Nov. 24, 1970 J. C. PULLARA 3,543,277

REDUCED SIZE BROADBAND ANTENNA

Filed Feb. 16, 1968 4 Sheets-Sheet 1

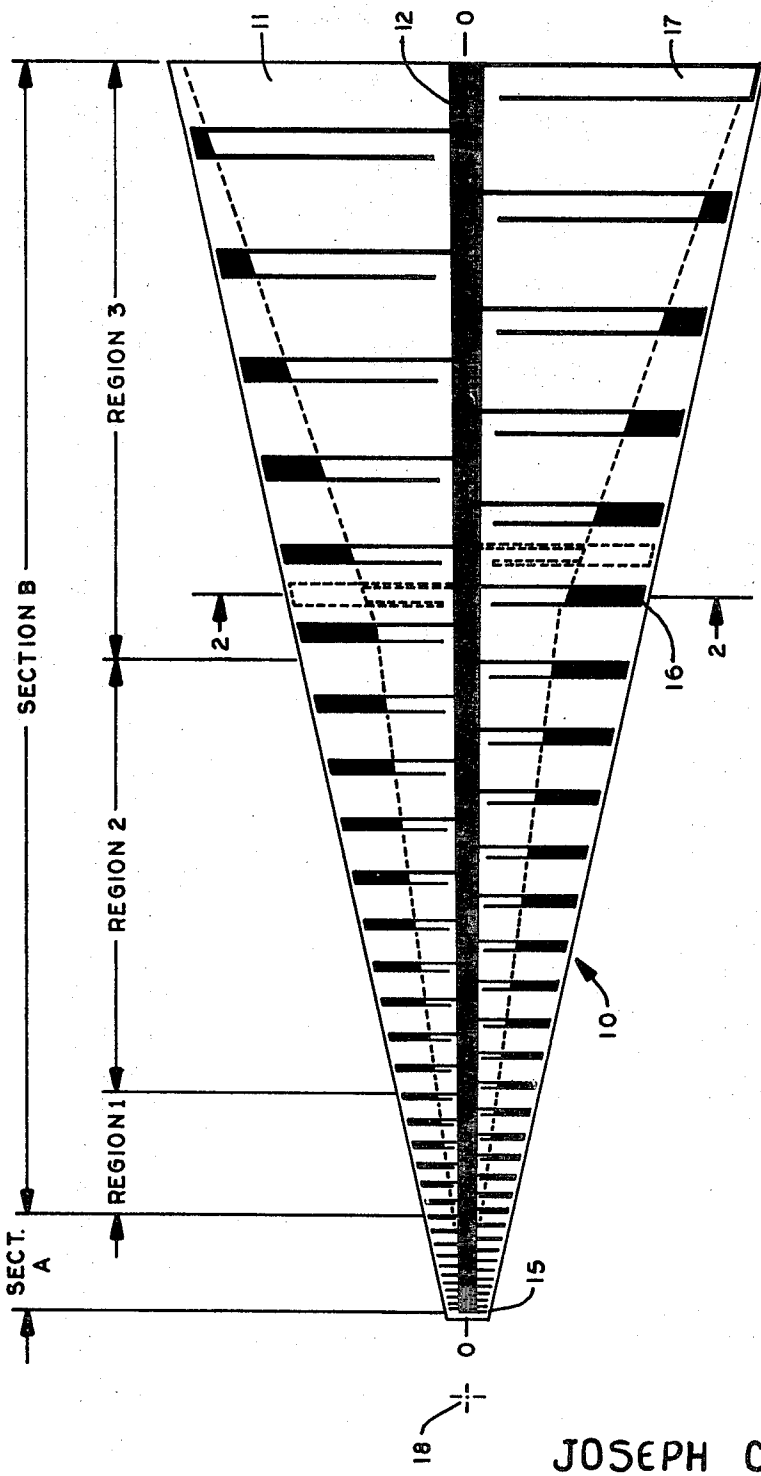

FIGURE 1

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REDUCED SIZE BROADBAND ANTENNA

