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FREQUENCY INDEPENDENT (LOG PERIODIC) MONOPOLE AND DIPOLE ANTENNAS

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FIG. 2

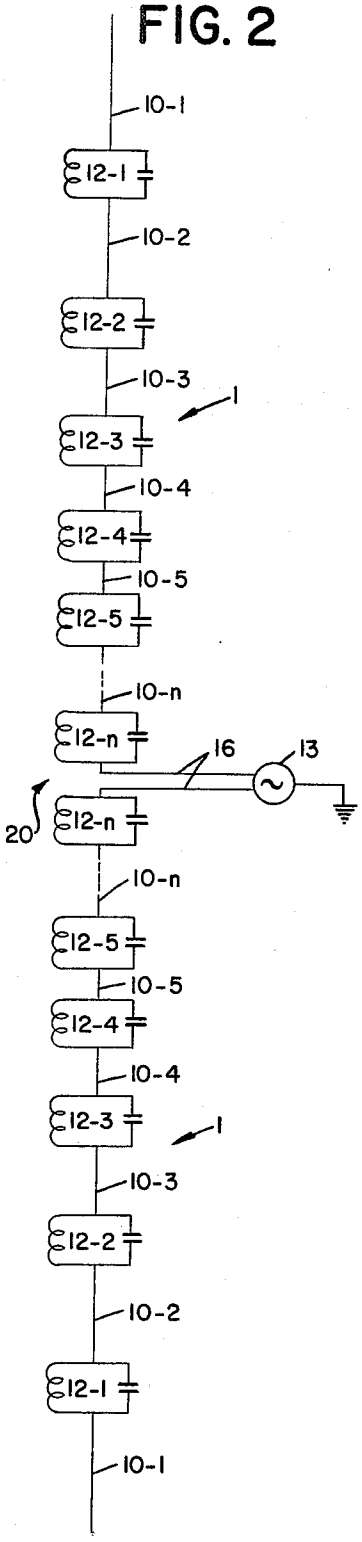


FIG. 1

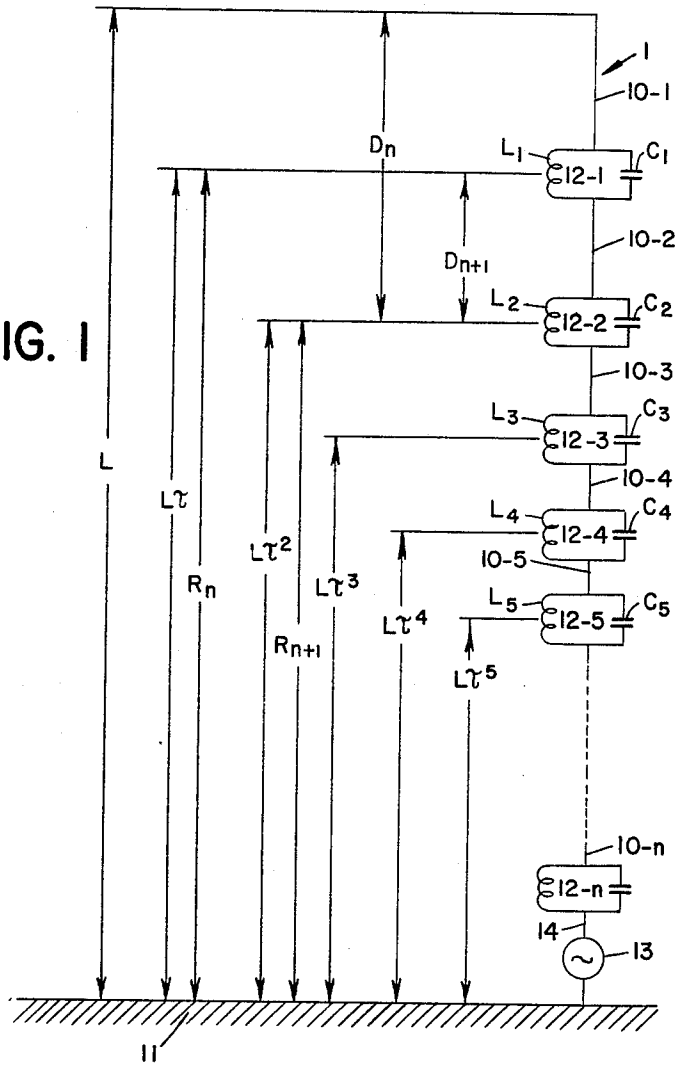
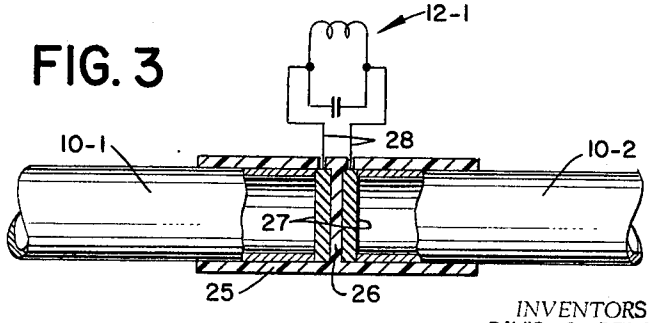


