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Willie et al.

[11] **3,827,053**

[45] **July 30, 1974**

[54] **ANTENNA WITH LARGE CAPACITIVE TERMINATION AND LOW NOISE INPUT CIRCUIT**

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[21] Appl. No.: **229,992**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 64,054, July 23, 1970, abandoned, which is a continuation-in-part of Ser. No. 644,768, June 7, 1967, abandoned.

[52] **U.S. Cl.** **343/701,** 343/828, 343/899, 325/377

[51] **Int. Cl.** **H01q 1/26,** H04b 1/10

[58] **Field of Search** 343/701, 828, 899; 325/373, 376, 377

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Attorney, Agent, or Firm—Darby & Darby

[57] **ABSTRACT**

An antenna having a short stem and a larger than normal capacitive termination to provide improved performance over antennas of the same effective electrical length, and an input circuit having a larger than normal total input resistance for obtaining improved signal-to-noise ratios by using the capacitive reactance of said antenna as a noise sink.

4 Claims, 10 Drawing Figures

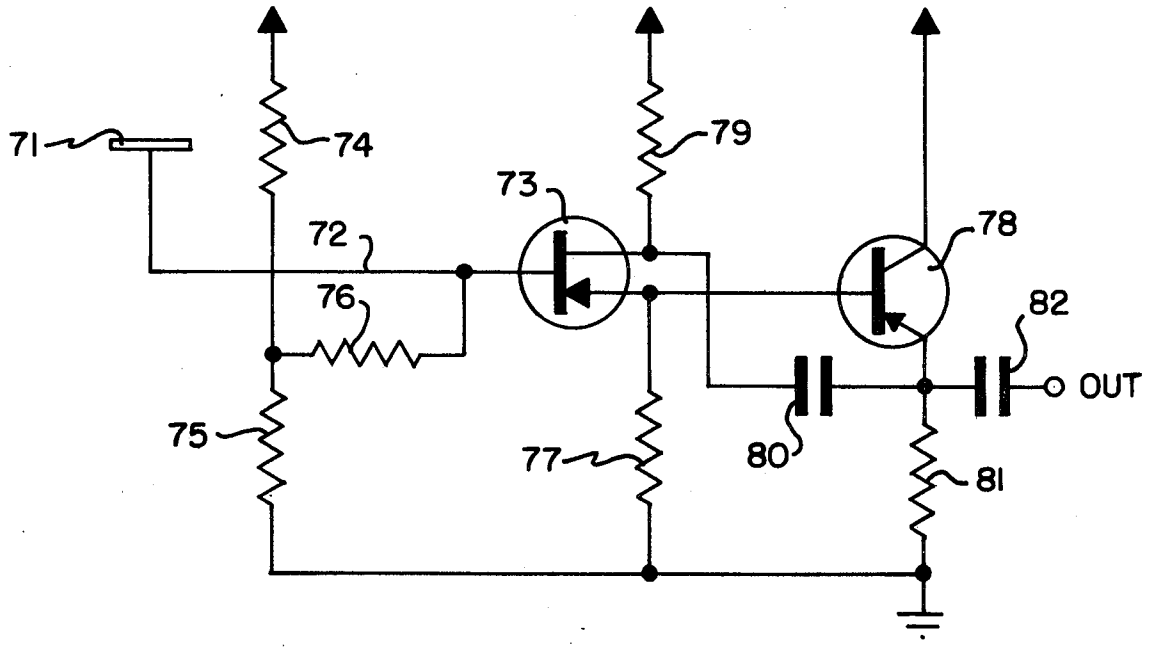


FIG.1.

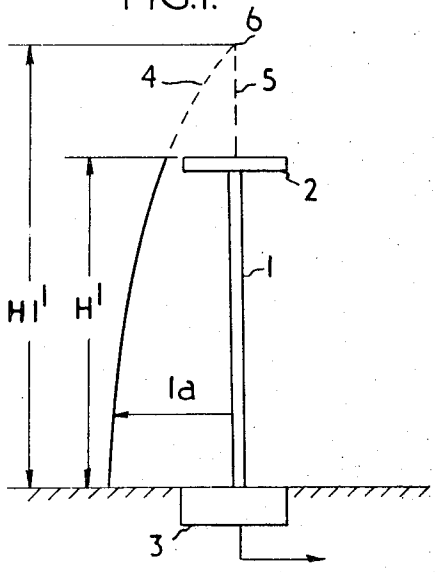


FIG.2.

