of a radio frequency radiation within an inner area (90) enclosed by a plurality of antenna elements (20 – 24') according to a desired intensity distribution, comprising: providing the antenna elements (20 – 24') with distinct characteristic impedances and supplying the antenna elements (20 – 24') with a radio frequency signal, thereby generating distinct field strengths by the antenna elements (20 – 24') having distinct characteristic impedances, wherein the distinct field strengths adapt the intensity distribution generated by the antenna elements (20 – 24') to the desired intensity distribution.

14. Method according to claim 13, wherein supplying the antenna elements (20 – 24') comprises: forwarding the radio frequency signal from one of the antenna elements (20 – 22) to another antenna element (22 – 24) having a distinct characteristic impedance, and wherein the radio frequency signal is forwarded via a connection (30 – 34), which adds a phase shift of approximately (n1 x 180°) to the forwarded radio frequency signal, n1 being an integer number ≥ 1, preferably an odd integer number ≥ 1.

15. Method according to claim 13 or 14, wherein the radio frequency signal is forwarded from one of the antenna elements (20) to a subsequent antenna (22) element as well as through the subsequent antenna (22) element itself, wherein at least one of the antenna elements between which the radio frequency signal is forwarded adds a phase shift of an angle phi to the radio frequency signal, phi being approximately n2 x 180°, wherein n2 is an integer number ≥ 1, preferably equal to 1.

16. Method according to one of claims 13 - 15, wherein the radio frequency signal is forwarded to a termination (70) absorbing the radio frequency signal, after being forwarded through at least one, two or more of the antenna elements (20 – 24').

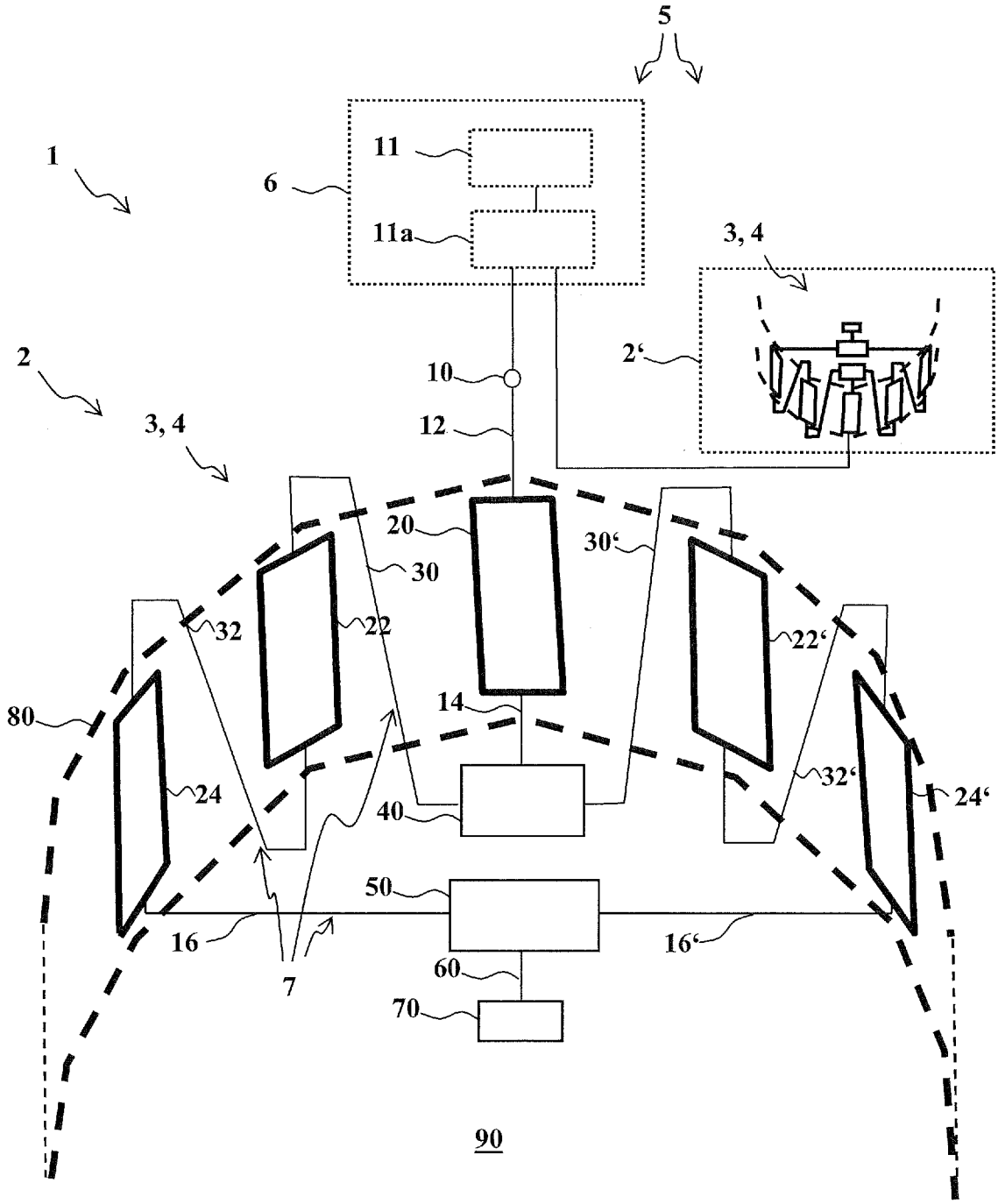
5
1
6
11
11a
3, 4
2
2'
10
12
3, 4
20
30'
30
32
22
22'
80
14
24
32'
24'
40
50
16
16'
60
7
70
90