FIG. 3



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FREQUENCY INDEPENDENT (LOG PERIODIC) MONOPOLE AND DIPOLE ANTENNAS

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This invention relates to antennas and more particularly to frequency independent (log periodic) antennas of the monopole and dipole types, having extended ranges of frequencies of operation.

It is well known that dipole and monopole antennas have limited bandwidths of operation, i.e. the range between a minimum and maximum operating frequency in which they will effectively radiate radio frequency energy. This bandwidth is limited principally by the finite physical length of the antenna. Since the physical dimensions of a monopole or dipole antenna, measured in wavelengths of the operating frequency, change with the operating frequency the impedance and the radiation patterns of the antenna also change. This variation of impedance and radiation patterns limits the useful range of frequency of operation of any antenna by a factor which is primarily determined by the antenna's physical length.

The variation of impedance exhibited by conventional monopole and dipole antennas has been overcome to a certain extent by the use of biconical and discone antennas. While these types of antennas have an increased operating bandwidth they still exhibit wide variations in the radiation patterns when used in applications where the operating bandwith exceeds the design frequency by a ratio of greater than 2:1. When this bandwidth is exceeded, the vertical radiation pattern of biconical and discone antennas break up into a number of lobes. The maximum lobe is directed closer and closer to the direction of the cone element as the operating frequency is increased. Therefore, even though these biconical and discone antennas present a substantial improvement over conventional monopole and dipole antennas, they are still not completely effective in many applications. This is particularly true in high frequency radio communications applications where best communications are obtained when the maximum lobe of the radiation pattern lies in a plane parallel to the horizon.

A type of antenna which has made its appearance in recent years is the so-called frequency independent or log periodic antenna. This type of antenna utilizes a number of radiating elements whose spacing and physical lengths are determined in accordance with a logarithmic type design formula. It has been found that these log periodic antennas have considerable advantages in providing radiation patterns of constant beamwidth and nearly constant antenna impedance over an extremely wide operating bandwidth. These broadband properties are extremely desirable in many applications.

The present invention relates to monopole and dipole antennas which are designed, in accordance with the log periodic antenna design technique, in a manner to achieve increased operating bandwidths. In accordance with the present invention a monopole or dipole antenna is broken up into a number of radiator elements whose respective lengths are determined by log periodic design formulae. Adjacent elements of the antenna are then connected together by a loading circuit, which is preferably a parallel resonant circuit, whose parameters are also selected as a function of the log periodic design formulae. These circuits serve to change the electrical length of the antenna in accordance with the applied operating frequency.

The log periodic monopole and dipole antennas made in accordance with the present invention have substantially the same radiation pattern over a wide bandwidth at any frequency above a given design frequency determined by the antenna's maximum physical length. The antennas of the present invention also exhibit a relatively constant impedance over a wide bandwidth of operating frequencies. Thus, monopole and dipole antennas are provided which have improved operating characteristics over conventional monopole and dipole antennas of substantially equivalent physical dimensions. These log periodic antennas are relatively simple in form and relatively simple in form and relatively easy to construct.

It is therefore an object of this invention to provide log periodic monopole and dipole antennas.

Another object of the invention is to provide log periodic monopole and dipole antennas having increased bandwidths of operation.

A further object of the invention is to provide log periodic monopole and dipole antennas formed by a number of radiator elements connected together by parallel resonant circuits, the lengths of the respective radiator elements and the parameters of the parallel resonant circuits being selected in accordance with certain criteria of log periodic antenna design formulae.