Filed Feb. 16, 1968 4 Sheets-Sheet 2

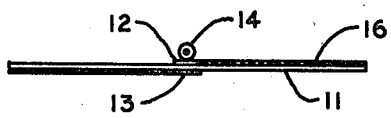

FIGURE 2

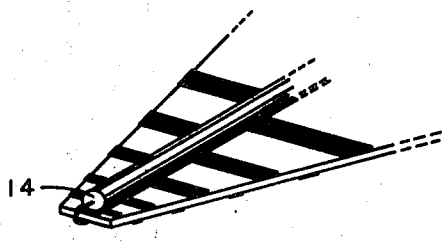

FIGURE 3

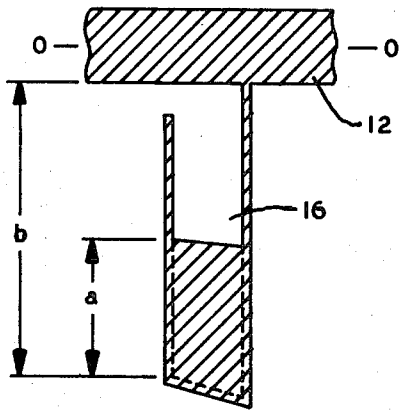

FIGURE 4

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REDUCED SIZE BROADBAND ANTENNA

Filed Feb. 16, 1968 4 Sheets-Sheet 3

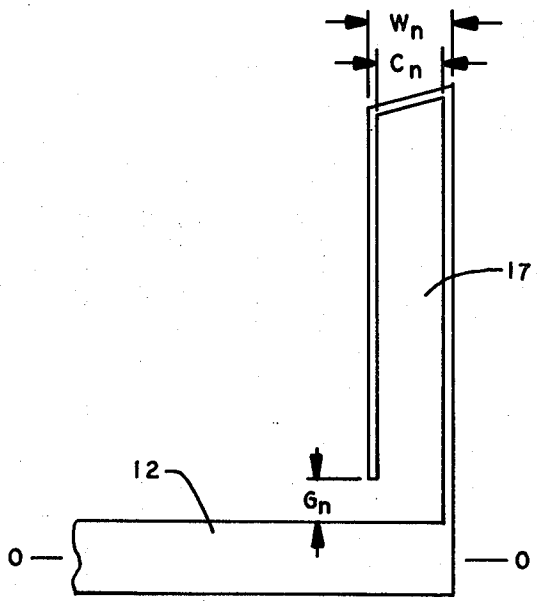

FIGURE 5

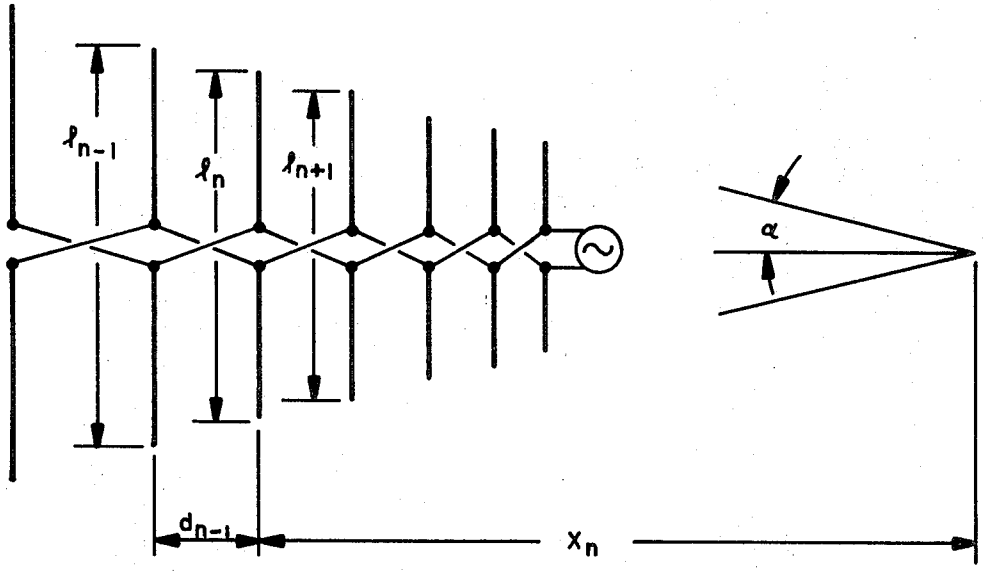

FIGURE 6
PRIOR ART

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REDUCED SIZE BROADBAND ANTENNA