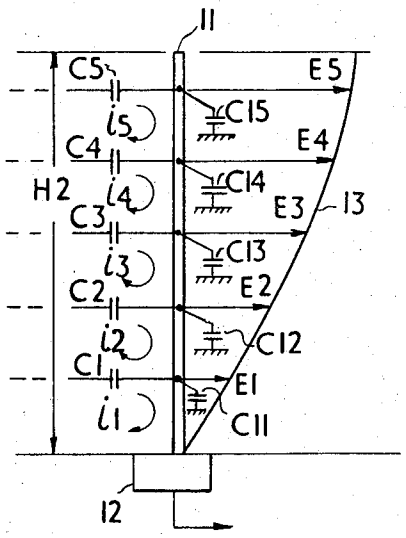


FIG.3.

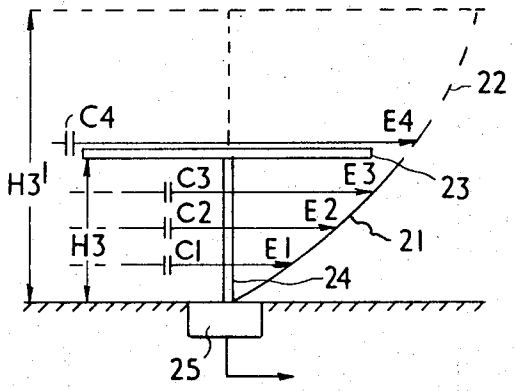


FIG.4.

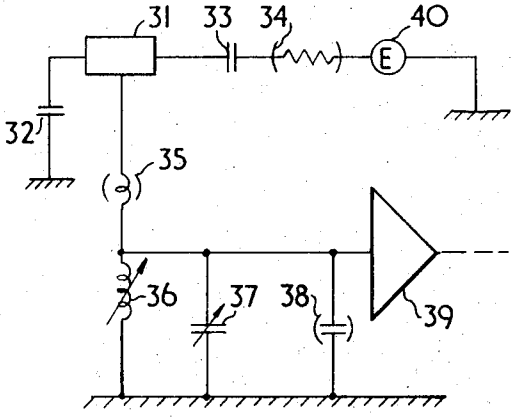


FIG.5.

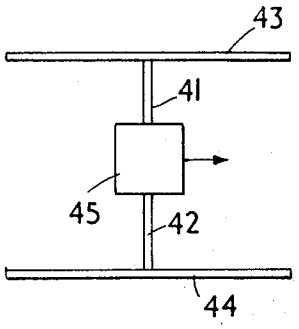


FIG.6.

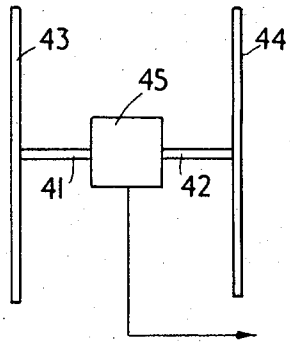
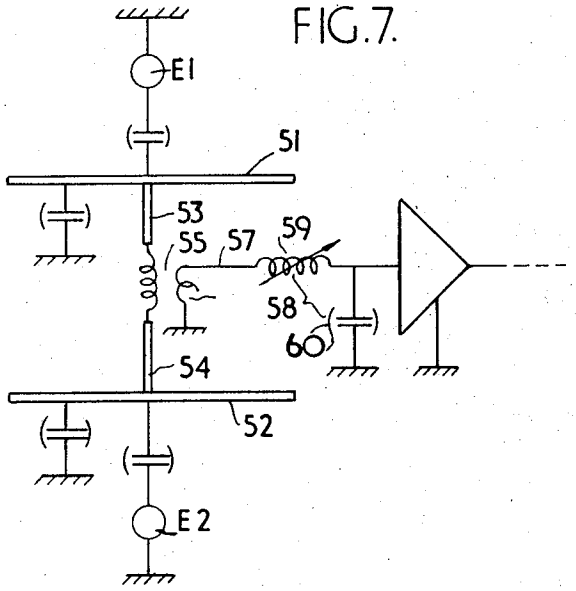


FIG.7.