Yet a further object of the invention is to provide log periodic monopole and dipole antennas which are loaded by parallel resonant circuits to have substantially constant impedance characteristics and radiation patterns over a wide bandwidth of frequencies of operation.

Other objects and advantages of the present invention will become more apparent upon reference to the following specification and annexed drawings in which:

FIGURE 1 is a diagram of a log periodic monopole antenna made in accordance with the present invention;

FIGURE 2 is a diagram of a log periodic dipole antenna made in accordance with the principles of the present invention; and

FIGURE 3 shows a plan view taken partially in section of one arrangement for joining adjacent radiator elements of the antenna.

FIGURE 1 shows a conventional mnopole antenna **1** mounted above a ground plane **11**. The overall length L of the antenna is designed to be a quarter wavelength long at the lowest operating frequency, as is conventional with this type of antenna. The antenna **1** is formed by a number of separate radiator elements **10**–2, **10**–2, **10**–3, **10**–4, **10**–5, . . . **10**–*n* of different lengths (where *n* is any integer). Adjacent elements **10** are electrically connected together by the respective parallel resonant circuits **12**–1, **12**–2, **12**–3, **12**–4, **12**–5 . . . **12**–*n*. The last parallel resonant circuit **12**–*n* is supplied with radio frequency energy from any suitable source **13** such as an oscillator by a feed line **14**. Since antennas are reciprocal devices, the source **13** may be replaced by a suitable receiving transducer, for example a radio receiver, so that the antenna can be used for both transmitting and receiving radio frequency energy.

Each parallel resonant circuit **12** is formed by a capacitor C and an inductor L. The subscripts adjacent each C and L element designate the resonant circuit to which the capacitors and inductors pertain, e.g., capacitor C_1 is in circuit **12**–1, C_2 in circuit **12**–2, etc. The capacitors and inductors may be of the physical lumped type or else short circuit transmissions lines which are resonant at desired frequencies may be used.

The distances of the upper ends of the respective elements **10** of the monopole with respect to the ground plane **11** are selected in accordance with the well known design formulae relating to log periodic antennas. The design ratio τ, for log periodic antennas as is known, is given by

$$\tau=\frac{R_n+1}{R_n} \quad (1)$$

In the straight wire type monopole shown, Equation 1 corresponds to the distance from the ground plane to the upper end of one element divided by the distance from the ground plane to the upper end of the next higher element.

The physical lengths d of the individual elements **10**–1, **10**–2 . . . **10**–n is similarly given by

(2) $$\tau=\frac{d_n+1}{d_n}$$

This corresponds to the length of one element divided by the length of the next adjacent longer element. The design ratio τ is normally selected on an empirical basis to obtain certain desired operating characteristics. As should be clear, τ is less than one. The distances of the upper ends of the elements **10** from the ground plane **11** is shown in FIGURE 1. The resonant circuits **12** have no or negligible physical length.

The lowest frequency energy which can be radiated by an antenna is determined by its maximum length. In the antenna of FIGURE 1, this is the length L. The highest frequency which can be radiated is determined by the frequency at which the radiation pattern of the antenna becomes useless either from a standpoint of directivity or from its ceasing to exist as an efficient radiator. This also depends to a considerable extent upon the physical dimensions of the antena. The "bandwidth" of the antenna may then be defined as the range between the minimum and maximum frequencies which can be effectively radiated by the antenna. In general, log periodic antennas can be used effectively over a relatively wide bandwidth of frequencies. Of course the lower frequency limit of log periodic antenna is still determined by its physical dimensions.

The resonant circuits **12** are designed to have increasingly higher resonant frequencies going from the top of the antenna to the bottom, i.e. from circuit **12**–1 to **12**–n. These circuits serve to prohibit current above the resonant frequency from flowing past the point on the antenna at which a respective circuit **12** is resonant. This keeps the electrical length of the antenna (measured in wavelengths) relatively constant with the applied operating frequency ω because the length of the antenna changes as the operating frequency changes, i.e. its length decreases as the operating frequency increases. By using this technique the upper frequency limit of the log periodic antenna may be extended considerably over its normal upper frequency limit. This serves to increase the overall operating bandwidth of the antenna.