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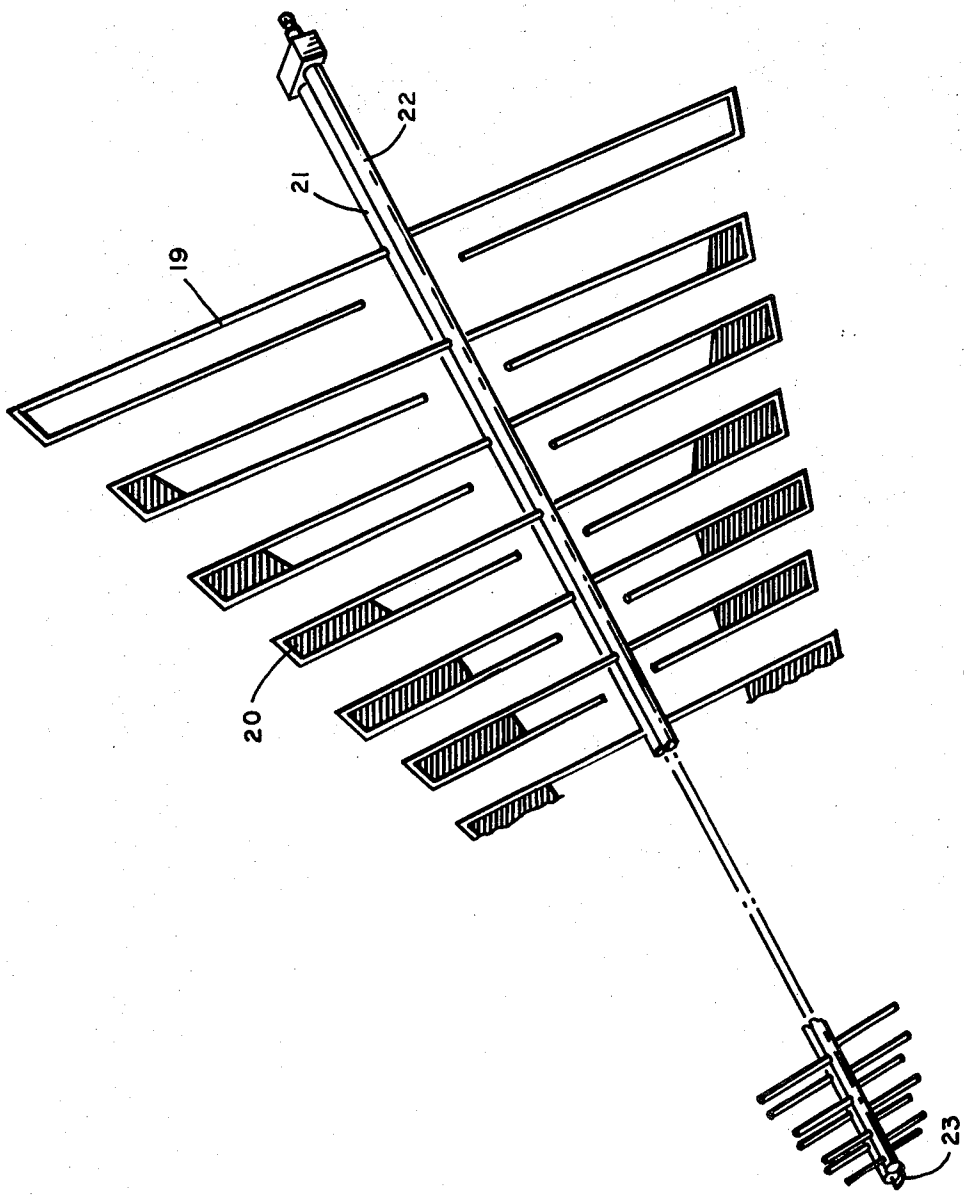

FIGURE 7

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United States Patent Office 3,543,277
Patented Nov. 24, 1970

3,543,277

REDUCED SIZE BROADBAND ANTENNA

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Int. Cl. H01q 11/10, 9/16
U.S. Cl. 343—792.5 13 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to an improved reduced size log periodic antenna in which selected elements are successively loaded to reduce the resonant frequency of such selected elements, thus to provide a desirable over-all reduction in operating frequency of my antenna as compared to the lowest operating frequency of a prior art antenna of similar size, while maintaining essentially frequency-independent performance over a very wide frequency range.

This invention relates to improved log periodic dipole and monopole antenna arrays, and more particularly to reduced size log periodic antennas whose elements have been selectively loaded so as to operate over extremely broad frequency bands, while occupying a space much less than that ordinarily required for conventional log periodic dipole antennas having such frequency range and performance characteristics.

Loading is to be understood as a technique employed for reducing the resonant frequency of a given size antenna by altering its electrical or mechanical configuration. The loading factor (F) is a measure of the frequency or size reduction achieved as in the expression

$$F=\frac{f_n}{f_l}$$

where f_n is the normal resonant frequency and f_l is the loaded resonant frequency of a given size antenna. For example, if an antenna is loaded such that it operates at one-half its normal design frequency, its loading factor is said to be 2.