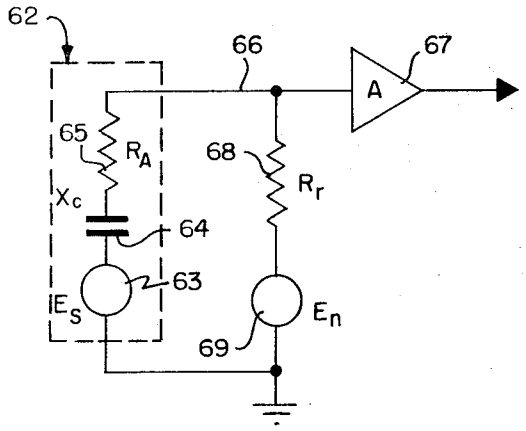


FIG. 8

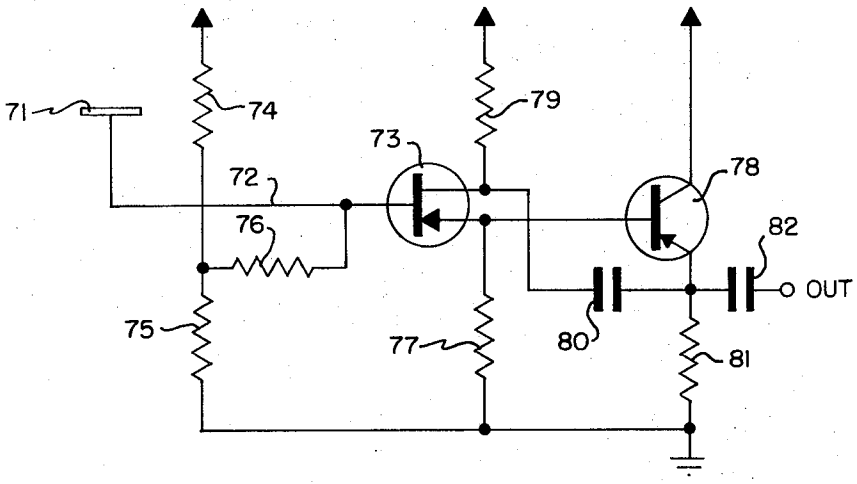


FIG. 9

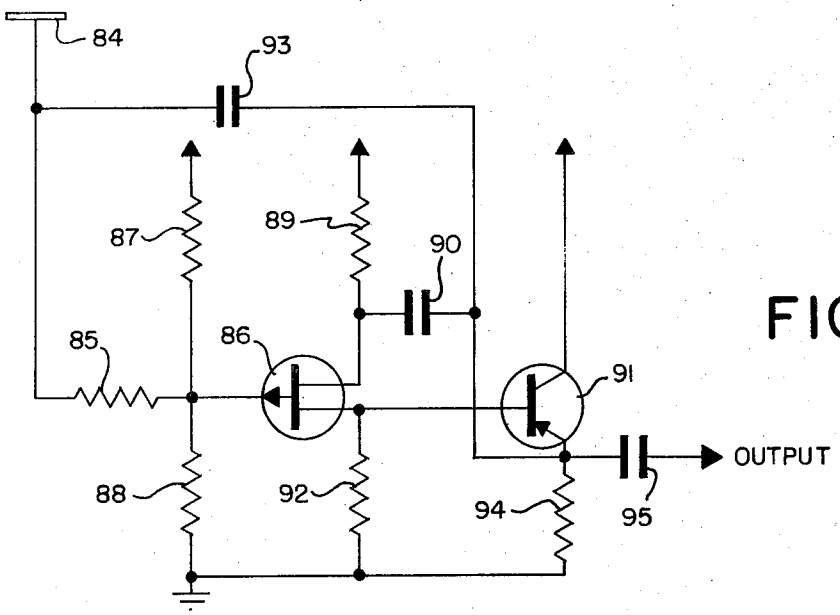


FIG. 10

ANTENNA WITH LARGE CAPACITIVE TERMINATION AND LOW NOISE INPUT CIRCUIT

This application is a continuation-in-part of copending application Ser. No. 64,054 filed July 23, 1970 now abandoned, which was a continuation of prior copending application Ser. No. 644,768 filed June 7, 1967 also abandoned.

This invention relates to linear antennas which are capacitively terminated or, as they are sometimes referred to in the technical literature, top-loaded or end-loaded antennas. It is well understood that such capacitive loading re-distributes the antenna currents and other electrical properties such as radiation resistance, radiation patterns and phase shift patterns in such a way as to make the conventional capacitively loaded antenna appear electrically similar to an unterminated antenna of greater physical length. By conventional capacitive loading, the equivalent electrical length of an antenna can be increased up to about 180 percent of its physical length.

It is an object of this invention to provide an antenna having a performance which is improved beyond that which is obtained by increasing the effective electrical length of the antenna through conventional capacitive loading.

It is another object of this invention to provide a compact antenna which is capable of being enclosed within a receiver cabinet.

It is also an object of this invention to provide an antenna having an improved resonant gain efficiency.

It is another object of this invention to provide an antenna and input circuit in combination to provide an improved signal-to-noise ratio.

