FOLDED MONOPOLE ANTENNA WITH TOP LOADING AND LUMPED INDUCTANCE AT BOTTOM

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ABSTRACT OF THE DISCLOSURE

A broad band folded monopole antenna structure having at least three radiating elements utilizing top hat loading and lumped inductive coupling between the folded radiations. The structure exhibits resonance at more than one frequency, thus providing broad band response.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1 there is shown a known top hat loaded folded monopole antenna configuration comprising radiating elements 1 and 2 coupled together at their upper ends by inductive impedance 3. The lower end of element 1 is coupled to ground 22 and the input signal source is applied between the lower end of radiating element 2 and ground potential. The height of the overall structure is H and the spacing between said elements is b. The diameter of each of the radiating elements is 2a.

This type of antenna structure is well known in the art and it can be easily shown that the input admittance thereof is

\[ Y_{in} = \frac{1}{\sqrt{2}} \left( \frac{Z_0 + Z_L}{Z_0 + Z_L} \right) \tan \frac{bH}{2a} \]

where \( Z_0 \) is the input impedance of a center driven isolated cylindrical dipole antenna of height 2H and radius \( \sqrt{2}b \) and \( Z_L \) is the load impedance.

This type of antenna structure may be designed to operate in a push-pull mode with a negligible push-pull mode current distribution and the impedance thereof may be made approximately four times the impedance of an equivalent length single monopole. These properties of top hat loaded folded antennas are well known in the art and a detailed description and analysis thereof is deemed unnecessary for a proper understanding of the instant invention.

It has been found that by inserting a lumped inductive coupling between the radiating elements 1 and 2 of FIG. 1, the frequency response of the antenna was shifted in the frequency domain. The resultant antenna structure is illustrated in FIG. 2 which comprises radiating elements 5 and 6 coupled together at the tops thereof by inductive impedance 7. The lower end of elements 5 and 6 are coupled together inductively by means of lumped mutual inductance 8 which provides a predetermined mutual coupling, k. The input signal source 9 is applied between one end of the primary winding 10 of mutual inductance 8 and ground potential 22, the other end of primary winding 10 being coupled to the lower end of element 5. One end of secondary winding 11 of mutual inductance 8 is coupled to the lower end of element 6 and the other end of winding 11 is coupled to ground potential 22. The antenna elements 5 and 6 are separated by a distance d which is very small or which may be comparable with the wavelength and the height thereof is H. It is seen that the two monopoles 5 and 6 are coupled by (1) the distributed electromagnetic interaction as previously described with respect to FIGURE 1, and (2) the lumped inductive interaction provided by lumped mutual inductance 8.

In order to analyze the behavior of the antenna of FIG. 2, the effect of the lumped mutual inductance 8 may be considered separately from the effects of the distributed electromagnetic interaction. For this purpose, referring to FIGURE 3, the antenna elements 5 and 6 are represented by equivalent series-resonant circuits coupled together inductively by mutual inductance 8 which has a mutual coupling coefficient k. The series resonant circuit comprising capacitor C and resistor R_p (which represent monopole element 5) is series coupled with the primary winding 10 of mutual inductance 8. The series combination of capacitor C and resistor R_p (which represent monopole element 6) are series coupled together with the secondary winding 11 of mutual inductance 8. The coupling coefficient between windings 10 and 11 is designated as k and the input signal source 9 is applied between one end of winding 10 and the other terminal of resonant circuit C_R_p. The resonant frequencies of the primary and
of the secondary windings are assumed to be identical. It is well known that, under the application of a sinusoidal voltage at the primary winding, the following currents are produced:

$$I_1 = \frac{E}{Z_a + \frac{1}{j\omega M Z_a}} = I_2 = \frac{-j\omega M}{Z_a}$$

where $I_1$ is the primary current, $I_2$ is the secondary current and the subscripts $s$ and $p$ denote quantities related to the secondary and primary windings, respectively, of mutual inductance $s$. Since

$$Z_s = R_s + j\omega L_s - \frac{1}{s\omega C_s}$$

reverses the sign of its phase when the frequency passes through resonance, the current $I_2$ similarly reverses the sign of its phase angle with respect to the phase angle of the current $I_1$.

Indicating with $k$ the coupling coefficient:

$$k = \frac{M}{\sqrt{L_s L_p}}$$

and with $Q_s$, $Q_p$ and $Q$ factors of primary and of secondary, respectively, of mutual inductance $s$, it is found that the currents $I_1$ and $I_2$ exhibit two separate peaks where the coefficient $k$ satisfies the relation:

$$k > \frac{1}{\sqrt{Q_s^2 + Q^2}}$$

The frequencies at which these peaks occur are, respectively:

$$f = f_0 \left(1 \pm \frac{k}{2}\right)$$

and critical coupling occurs when:

$$k = k_c = \frac{1}{\sqrt{Q_s Q_p}}$$

FIG. 4 illustrates the primary and secondary currents, $I_1$ and $I_2$, respectively, of mutual inductance $s$ as functions of frequency for various values of the coupling coefficient $k$. It is seen from these curves that for different values of $k$, the currents peak (i.e. the input admittance is a maximum) at different frequencies. Therefore with the proper value and sign of $k$ and with the appropriate antenna structure, the antenna of FIG. 3 could be designed to operate at various different frequencies.

Assume that the top hat inductance $t$ has been selected such that only the push-push mode current distributions in the antenna configuration will be excited. If the coupling coefficient $k$ is larger than critical, the input admittance exhibits two peaks at respective frequencies:

$$f = f_0 \left(1 \pm \frac{k}{2}\right)$$

as shown in FIG. 4. However, only one current-mode distribution will tend to be excited in correspondence of each frequency, because of the constraint represented by the lumped mutual inductance, i.e., the sign of $k$. Note also that of these two modes, only the push-push mode will be sustained by the folded monopole, because of its top-end impedance termination.