Log periodic antennas have the desirable characteristics of maintaining a relatively constant radiation pattern and impedance over indefinitely large bandwidths. The dipole is one of the most basic and commonly employed antennas because of its simplicity of design, construction and operation, and therefore it has become a well known technique to develop log periodic dipole antenna arrays comprising a plurality of center fed dipoles orthogonally centered along a reference axis. Generally, the highest and lowest operating frequencies of the log periodic array are governed by the physical lengths of the smallest and largest dipole elements. The lengths of the dipoles and the spacing between axially adjacent dipoles therefore typically increase from one end of the array to the other in a well known log periodic fashion. In order that the array operates independently of frequency, it is necessary that each dipole be electrically driven 180 degrees out of phase with respect to adjacent dipoles, but several state of the art techniques are available for accomplishing such phase relationships, and these details form no part of the present invention.

Certain desired applications of log periodic antennas involve limiting the physical size of the structure for either mechanical requirements or space limitation reasons, while preserving the performance and wide frequency response of the antenna. As will be noted hereinafter, the technique of size reduction in accordance with

this invention is based on reducing the frequency response of selected dipole elements of the array by appropriately loading to achieve the desired antenna size reduction. However, it should be noted that the indiscriminate use of reduced size dipole radiators is carefully avoided, for such would introduce several problems which would adversely affect the performance of a reduced size log periodic dipole antenna as compared to a full size structure.

For example, in a conventional log periodic dipole array, the dipoles are center fed from a two-wire transmission line, which supports a slow wave progressing from the apex (front of the array) toward the rear. When energy reaches a portion of the structure containing near resonant dipoles, i.e., those which are nearly a half wavelength long, this energy is radiated by these dipoles in a direction toward the apex. Within this region of near resonant elements, commonly called the "active region," the transmission line currents decay rapidly due to radiation. Therefore, the longer elements beyond the active region play no role in determining pattern and impedance characteristics because there is no energy available for them to radiate. This attenuation through the active region is extremely important because it allows the structure to be conveniently truncated. If the radiation efficiency and attenuation in this active region is not sufficiently high, then energy not radiated in the active region may continue down the feed line and may radiate in an undesired second active region wherein the dipole lengths are nearly $3\lambda/2$. Radiation from the second active region is to be avoided because its radiation pattern is such as to degrade the normal log periodic dipole antenna radiation pattern by introducing high sidelobes and multilobed main beams.

It should be carefully noted that it is not sufficient to merely scale loaded resonant dipoles by a given periodicity factor to insure frequency independent operation of a reduced size log periodic dipole antenna, for in order to achieve proper operation, the log periodic antenna should possess certain additional properties.

First, it is desirable that the electrical distance from the antenna apex to the active region should be long enough (at least 0.3λ) to allow sufficient impedance transformation along the transmission line.

Second, the bandwidth of the active region should be at least large enough to contain a minimum of one near resonant dipole at each frequency in the operating band. This bandwidth is inversely proportional to the Q of the individual dipoles, where Q is defined as the ratio of antenna characteristic impedance to resistance at resonance, thus placing emphasis on the Q of the element as an important factor in design.

Third, the attenuation of energy through the active region must be great enough (15 db typical) to eliminate so-called "end effects" due to reflections from the rear truncation and/or energy coupled to dipoles resonant in higher order modes ($3\lambda/2$, $5\lambda/2$, etc.).

The above mentioned properties achieve added significance when the dipoles are electrically loaded to reduce their resonant frequencies. It is typical that when dipoles are so loaded, their characteristic impedance and Q rise sharply. The high Q of the reduced size dipoles reduces the number of near resonant dipoles in the active region, thus reducing the attenuation of energy through the active region tending to cause large fluctuations in radiation pattern and impedance over the frequency band of operation. It is therefore most important in loading, to establish the degree of dipole loading necessary to achieve the desired reduction in frequency while maintaining the active region efficiency necessary to insure broadband performance.

If the impedance match from the two wire transmission line to the active region dipoles is poor, there is insufficient antenna radiation and hence insufficient attenuation through the active region, also causing unpredictable pattern and impedance deterioration. Therefore, what is also needed is a procedure for loading the dipole elements which produces a compromise between the lowest Q and lowest characteristic impedance consistent with a given size reduction.