In accordance with the above objects the present invention provides an antenna which is capacitively loaded to an extent far beyond that which is contemplated by conventional practice. More particularly, we have found that advantageous properties are obtained by antennas which are capacitively loaded to an extent far beyond that which would be required to increase their equivalent electrical length to 180 percent of their physical length. We call such capacitive loading heavy capacitive loading.

In addition, we have found it advantageous to greatly shorten the physical length of our heavily capacitively loaded antennas. More particularly, we have found it advantageous to shorten the physical length of the stem of our heavily capacitively loaded antennas to less than about ⅛ of the shortest wavelength at which the antenna is to be operated so that, even with an increase of as much as about 180 percent in the equivalent electrical length of the antenna due to the capacitive loading, the equivalent electrical length of the antenna will still be less than ¼ wavelength so that the antenna will be non-self-resonant and thus capable of being tuned over a wider range.

The antenna of the present invention is thus physically short with a large capacitive termination and thus somewhat resembles a parallel plate condenser. More specifically, the diameter of the termination is of the same order of magnitude as the length of the stem, that is less than about ⅛ of the shortest wavelength, and the area of the termination of the present antenna may be on the order of 1,000 times the cross-sectional area of the stem.

In combination with the heavily capacitively loaded antenna, the present invention provides an input circuit having a larger than normal total input resistance for the purpose of providing an improved signal-to-noise ratio. According to conventional practice, the total input resistance of the input circuit is matched to the capacitive reactance of the antenna so as to maximize the signal power transferred from the antenna to the input amplifier. By using a higher total input resistance, the input circuit of the present invention causes the capacitive reactance of the antenna to serve more effectively as a sink for the thermal noise of the input resistor and thus obtains an improved signal-to-noise ratio.

The amount of capacitive loading used according to the present invention and the results obtained differ substantially from conventional practice. For example, a small, vertical, heavily capacitively terminated dipole in accordance with the present invention was found to be able to essentially duplicate, and at certain frequencies even excel, the signal-to-noise ratio as well as absolute signal voltage level, delivered to the input terminals of the first amplification stage, when replacing a conventional 3 foot whip in a small, portable television receiver. Yet, the heavily capacitively loaded dipole antenna was only four inches high and the area of its termination was 10 square inches while its stem cross-sections were under 0.001 square inches. These physical dimensions show that antenna volume, or more precisely an antenna's volume which is linked with space, can be increased and traded against antenna height or length, without loss of effectiveness of signal extraction from space. In terms of volume, our test antenna actually exceeds the conventional whip antenna, while in terms of height it would be considered to be drastically miniaturized.

Our invention will be better understood by reference to the following detailed description and attached drawings which set forth, by way of example, the principle of the invention and the best mode contemplated of applying that principle.

IN THE DRAWINGS:

FIG. 1 shows a conventional, capacitively terminated monopole aerial, and the current distribution along its stem (prior art),

FIG. 2 the E-field distribution along a vertical quarter wave antenna and its elementary radiation capacities, causing spatial circulating current and losses,

FIG. 3 the E-field, radiation capacities and circulating currents of a heavily capacitively terminated (parallel plate condenser) antenna (monopole),

FIG. 4 the identification of radiation capacity and its participation in antenna tuning circuits, to be used for explanation of "resonant gain efficiency",

FIG. 5 a vertical parallel plate condenser antenna, being a dipole,

FIG. 6 the same, but horizontal,

FIG. 7 a transformer-coupled, vertical, tuned dipole circuit, to be used for evaluation of transformation-reflected radiation resistance and radiation capacity with new concepts, forming part of our invention,

FIG. 8 is a circuit diagram of an antenna and receiver input circuit showing equivalent circuit elements for the antenna,

FIG. 9 is a diagram of a receiver input circuit in combination with a heavily capacitively loaded antenna according to the present invention, and

FIG. 10 is a diagram of a modified receiver input circuit in combination with a heavily capacitively loaded antenna according to the present invention.

The following description of these figures, in detail, will serve best to convey the nature of our invention, and to separate it from prior art:

In FIG. 1, the vertical monopole 1, representing prior art, has a conventional, relatively small, horizontal, capacitive termination 2 which may be a disc, a rectangular plate, a wire, tube, ornament or other conveniently shaped object. This termination, or top load, raises the aerial's true height H_1 to a new, larger, effective height H_1'. The antenna is grounded through a low impedance coupling device 3 which transfers the signal between the antenna and the transmitter or receiver. The current I_a, flowing in the antenna's stem, is essentially sinusoidally distributed and, assuming that effective antenna height is below quarter wave length, substantially smaller at the stem's top than at its bottom. In the case of perfect self-resonance, the antenna's top loading capacity is chosen in such manner that effective antenna height equals quarter wave length while the dotted, extended sine curve extension 4, representing current distribution in the effectively extended serial, intersects with the stem's centre line 5 at a point 6 which determines effective antenna height and where antenna current is zero.