By virtue of the use of the novel antenna configuration illustrated in FIG. 5, the radiative operation of an antenna structure is extended to both frequency peaks for any of the under-critically coupled cases illustrated in FIG. 4 (i.e. $k > 0.01$). In the embodiment of FIG. 5, radiating elements 12 and 13 are coupled together at their tops by impedance 15, elements 13 and 14 are coupled together at their tops by impedance 16 and elements 12 and 14 are coupled at their tops by impedance 17. The lower ends of radiating elements 12 and 13 are coupled together by lumped mutual inductance 18 having a coupling coefficient $k_1$ and the lower ends of radiating elements 12 and 14 are coupled together at their lower ends by lumped mutual inductance 20 having a coupling coefficient $k_2$. Radiating elements 13 and 14 are coupled together at their lower ends by means of a lumped mutual inductance 19 having a coupling coefficient $k_3$. A signal source 21 is coupled to the lower end of radiating element 13 and the lower ends of radiating elements 12 and 14 are coupled to ground potential 22 via the respective lumped mutual inductances. In this configuration, the coupling coefficients $k_1$ and $k_3$ are substantially equal in the magnitude but are opposite in sign. Therefore, the input admittance of the driven element 13 operating in conjunction with elements 12 and 14 will present maxima at the frequencies $f_0(1-k/2)$ and $f_0(1+k/2)$, respectively. See FIGURE 4. Radiating elements 12 and 13 will cooperate and radiate at a first frequency $f_0(1-k/2)$ and radiating elements 13 and 14 will cooperate to radiate at a second frequency $f_0(1+k/2)$. By making the coupling coefficient $k_2$ of lumped mutual inductance 20 the proper value, the structure will resonate at yet another frequency which is determined by the magnitude and sign of $k_2$. In this manner, broad band operation is achieved since the antenna structure will have an input admittance which presents a maxima at a plurality of frequencies instead of at a single frequency as is normally the case for standard folded monopole top hat loaded antennas.

A more detailed analysis of the configuration of FIGURE 5 is deemed unnecessary for a proper understanding of the invention in view of the above discussion and the analysis of the antenna structures shown in FIGURES 1 and 2. The details of the operation of the antenna structure of FIGURE 5 should be apparent to one ordinarily skilled in the art in view of these aforementioned descriptions.

In order to obtain operation over a broader band of frequencies, more radiating elements and lumped inductances may be coupled to the structure of FIG. 5, the radiating elements and lumped mutual inductances being dimensioned to provide input admittance maxima at the desired frequencies. It is believed that these modifications could be made by one ordinarily skilled in the art within the spirit of this invention.

It is pointed out that a broad band antenna structure is thus achieved according to this invention without the use of external tuning and/or matching networks, the enhanced bandwidth being obtained intrinsically without recourse to external means.

While I have described above the principles of my invention in connection with specific apparatus it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A broad band antenna comprising:
   at least first, second and third radiating elements;
   a first impedance coupled between the upper ends of said first and second radiating elements;
   a second impedance coupled between the upper ends of said second and third radiating elements;
   a first lumped mutual inductance coupled between the lower ends of said first and second radiating elements;
   a source of input signal coupled to the lower end of said second radiating element; and
   means coupling the lower end of said third radiating element and one terminal of said lumped mutual inductance to ground potential.

2. A broad band antenna according to claim 1 further comprising a second lumped mutual inductance coupled between the lower ends of said second and third radiating elements.

3. A broad band antenna according to claim 1 further comprising a third impedance coupled between the upper ends of said first and third radiating elements.
4. A broad band antenna according to claim 3 further comprising said second lumped mutual inductance coupled between the lower ends of said second and third radiating elements and a third lumped mutual inductance coupled between the lower ends of said first and third radiating elements.

5. A broad band antenna according to claim 4 wherein said first, second and third lumped mutual inductances have respective coefficients of coupling $k_1$, $k_2$ and $k_3$, each said coefficient of coupling having different values, said antenna thereby being operable at three different predetermined frequencies.

6. A broad band antenna according to claim 1 wherein said first impedance and the coefficient of coupling of said first lumped mutual inductance are dimensioned such that substantially only push-push current modes are radiated from said first and second radiating elements at a first predetermined frequency.

7. A broad band antenna according to claim 1 wherein said second impedance is dimensioned such that substantially only push-push current modes are radiated from said second and third radiating elements at a second predetermined frequency.

8. A broad band antenna according to claim 2 wherein said second impedance and said second lumped mutual inductance are dimensioned such that substantially only push-push current modes are radiated from said second and third radiating elements at a third predetermined frequency.

9. A broad band antenna according to claim 3 wherein said third impedance is dimensioned such that substantially only push-push current modes are radiated from said first and third radiating elements at a fourth predetermined frequency.

10. A broad band antenna comprising:
- a plurality of radiating elements;
- a plurality of impedance means, each said impedance means being coupled between the upper ends of a different pair of said plurality of radiating elements;
- a plurality of lumped mutual inductances, each lumped mutual inductance being coupled between the lower ends of a different pair of said plurality of radiating elements;
- a source of input signal coupled to the lower end of one of said radiating elements; and
- means coupling the lower ends of the rest of said radiating elements to ground potential;
- said antenna being operable at a plurality of predetermined frequencies.

11. A broad band antenna according to claim 10 wherein each said lumped mutual inductance has a different coefficient of coupling, thereby rendering said antenna operable a plurality of different frequencies, said plurality of different frequencies being equal in number to the number of said plurality of radiating elements.

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