If all of the dipoles of log periodic dipole array are unloaded, the array will operate in a conventional manner only down to a lowest frequency determined by the size of the largest element. However, in accordance with this invention, I have evolved an effective antenna design such that by selective capacitive loading of the dipoles comprising the log periodic antenna, the antenna will advantageously have frequency independent performance down to a frequency half that of the conventional log periodic dipole antenna, accomplished within the size limits of the otherwise conventional counterpart.

It should be noted that a constant loading ratio applied to all dipoles of the log periodic antenna as attempted by others is not satisfactory, for as each dipole is loaded to achieve the desired loading factor, it becomes less efficient as a radiator, its bandwidth is reduced, and the recommended minimum number of dipoles in the active region is not obeyed, with the net result being undesirable frequency independent performance. Therefore, my reduced size antenna comprises several sections, each having different loading factors, with it being of significant importance that selective transition regions from unloaded dipoles to loaded dipoles are employed.

One section of my antenna may comprise small, unloaded dipoles inasmuch as already small dipole dimensions may not be amenable to size reduction due to practical limitation of fabrication tolerances. However, it is not essential to have an unloaded section. Another section comprises loaded dipoles, with the point of transition from loaded to unloaded dipoles depending on the upper frequency limit and the fabrication tolerances which can be maintained. Actually, the loaded section can be considered to involve three basic regions, these being (1) the transition from unloaded to partially loaded dipoles; (2) nominally loaded dipoles; and (3) transition to lowest operating frequency or maximum dipole loading. The first of these regions provides a gradual increase in the loading factor to insure continuous, frequency independent performance from the region of no loading to the region of nominal loading. Without this first region, the radiation performance of the antenna would be erratic with only relatively small changes in frequency.

In the second region of the loaded section, the dipoles are loaded by a nominal amount to effect some resonant frequency reduction while still maintaining a reasonable radiation efficiency in the active region. It should be noted that if the loading factor in this region exceeds approximately 1.5, the radiation efficiency of the associated active regions will be low, giving rise to secondary radiation along the antenna axis. Such secondary radiation ($3/2\lambda$, $5/2\lambda$, etc. mode) may combine unpredictably in phase and amplitude with the primary radiation ($\lambda/2$ mode) and produce erratic and unacceptable performance throughout that portion of the frequency band. Therefore, it will be appreciated that the nominal loading factor must be carefully evolved and adhered to.

The third region of the loaded section provides a taper from the nominally loaded dipoles of the second region to a maximum desired loading factor of the last dipole. Although in this region it is important to achieve the completely loaded condition of the last element in order to realize the lowest operating design frequency, it is also important to note that the loading factor transition must be sufficiently gradual in order to insure acceptable performance. The efficiency of the dipoles of the third region decreases as the loading is increased, but it is significant

to note that secondary radiation from the $3/2\lambda$ and higher order modes cannot be generated because the antenna is truncated prior to the region which can support these modes.

It is therefore an object of my invention to provide a reduced size log periodic dipole antenna wherein the loading factor of successive dipoles comprising the antenna array is gradually varied in three or more steps to provide for continuous frequency independent performance characteristic of a properly designed conventionally sized log periodic dipole antenna, down to a frequency much lower than was previously possible.

It is also an object of my invention to provide a reduced size log periodic antenna utilizing a novel capacitive loading technique so as to provide a ready means of independently adjusting dipole resonant frequency, bandwidth and efficiency commensurate with the requirements imposed upon the dipoles required in each of the three regions of the antenna.

Another object of my invention is to provide an improved reduced size log periodic antenna in which an effective suppression of secondary radiation is brought about by the selective loading of the dipoles comprising the reduced size log periodic dipole array.

These and other objects, features, and advantages will be apparent from a study of the enclosed drawings in which:

FIG. 1 is a side elevational view of a reduced size log periodic antenna constructed in accordance with this invention, and built in accordance with printed circuitry techniques;

FIG. 2 is a cross-sectional view taken along lines **2—2** in FIG. 1;

FIG. 3 is a fragmentary view of feed details, taken to a somewhat larger scale;

FIG. 4 is a fragmentary view of a partially loaded dipole half, also taken to a larger scale;

FIG. 5 is a view similar to FIG. 4, but with a fully loaded dipole half;

FIG. 6 is a view of a prior art log periodic antenna, which is utilized to show the basic parameters of such a device; and

FIG. 7 reveals a log periodic antenna embodiment in accordance with this invention, in which skeletal or tubular techniques are employed, with some of the dipoles being omitted for clarity reasons.