As explained above, the resonant frequency of each circuit **12** is selected in a manner such that the log periodic antenna **1** will effectively have a number of different electrical wavelengths at different operating frequencies supplied by source **13** or received from space. The resonant frequency for any circuit **12** is given by

(3) $$\omega_{on}=\frac{1}{\sqrt{L_nC_n}}$$

where n is any integer corresponding to the circuit **12** subscript. It should be understood that when a circuit **12** resonates at its designed frequency in response to an applied signal that the impedance of this circuit is infinite. Therefore, if one of the circuits **12** is resonant at the operating frequency supplied from source **13**, current from the source will not flow past that circuit and the antenna element **10** above the resonant circuit will not receive current and will not be effective as a radiator. For example, consider the situation where the resonant frequency of circuit **12**–1 is given by the following:

(4) $$\omega_{01}=\frac{1}{\sqrt{L_1C_1}}$$

If the operating frequency ω is equal to the resonant frequency ω_{02} for circuit **12**–1 this circuit will be resonant. When this occurs current from the source **13** will not flow past circuit **12**–1 and the effective electrical length of the antenna will be $L\tau$. This means that the antenna is electrically shorter and thus can be used to radiate higher operating frequencies. Similarly, if the resonant frequency ω_{02} for circuit **12**–2 is made higher than the resonant frequency ω_{01} for circuit **12**–1 then the electrical length of the antenna will be terminated at circuits **12**–2 when the impedance to the source current becomes infinite at the operating frequency ω_{02}.

The parameters of the conductors L and capacitances C for the various circuits **12** are also related by the antenna design ratio τ. With the resonant frequency for any circuit **12** given generally as:

(3) $$\omega_{on}=\frac{1}{\sqrt{L_nC_n}}$$

and the values of L_1 and C_1 being used to produce a resonant frequency of ω_{01} at circuit **12**–1, then for each of the circuits **12**–2, **12**–3, **12**–4, **12**–5 . . . **12**–n:

$L_2=L_1\tau$	$C_2=C_1\tau$
$L_3=L_1\tau^2$	$C_3=C_1\tau^2$
$L_4=L_1\tau^3$	$C_4=C_1\tau^3$
$L_5=L_1\tau^4$	$C_5=C_1\tau^4$
.	.
.	.
.	.
$L_n=L_1\tau^{n-1}$	$C_n=C_1\tau^{n-1}$

The values of C_2 and L_2 and successively higher subscript numbered C's and L's for the circuits **12**–2, **12**–3 . . . **12**–n will always be less than C_1 or L_1 since τ is less than one. This means that the resonant frequency of each successively higher numbered circuit **12**–2, **12**–3 . . . **12**–n is higher than that of the preceding circuit by a factor $1/\tau$. Therefore, starting with the resoant frequency of circuit **12**–n and going up towards the upper end of the antenna at circuit **12**–1 the resonant frequencies of the circuits **12** decrease in a manner related to the design factor τ.

The characteristic impedance Z_0 of the parallel resonant circuits **12** (or transmission lines) is preferably selected to be identical for every circuit. The characteristic impedance Z_0 of each parallel resonant circuit is defined as its impedance at one-half its designed resonant frequency. Preferably, this impedance Z_0 is kept within certain limits. An adequate selection of limits for Z_0 has been found to be

$$\tfrac{2}{3}\sqrt{\frac{L_n}{C_n}}$$

Of course, other suitable limits may be selected.

To explan the importance of Z_0, the characteristic impedance for the parallel resonant circuits, assume that

$$\omega=\omega_{02}=\frac{1}{\sqrt{L_2C_2}}$$

In this case, the impedance of resonant circuit **12**–2 is infinite which prohibits the current from the source **13** from flowing above element **10**–3. At this time circuits **12**–3, **12**–4, **12**–5 . . . **12**–n are all below their tuned resonant frequencies, i.e. ω is lower than their designed resonant frequencies, and they would have impedances which would be inductive. It should be understood that for any given parallel resonant circuit if the frequency applied thereto is less than its resonant frequency then the circuit will look like an inductor. On the other hand, if the frequency is higher than the resonant frequency the circuit will look like a capacitive load. In the situation being described, the inductive impedances presented by the circuits **12**–3, **12**–4, **12**–5, . . . **12**–n serve to inductively load the antenna and cause a phase shift between the currents on adjacent elements of the antenna. If the characteristic impedance Z_0 of each circuit **12**–3, **12**–4, . . . **12**–n is too high, then the inductive impedances of these circuits will be large. This will load the antenna heavily and cause large phase shifts between the currents

on the adjacent elements. If the inductances presented by the circuits are large enough, then the phase difference between the currents in adjacent elements would be close to π and very little radiation would occur from the entire antenna. This would occur because the current on adjacent elements would be out of phase so that a net radiation of zero would be produced from the antenna.