The increase of observed effective antenna height is brought about by re-distribution of antenna current along the antenna's stem, particularly its increase near the upper end, where radiation increase counts more than at the lower end, near ground. The general literature does not elaborate on the curious relationship which exists between the capacitive top-loading properties of an antenna, as shown in FIG. 1, and the change of its magnetic radiation properties. It simply states the result. Actually, it is the extra radiation capacity (i.e., the capacity which links the top section with space) which extracts from or causes to flow into space (reception vs. transmission) a capacitive current which creates a supplementary magnetic field around the antenna stem which, in turn, changes the current distribution, together with the initial top-sectional capacitive current, in the antenna's stem. This dual E and H field linkage is relatively unimportant if conventional moderate top or no loading is used. It acquires vital importance if heavy loading is introduced.

A heavily capacitively terminated serial of subquarter wave dimensions is essentially a highly reactive (capacitive) device which is dominated by its radiation capacity, i.e., that portion of its capacity which (contrary to ground capacity) is linked with space and the E-field existing in it. An unterminated linear antenna has widely distributed elementary space capacities which, as shown in FIG. 2, create circulating current losses which a moderately loaded antenna reduces, and which are nearly completely eliminated through heavy loading, as shown in FIG. 3. These losses shall first be explained with the help of FIG. 2.

The vertical, conventional, unloaded quarter wave length monopole 11, once more linked to a receiver or transmitter through a low impedance coupling system 12, has a physical height H_2 which, in accordance with well-established principles, is nearly equal to an actual quarter wave length for optimum performance under properly matched coupling network and transmission line impedance conditions. Current distribution along the aerial is not shown here, to avoid overcrowding. It is nearly but, as is generally known, not perfectly sinusoidal. The deviations from a true sinusoidal distribution, often looked upon as minor measuring errors or attributed to various secondary effects, are actually mainly caused by local circulating currents $i_1, i_2 \ldots i_5$ which are the result of non-linear (essentially sinusoidal) vertical E-field potential distribution parallel with the aerial, while each elementary antenna section has its own elementary radiation capacity, $c_1, c_2, \ldots c_5$ which, in conjunction with its neighbours, generates different, capacitively from the E-field extracted, voltage drops along the antenna. These varying voltage drops then combine with other voltage drops, caused by the H-field, and the result is the creation of considerable voltage differentials between neighbour sections along the aerial. Since the elementary radiation capacities in this system are not only linked with circular cross sections of space, surrounding the aerial, but are also series-connected to each other through space, loops are now available for the circulating or spatial eddy currents $i_1, i_2, \ldots i_5$, already mentioned. The effect is further enhanced by widely varying ground capacities $c_{11} \ldots c_{15}$.

When equipping the unterminated aerial, as shown in FIG. 2, with a large capacitive termination, while shortening it to prevent an undesirable increase of its effective height, as shown in FIG. 3, the effect of the previously discussed circulation losses is greatly reduced for two reasons: (a) the shortened antenna is now physically linked with a partial, and therefore more linear section 21 of the sinusoidal E-field distribution curve. Its remainder 22, being again only part of the full curve, and, in addition the naturally more linear section of it, is so linear in comparison with the full E-field curve in FIG. 2, that the generation of circulation currents between space and the antenna portion linked with it is negligible. In addition, the following reason (b) reduces circulation losses in the antenna of FIG. 3 by more than an order of magnitude. This is the simple fact that the radiation capacity C4 of the large capacitive termination 23 (antenna leaf) completely dominates the antenna's total radiation capacity, making the distributed radiation capacity ($c_1 \ldots c_4$) of its stem 24 and its associated circulation losses a second order phenomenon. Circulating currents and losses in the leaf 23 are small because the leaf is placed horizontally, i.e. in the absence of a wave tilt, within an equipotential plane of the E-field.

Another, logically independent way of analysing the performance improving capability of a parallel plate condenser aerial, such as the vertical, heavily capacitively terminated monopole in FIG. 3, is to compare its lumped radiation capacity with the lumped radiation capacity of an unterminated or, in accordance with current practices, moderately end-loaded monopole, while assuming that in either case the aerial in question is a contributing member of the passive tuning network, preceding the first amplification stage of a receiver. This assumption excludes the use of a long transmission line as well as the insertion of an inefficient (high loss) coupling transformer between the aerial and its transmission line, both being represented in FIG. 3 by box 25.