A reduced size log periodic dipole antenna **10** constructed in accordance with a preferred embodiment of this invention is shown in FIG. 1. This antenna comprises a pair of parallel, axially spaced conducting elements extending along center axis **0—0**, to which are connected a plurality of dipoles. This particular embodiment of my invention was created in accordance with printed circuitry techniques, with a plurality of dipole halves disposed on each side of the substrate **11** and connected in an alternate staggered arrangement to the conductors **12** and **13** disposed along the center axis. As will be noted, only conductor **12** is visible in FIG. 1, and recourse must be had to FIG. 2 for an indication of conductor **13**. Both of these conductors are typically of copper, to which a coaxial transmission line **14** is attached for coupling electromagnetic wave energy between the apex end of the parallel transmission conductors **12** and **13** and the associated transmitting and receiving circuits.

The means of connecting the coaxial line to the two conductor parallel transmission line disposed along axis **0—0** is illustrated in FIG. 3, although such is not unique and not an object of this invention.

It will be noted that dipole half **15** represents a completely unloaded or conventional element, whereas dipole half **16** represents the many partially loaded dipoles, and dipole half **17** is completely loaded. The dipole halves shown in full lines in FIG. 1 are on the near side of the substrate, with it being understood that each illustrated dipole half is opposite a dipole half disposed on

the other side of the substrate, as indicated in dotted line at the mid-location of the antenna. Thus it will be understood that each dipole half shown in full lines on the upper side of axis **0—0** as viewed in FIG. 1 is opposite a half disposed on the lower portion of the opposite side of the substrate, and each dipole half on the lower side of the axis is opposite a half disposed on the upper portion of the opposite side of the substrate. The dipole halves disposed on the near side of the substrate are connected to conductor **12**, and those on the opposite side are connected to conductor **13** as illustrated in FIG. 2.

Referring to FIG. 6, it will be noted that the outside linear dimensions, axial spacing of the dipoles, and the width of the dipoles increase in the direction from the point of convergence or apex **18** to the opposite end of the antenna according to the conventional log periodic relationship:

$$\tau=\frac{X_n}{X_{n-1}}=\frac{l_n}{l_{n-1}}$$

where τ is a constant having a value less than 1, X_n is the distance from the point of convergence to the nth element, X_{n-1} is the corresponding distance from the point of convergence to the $n-1$th element, l_n is the total height of the nth dipole, and l_{n-1} is the corresponding height of the $n-1$th dipole. Although FIG. 6 represents a log periodic antenna in accordance with the prior art, it nevertheless is of consequence here, for the novel dipole configurations I utilize nevertheless are governed from the length and spacing standpoints by the teachings of the prior art applicable to log periodic antennas.

Referring back to FIG. 1, it will be observed that each of the half dipole elements such as **16** and **17** is in the shape of the letter "U," with one leg of the "U" longer than the other leg. The longer leg of each "U" element is connected to the adjacent conductor of the transmission line, while the shorter leg of said U shaped element is insulated from both of the transmission line conductors.

It will also be noted that the cavity part of each U shaped element such as **16** shown in FIG. 1 and in more detail in FIG. 4 is partially truncated by a factor of S, wherein $S=a/b$ and a is the length of the cavity truncation, whereas b is the height of the "U" cavity. S may take on values from 0 to 1.0, with a truncation factor S=0 corresponding to a fully loaded (reduced frequency) element and a truncation factor of .99 corresponding to a condition approximating a completely filled "U" cavity. A truncation factor S=1.0 would result in the conventional log periodic antenna dipole element and therefore a condition wherein all elements have S=1.0 would not be consonant with the purpose of this invention.

The elements of the antenna shown in FIG. 1 are grouped into regions according to their truncation factor S. Each region comprises element with truncation factors S decreasing starting from the point of convergence **18** to the other or large end of the antenna.

For example, the antenna shown in FIG. 1 is comprised of two distinct sections of elements. Section A is comprised of elements having a truncation factor S equal to 1 while Section B is comprised of three regions of elements with varying truncation factors. The elements of Region **1** have truncation factors ranging in a substantially continuous manner from .99 to .50 in order to produce the necessary gradual transition from the conventional unloaded elements of Section A to the loaded elements of Section B. Region **2** comprises elements which each have a truncation factor of 0.5. Finally, Region **3** contains elements which have a gradual and substantially continuous truncation factor from 0.5 to 0.0.