By changing the operating frequency ω the locus of impedance points as plotted an a Smith chart would form a large circle representing a very high voltage standing wave ratio (VSWR). If the characteristic impedance Z_0 of each of the circuits is lowered then, in the example being described where the operating frequency ω_{02}, the inductive reactance of circuits **12–3**, **12–4**, **12–5**, . . . **12–*n*** at the operating frequency is reduced. Continued reduction of Z_0 produces less and less phase shift between the currents on the adjacent elements and consequently greater overall radiation from the antenna. In the limit, as $Z_0 \rightarrow 0$ the phase shift between the currents on adjacent elements **10** becomes zero and the antenna produces maximum radiation equivalent to that produced by a monopole antenna $L\tau^2$ high, for an operating frequency of ω_{02}.

The characteristic impedance Z_0 of the parallel resonant circuits has a lower limit which is set by theoretical as well as practical considerations. When Z_0 is lowered too far, then the impedance of a circuit **12** near its resonant frequency drops to a relatively low value. This allows current to progress past it and causes end effect, meaning that energy will be radiated from the next higher element even though little or no energy should be radiated from this element. When this occurs, the frequency independent properties of the antenna are destroyed.

From theoretical and practical considerations it has been found that an effective value of Z_0 is

$$\tfrac{2}{3}\sqrt{\frac{L_n}{C_n}}$$

Of course, other suitable values may be used.

While the antenna **1** of FIGURE 1 has been described as being a monopole which is one-quarter wavelength high at the lowest operating frequency, it should be understood that the height can be reduced below this value. The reason for this is that the impedances of circuits **12** can be used to load the antenna **1** in a manner which can compensate for the reduced height. In this case the resonant frequencies of one or more of the circuits **12** can be adjusted, to deviate slightly from the $1/\tau$ relationship, to make a portion of the antenna either inductive or capactive as desired.

FIGURE 2 shows the principles of the present invention applied to a log periodic dipole antenna **20**. As should be clear this dipole antenna comprises two of the monopole antennas **1** of FIGURE 1 laid end to end. The same reference numerals are applied for the same elements of the antenna of FIGURE 1 and the same design characteristics are used for the lengths of the various antenna elements, i.e.

$$\tau = \frac{d_n + 1}{d_n} \tag{2}$$

The L and C parameters for the resonants circuits are also selected in the same way as described above and the same characteristic impedance Z_0 is also preferably kept for the circuits **12**.

The dipole antenna of FIGURE 2 functions as conventional dipole with the two monopoles being fed from the source **13** by a two wire transmission line **16**. However, because of the log periodic characteristics of the antenna Z_0 and the use of the resonant circuits **12**, the antenna Z_0 has a greatly increased bandwidth of operation.

FIGURE 3 shows a view of one form of arrangement for joining two of the adjacent elements **10–1** and **10–2** of the antenna together. Here, an insulator **25** is provided which has an insulating center piece **26** dividing the insulator into two portions. The center piece **26** has a conductive plate **27** on each side thereof with wires **28** connected thereto and passing out through the insulator. The ends of two adjacent elements, illustratively **10–1** and **10–2** are placed into each end of the insulator and held fast in the insulator against the respective contact plate **27** by any suitable fastening device (not shown), for example, a screw. The resonant circuit **12–1**, or suitable transmission line, is connected to the two wires **28**. The circuit **12–1** is suitably encapsulated (not shown) to protect it against weather. It should be understood that any suitable apparatus may be used to hold two of the elements **10** together, all of which are well known in the art.

It should be understood that the log periodic monopole and dipole antennas described herein may be used in any polarization. In the case of a horizontally polarized monopole, its length could be made in the order of one half wavelength at the lowest operating frequency. As explained before, this length can also be reduced due to the loading produced by circuits **12**. The antennas of the present invention may also be used as part of an array in the conventional manner.

It therefore can be seen that log periodic monopole and dipole antennas have been described which have extremely useful results in that they can be used over relatively wide bandwidths of operation while presenting a relatively constant impedance and having relatively constant radiation patterns. Tests have been run with conventional monopole and dipole antennas of comparable sizes as those using the principles of the present invention and it has been found that the antennas of the present invention exhibit better radiation pattern characteristics and impedance over a wider bandwidth of operation.