FIG. 4 shows the equivalent circuit of an essentially capacitive aerial, such as a moderately or heavily capacitively terminated monopole of sub-quarter-wavelength dimension. The aerial **31** has a lumped ground capacity **32** and a lumped radiation capacity **33,** the latter being in series with radiation resistance **34.** It also has stem inductance **35,** which is shown as being in series with tuning inductance **36.** The latter, in this example, is rounded. Additional tuning components are the also grounded tuning capacitor **37** and the incidental input ground capacity **38** of the first amplification stage **39.** Signal source, referred to ground, is the E-field, represented by generator **40.** It is in series with radiation resistance **34,** radiation capacity **33** and the aerial **31.**

Tuning frequency is determined by inductors **35** and **36** and their parallel capacities **33, 32, 37** and **38.** Resonant gain is determined by the system's Q. More important, and often not recognised, is the concept of resonant gain efficiency. It is determined by the ratio of radiation capacity **33** to the sum of all capacities. Resonant gain efficiency would be **100%** of all capacities, except radiation capacity, were zero, which is practically impossible. Standard practice, prior to our invention, has been to minimise these reasonant-gain-reducing capacities and to consider the thus obtained resonant gain efficiency (whether identified by that name or not) the practically achievable optimum.

In accordance with our invention resonant gain efficiency can, however, be substantially increased beyond this hitherto considered achievable optimum by drastically increasing radiation capacity. Such increase of the system's "signal contributing capacity", as we like to describe radiation capacity's function in an antenna and passive tuning circuitry network, raises the aforementioned ratio between radiation capacity and the remaining intentional and incidental ground capacity plus radiation capacity; it thereby increases resonant gain efficiency and, concurrently, apparent antenna efficiency.

A practical survey disclosed that over a wide frequency range, 20 kc to over 200 mc, resonant gain efficiencies range between 1, 2 or 3 percent and 20 to 30 percent, the latter values being extremely rare and usually restricted to special narrow band or special purpose applications. Heavy capacitive top or end loading of a linear aerial then emerges as an extremely powerful tool for the realisation of substantially larger resonant gain efficiencies than have, heretofore, been obtained. Our experiments have fully confirmed this concept.

Capacitive top or end loading has, in the past, been used to only a moderate extent because its main practical purpose has always been considered to be to make a linear antenna of limited physical length or elevation look taller or longer. Since theoretically, as well as practically, such increase of effective antenna height or length cannot be made to exceed approximately a 2 : 1 ratio, there never seemed to be any point in increasing top or end loading beyond a region where effective doubling, or near-doubling, of aerial height or length had been achieved. Our resonant gain efficiency concept, based on the recognition of the important role which radiation capacity plays when an effort is made to increase resonant gain efficiency significantly beyond currently accepted best values, has led us to the realisation that heavy top or end loading can offer much greater advantages in the performance of linear antennas than simply doubling their height or length.

Resonant gain, if properly applied, can control directly signal-to-noise ratio of a receiving system and improve it substantially. Poor noise figure at the input terminals of the first amplification stage can, as we have experimentally confirmed, often be strongly improved by increase of resonant gain because signal source impedance at the amplifier input terminals is seldom obtained for noise figure at these terminals, not due to lack of understanding of the need for optimisation but because it is physically impossible, for lack of suitable circuit components. Increasing signal voltage by higher resonant gain, free from amplifier noise and subject only to thermal noise, can therefore, as experimentally confirmed by us, greatly alleviate the noise figure problem and yield substantially better signal-to-noise ratios.

The foregoing analysis does not include changes of antenna radiation resistance and the corresponding thermal noise changes. Suffice it to say that radiation resistance of a top or end loaded aerial follows closely its effective height. It does not increase, and eventually even decreases, after gradually increased top or end loading reaches the effective aerial lengthening (doubling) limit. On the other hand, radiation capacity continues to increase, and it is this thermally unaffected increase with heavy loading which improves noise figure and signal-to-noise ratio so drastically, as discussed and experimentally confirmed.

A third definition (c), functional in its nature rather than mechanical, as the original two definitions of heavy capacitive loading of linear antennas, previously given, were, therefore now suggests itself, as a result of our understanding of the significance of radiation capacity and resonant gain efficiency: "A linear antenna is heavily top or end loaded, if such loading, represented by antenna leaf cross section, seen in the direction of the antenna's stem axis, is a multiple of a cross section which effectively doubles or approximately doubles antenna height; or, if radiation capacity of the antenna's capacitive termination or terminations is a multiple of the radiation capacity of an identical antenna, having however a smaller termination or terminations, sufficiently large only to double or nearly double effectively the antenna's height or length."