Fig. 1

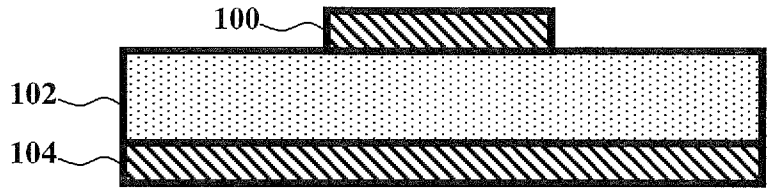

Fig. 2a

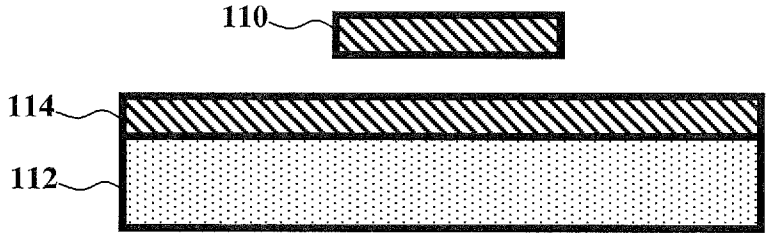

Fig. 2b

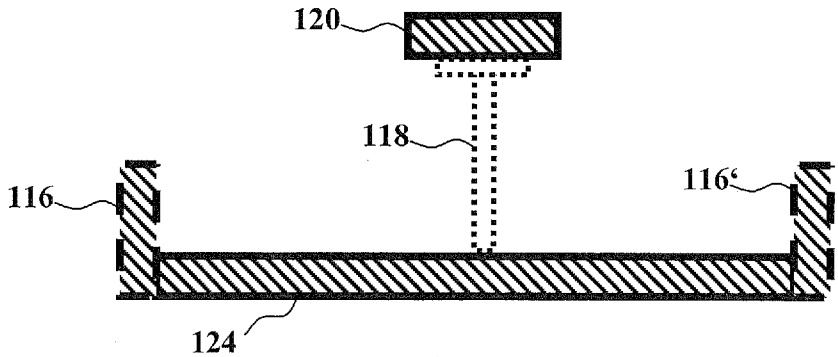

Fig. 2c

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/057990

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/3415 G01R33/561
ADD.

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)
G01R

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, BIOSIS, COMPENDEX, EMBASE, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/192382 A1 (NISTLER JUERGEN [DE] ET AL) 30 July 2009 (2009-07-30) paragraph [0011] - paragraph [0056] figures 3,4,6	1,4,5, 9-13
X	EP 0 325 351 A2 (UNIV CALIFORNIA [US]) 26 July 1989 (1989-07-26) figure 2a	1,11-13
X	US 2008/129298 A1 (VAUGHAN J T [US] ET AL VAUGHAN J THOMAS [US] ET AL) 5 June 2008 (2008-06-05) paragraphs [0264], [0314]	1,11-13

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2012	30/07/2012

Name and mailing address of the ISA/	Authorized officer
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