The width of each element W_n, the width of the cavity C_n, and other element parameters as shown in FIG. 5 are selected to provide the desired reduction of size or frequency. The technique of establishing the dimension of the maximally loaded element **17** is not of consequence here, but rather it is important to this invention that these elemental parameters be properly applied to a log periodic antenna to reduce its operating frequency.

All other dimensions and parameters of the log periodic dipole antenna not defined herein are dependent on the desired frequency range of operation, radiation beam width, gain and impedance. The values of these parameters are easily determined by the design equations of ordinary conventional log periodic dipole antennas and are not objects of this invention. Examples of parameters not related to the objects of this invention are: number of elements in the antenna array, number of elements in each section and region, the apex angle, the width and separation of the two wire transmission line, the dielectric constant of the substrate material, etc.

Dimensions of an antenna of the type described in conjunction with FIG. 1, which has proven operationally successful from 400 mHz. to 11,000 mHz. are—

Log periodic parameters:

$\tau=0.95$.

$\alpha=12$ degrees.

$\sigma=\frac{d_n}{2l_n}=0.059$

Number of dipole elements:
- Section A (unloaded)—21.
- Section B (loaded):
  - Region **1**—19.
  - Region **2**—14.
  - Region **3**—11.

Dipole lengths:
- Longest dipole—7.0 inches.
- All others—$\tau\times$(length of longer adjacent dipole).

Dipole Width (W_n, see FIG. 5):
- Longest dipole—0.438 inch.
- All others—$\tau\times$(width of longer adjacent dipole).

Dipole Loading ($S=\frac{a}{b}$, see FIG. 4):
- Section A (all elements)—S=1.
- Section B—
  - Region **1**: Shortest element—S=0.9.
    Longest element—S=0.55.
  - Region **2**: (all elements)—S=0.5.
  - Region **3**: Shortest element—S=0.42.
    Longest element—S=0.0.

"U" Cavity width (C_n, see FIG. 5):
- Longest dipole—0.344 inch.
- All others in Section B—$\tau\times$(cavity width of longer adjacent dipole).

Gap spacing (G_n, see FIG. 5):
- Longest dipole—0.170 inch.
- All others in Section B—$\tau\times$(gap spacing of longer adjacent dipole).

Parallel two-wire transmission line:
- Conductor width—.200 inch front to .416 inch other end continuous.
- Impedance—25 ohms front to 12.5 ohms other end continuous.
- (Unique impedance designed for intended application.)

Substrate:
- Material—Fiberglas.
- Thickness—.032 inch.
- Dielectric constant—4.9.

Coaxial cable—UT—85.

The tubular or skeletal embodiment of the reduced size log periodic dipole antenna as shown in FIG. 7 is another of the applicable embodiments of my invention. It is to be understood that when reference is made to a skeletal embodiment of this invention, this includes all tubular,

channel, rod, and sheet metal construction techniques and the like. In this example, each dipole **19** is comprised of rods or tubes of conductors connected to resemble the U shape of the previously described printed circuit antenna elements. The truncation of the "U" cavity may be implemented by a solid conductive plate **20**, but of course other techniques may be preferable. The parallel two wire transmission line may take the form of two parallel tubes **21** and **22** wherein the energy is delivered to the two conductor lines through a coaxial line **23** contained within one of the two tubes.

Furthermore, my invention applies to reduced size monopole antennas which can be considered as the upper half only of either of the two previously described embodiments of the log periodic dipole antenna. The details of construction, grounding, and the delivering of energy to the log periodic monopoles would not be affected by my selective loading of the monopole elements, and hence these details are not discussed herein.

Also, my invention is not to be limited to capacitive loading, for manifestly it may be preferable to employ inductive loading or material loading on selected dipole or monopole elements of the log periodic antenna.

Other modifications within the framework of my invention will be apparent to those skilled in the art, and I am not to be limited to the above-described embodiments except as required by the scope of the appended claims.

I claim:

1. A reduced size log periodic antenna utilizing a plurality of substantially parallel, axially spaced elements disposed along an axis of said antenna, with the axial spacing of successive elements increasing from one end of the antenna to the other, with the loading of the elements at said one end being minimal, and the loading of the elements at the other end being maximal, the elements in a region adjacent the location of minimal loading ranging in a substantially continuous manner from a truncation factor of .99 to a nominal truncation factor from .4 to .6 in order to produce a gradual transition to the region of loaded elements, with the region adjacent the location of maximal loading being such that the elements therein progressively have a truncation factor varying from the nominal truncation factor to 0.0, whereby frequency-independent performance is obtained over a wide frequency range.