FIG. 5 illustrates a different execution of the invention, a vertical, heavily capacitively terminated dipole, having two stems, **41** and **42** and two large leafs **43** and **44.** Their cross sections and radiation capacities are sufficiently large to satisfy the previously given three definitions for heavy capacitive loading, either summarily or individually only. **45** is a resonant or non-resonant coupling net-work to the receiver or transmitter.

FIG. 6 is a repetition of FIG. 5, except that the dipole is horizontal rather than vertical. The heavy capacitive loading causes this dipole to be nearly omni-directional, in contrast to conventional, unterminated or moderately terminated horizontal dipoles. The reason for this omni-directionality is found in the capability of the large end leaves to link themselves either with the E or with the H fields of the passing ratio wave.

FIG. 7 is a modification and combination of FIGS. 4 and 5, showing a vertical, capacitively heavily loaded, resonated (not resonant) dipole and an alternative tuning circuit, with reference to the circuit in FIG. 4: **51**

and **52** are the two large antenna leaves (as per previous three definitions), **53** and **54** their stems. **55** is a coupling transformer which converts the phase-opposed differential signals from the two leaves into a single-ended signal by having one of its secondary terminals **56** grounded. The other terminal **57** connects the secondary to a series-resonant tank, using inductor **59** and incidental or discreet capacity **60** to ground as its main reactive tuning components. Transformer **55** can be a unity turn ratio device, a step-up or a step-down device. Since the reactance of its secondary adds itself to the reactance of inductor **58,** the former must be taken into account. The secondary reactance of a perfect transformer is the combination of stray reactance and the reflection of the primary's load reactance. Similarly resistive or loss components are combined. Reflection follows the reciprocal of the square root of turn ratio. Since radiation capacity which, in accordance with our invention, is made deliberately larger than usually found in conventional antenna systems, its square law reflection at the secondary terminals must be considered and would usually call for a stepping down rather than unity or stepping up primary/secondary turn ratio, in order to avoid unreasonably large tuning capacities and correspondingly unreasonable, small tuning inductances.

If a stepping-down primary/secondary turn ratio is chosen, resonant voltage gain can usually more than offset the voltage loss due to the stepping-down ratio, the more so since the aerial's radiation resistance, a Q-derating parameter which, with close transformer coupling, can dominate total tank losses, is reduced by the square of the turn ratio. Assuming that bandpass considerations do not dictate a voluntary yielding of maximum achievable resonant gain, the system shown in FIG. **7** is capable of completely outperforming conventional antenna and tuning circuitry systems, as experientally confirmed by us in numerous instances, including the 4 inch high television aerial, replacing a 3 foot whip, which has been previously described. The highly efficient, special coupling transformer **55,** in FIG. **7,** is a subject of a co-pending patent application.

Referring now to FIG. **8** of the drawings, there is shown a circuit diagram of a receiver input circuit in combination with an antenna **62** which is illustrated in the form of equivalent circuit components. More particularly, antenna **62** comprises an equivalent voltage source (E_s) **63** which represents the signal voltage picked up by the antenna, an equivalent capacitive reactance (X_c) **64** which represents the antenna's radiation capacitance, and an equivalent resistance (R_a) **65** which represents the antenna's radiation resistance. The antenna **62** is connected by a line **66** to an input amplifier **67.** The resistance (R_r) **68** represents the total input resistance of the input circuit as seen by the antenna **62.** That is, resistance **68** represents the equivalent resistance of the bias resistors on line **66** in combination with the internal input resistance of amplifier **67.** The equivalent voltage source (E_n) **69** in series with the resistance **68** represents the unavoidable thermal noise voltage associated with the physical resistors used in the bias network at the input of amplifer **67.**

In a physically short antenna which is heavily capacitively loaded in accordance with the present invention, the capacitive reactance X_c is large and the radiation resistance R_a can be considered to be negligibly small in comparison with the antenna's capacitive reactance X_c or the input resistance R_r of the receiver input circuit. Further, it is well known that maximum signal power is transferred from the antenna **62** to the input amplifier **67** when the input resistance R_r is matched to the antenna's impedance. That is, neglecting the antenna's radiation resistance R_a, the maximum signal power is transferred from the antenna **62** to the input amplifier **67** when the input resistance R_r is equal to the antenna's capacitive reactance X_c. More specifically, in the very low frequency (VLF) range, a heavily capacitively loaded antenna according to the present invention may have a capacitive reactance on the order of several megohms. Therefore, the input resistance R_r should also be on the order of several megohms in order to maximize the signal power transfer from the antenna **62** to the input amplifier **67** in accordance with conventional practice.