Although a particular structure has been described, it should be understood that the scope of the invention should not be considered to be limited by the particular embodiments of the invention shown by way of illustration, but rather by the appended claims.

What is claimed is:

1. A log periodic antenna comprising:

a plurality of n radiator receptor elements of respectively different lengths related by the log periodic design characteristic τ, where n is an integer of three or more and τ is a number less than one,

and a respective means having the properties of a parallel resonant circuit connecting two adjacent elements together in order of increasing length, each said means having a respectively different resonant frequency.

2. A log periodic antenna comprising:

a plurality of n radiator receptor elements of respectively different lengths related by the log periodic design characteristic τ, where n is an integer of three or more and τ is a number less than one,

and means for electrically connecting the said plurality of elements together to form an antenna with the longest element at one end thereof and the other elements of successively smaller lengths placed toward the other end,

said electrical connecting means comprising a respective means having the properties of a parallel resonant circuit with a predetermined resonant frequency for electrically connecting two adjacent elements.

3. A log periodic antenna as set forth in claim **2** wherein the predetermined resonant frequency of each said means having parallel resonant circuit properties increases progressively going from the longer elements to the shorter elements.

4. A log periodic antenna as set forth in claim **3** wherein the difference in predetermined resonant frequencies between adjacent means having parallel resonant circuit properties is related to the design characteristic τ.

5. A log periodic antenna as set forth in claim **3** wherein the impedance of each said means having parallel

resonant circuit properties at one-half its predetermined resonant frequency is given by:

$$\tfrac{2}{3}\sqrt{\frac{L}{C}}$$

where L and C are the inductance and capacitance parameters forming the circuit.

6. An antenna of the log periodic type comprising:

a plurality of n radiator receptor elements having respectively different lengths related by a design factor τ, where τ is less than one,

a parallel resonant circuit having inductance and capacitance parameters, respectively designated L and C, for electrically connecting adjacent ones of said elements,

each said parallel resonant circuit having a predetermined resonant frequency given by,

$$\frac{1}{\sqrt{L_n C_n}}$$

where n is any integer, the predetermined resonant frequency of each said resonant circuit related to the one next adjacent by the design factor τ.

7. A log periodic antenna as set forth in claim 6 wherein the impedance of each said parallel resonant circuit at one-half its predetermined resonant frequency is given by:

$$\tfrac{2}{3}\sqrt{\frac{L}{C}}$$

8. An antenna of the log periodic type comprising:

a plurality of radiator receptor elements having respectively different lengths related by a design factor τ, where τ is less than one,

a respective means having the properties of a parallel resonant circuit and having inductance and capacitance parameters respectively designated L and C, for electrically connecting adjacent ones of said elements with the longest element at one end thereof and the other elements of successively smaller lengths placed toward the other end,

each said parallel resonant circuit having a predetermined resonant frequency, the predetermined resonant frequency of each said resonant circuit being higher than the one next adjacent to it by a factor $1/\tau$ progressing from the end of the antenna with the longest element to the other end.

9. A log periodic antenna as set forth in claim 8 wherein the impedance of each said parallel resonant circuit at one-half its predetermined resonant frequency is given by:

$$\tfrac{2}{3}\sqrt{\frac{L}{C}}$$

where L and C are the inductance and capacitance parameters forming the circuit.

10. An antenna as set forth in claim 8 wherein said elements are connected end to end to form a monopole.

11. An antenna as set forth in claim 10 wherein two of said monopoles are connected to form a dipole.

12. A log periodic monopole antenna comprising:

a plurality of n radiator receptor elements of different lengths related to each other by the log periodic design characteristic τ, where n is an integer of three or more and τ is a number less than one,

and a respective means for electrically connecting each two adjacent elements together to form a straight wire type monopole antenna with the longest element at one end thereof and the other elements of successively smaller lengths placed toward the other end, each said electrical connecting means having the properties of a respective resonant circuit which is resonant at a predetermined frequency, the resonant frequencies of adjacent electrical connecting means being related by the factor of substantially 1.

13. A log periodic antenna as set forth in claim 1 wherein adjacent connecting means have respective resonant frequencies related by the factor of substantially $1/\tau$.

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