2. A reduced size log periodic antenna utilizing a plurality of substantially parallel, axially spaced conducting elements disposed transversely along a central axis of said antenna, said conducting elements each being of a length different to that of adjacent elements, with the linear dimensions and axial spacing of successive conducting elements increasing from one end of the antenna to the other, with the loading of the elements at said one end being minimal, the loading of the elements at the other end being maximal, and the intervening elements being partially and selectively loaded, the elements in a region adjacent the location of minimal loading ranging in a substantially continuous manner from a truncation factor of .99 to a nominal truncation factor from .4 to .6 in order to produce a gradual transition to the region of loaded elements, with another region of elements then being employed in which all elements maintain a relatively constant truncation factor, with a final region of elements wherein the elements progressively have a gradual and continuous truncation factor varying from the nominally constant value of 0.0, whereby frequency-independent performance is obtained over a very wide frequency range, and feed means for coupling electromagnetic wave energy to and from said elements.

3. A reduced size log periodic antenna utilizing a plurality of substantially parallel, axially spaced elements disposed along an axis of said antenna, the axial spacing of successive conducting elements increasing from one end of the antenna to the other, with the elements adjacent said one end being unloaded, the elements adjacent the other end being loaded, and the intervening elements being partially and selectively loaded, the elements in the region adjacent the unloaded end ranging in a substantially continuous manner from a truncation factor of .99 to a nominal truncation factor from .4 to .6 in order to produce a gradual transition to the region of loaded elements, with another region of elements then being employed in which all elements maintain a relatively constant truncation factor, with a final region of elements wherein the elements progressively have a gradual and continuous truncation factor varying from the nominally constant value to 0.0, whereby frequency-independent performance is obtained over a wide frequency range.

4. A reduced size log periodic antenna utilizing a plurality of substantially parallel, axially spaced conducting elements disposed transversely along a central axis of said antenna, said conducting elements each being of a length different to that of adjacent elements, with the linear dimensions and axial spacing of successive conducting elements increasing from one end of the antenna to the other, with loading of the elements adjacent said one end being minimal, and the loading of the elements adjacent the other end being maximal, and the intervening elements being partially and selectively loaded, the elements in a region adjacent the location of minimal loading ranging in a substantially continuous manner from a truncation factor of $S_0=.99$ to a nominal truncation factor $S_1<.99$ in order to produce a gradual transition to the region of loaded elements, with another region of elements being employed in which all elements maintain the truncation factor S_1, then having another region of elements whose truncation factor varies in a substantially continuous manner from a truncation factor of S_1 to S_2 wherein $S_2<S_1$, and so on for n regions of elements so that $S_n=0$, whereby frequency-independent performance is obtained over a very wide frequency range, and feed means for coupling electromagnetic wave energy to and from said elements.

5. A reduced size log periodic antenna having a plurality of substantially parallel, axially spaced conducting elements, said elements being disposed along a longitudinal axis of said antenna, the element at one end of said axis being shorter than the element at the other end, with the axial spacing of said elements increasing from said one end to said other end in accordance with a preestablished relationship, the elements adjacent said one end of the axis having minimal loading, the elements adjacent said other end having maximal loading, the elements in a region adjacent the location of minimal loading ranging in a substantially continuous manner from a truncation factor of .99 to a nominal truncation factor from .4 to .6 in order to produce a gradual transition to the region of loaded elements, with another region of elements then being employed in which all elements maintain a relatively constant truncation factor, and a final region of elements wherein the elements have a truncation factor varying from the nominally constant value to 0.0, whereby frequency independent performance is obtained over a wide frequency range, and feed means for coupling electromagnetic wave energy to and from said elements.

6. The antenna as defined in claim **5** in which a substantial number of said elements are generally of U shape, with one leg of each U being longer than the other, said longer legs being connected to a conductor disposed along the length of said axis of said antenna.

7. The antenna as defined in claim **6** in which the U shaped elements are truncated to effect a variation in loading

8. The antenna as defined in claim **5** in which said elements are capacitively loaded.

9. The antenna as defined in claim **4** in which the variation in truncation factor in the last-named region continues on for n regions of elements such that $0 \leq S_n \leq S_{n-1}$.

10. The antenna as defined in claim 5 in which said antenna is created by printed circuit techniques.

11. The antenna as defined in claim 5 in which said antenna is made utilizing skeletal techniques.

12. The antenna as defined in claim 5 in which said elements are dipoles.

13. The antenna as defined in claim 5 in which said elements are monopoles.

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U.S. Cl. X.R.

343—802