We have found, however, that the performance of the combination of a heavily capacitively loaded antenna and a receiver can be substantially improved by greatly increasing the value of the input resistance R_r. More particularly, we have found that, for a given signal voltage E_s, the signal-to-noise ratio of the antenna-input circuit combination is improved if the input resistance R_r is given a value considerably greater than the antenna's capacitive reactance X_c.

The reason for this improvement in performance is that the thermal noise E_n associated with the physical resistors in the input network of amplifier **67** is a major noise source in the antenna-input circuit combination. This thermal noise is represented by the voltage source **69** in FIG. **8.** Generally, the thermal noise voltage of a resistor is given by:

$$E_n = \sqrt{4KTBR_r} = \sqrt{K_1 R_r}$$

where K is Boltzmann's constant, T is temperature in degrees Kelvin, B is the bandwidth in cycles per second, R_r is the resistance, and K_1 is a constant equal to $\sqrt{4KTB}$. The signal voltage, V_s which appears on line **66** at the input to amplifier **67** is given by:

$$V_s = R_r/(R_r - jX_c)\, E_s$$

the noise voltage, V_n, appearing on line **66** at the input to amplifier **67** is given by:

$$V_n = X_c/(R_r - jX_c)\, E_n$$

and, therefore, the signal-to-noise ratio, S/N, is given by:

$$S/N = R_r E_s/X_c E_n = R_r E_s/(X_c K_1 \sqrt{R_r}) = (E_s \sqrt{R_r})/K_1 X_c$$

which shows that, for a given signal voltage E_s and a given antenna reactance X_c, the signal-to-noise ratio, S/N, increases as the square root of the total input resistance R_r.

By reason of its large total input resistance **68,** the circuit of FIG. **8** may be said to utilize the capacitive reactance **64** of antenna **62** as a noise sink in order to reduce the input noise at the amplifier **67.** In this way, an improved signal-to-noise ratio is obtained. Although there is a reduction in the signal power transfer from the antenna **62** to the amplifier **67,** by reason of the impedance mismatch between input resistance **68** and the antenna's capacitive reactance **64,** the signal power level can readily be boosted, if necessary, by subsequent low-noise amplifier stages. By contrast, a poor signal-to-noise ratio at the input to amplifier **67** cannot later be cured by additional amplifier stages which would serve to amplify the noise as well as the signal.

Referring now to FIG. 9 of the drawings, there is shown a circuit diagram of a specific embodiment of the combination of a low noise input circuit and a heavily capacitively terminated antenna in accordance with the present invention. The antenna **71** is connected by a lead **72** to the control (gate) electrode of the amplifier **73.** The amplifier **73** may be of a type well known to those skilled in the art, preferably having a high input resistance. For example, amplifier **73** may be a field effect transistor (FET) such as the 2N4416. Junction FET's may have input impedances on the order of 1,000 megohms while metal-oxide-silicon FET's may have input impedances on the order of 10^{15} ohms.

A network of resistors **74, 75** and **76** are connected to line **72** to prrovide the appropriate bias for the control electrode of amplifier **73** and to provide the desired high input impedance in accordance with the principle of the present invention. Resistors **74** and **75** act as a voltage divider to establish the bias level, and resistor **76** has a high value, such as, for example, 1,000 megohms, in order to provide the desired high total input impedance for the network of resistors **74, 75** and **76** and amplifier **73.**

The source electrode of amplifier **73** is connected to a resistor **77** to ground and to the control (base) electrode of a second amplifier **78** which may be a junction transistor such as the 2N706. The drain electrode of amplifier **73** is connected through a resistor **79** to an appropriate d.c. voltage source and, via capacitor **80,** to the emitter of amplifier **78.** The emitter of amplifier **78** is also connected through a resistor **81** to ground and, via coupling capacitor **82,** to the remainder of the receiver system. Specific values for the circuit components of FIG. **9** are as follows:

Resistance **74** = 100Kω
Resistance **75** = 56Kω
Resistance **76** = 1,000Mω
Resistance **77** = 10Kω
Resistance **79** = 2.2Kω
Resistance **81** = 2.2Kω
Capacitor **80** = 0.05μf

The circuit of FIG. **9** works well with an antenna capacitance of approximately 7–10 picofarads over a frequency range of 10Khz up.

Referring now to FIG. **10** of the drawings, there is shown a circuit diagram of a modified form of input circuit in combination with a heavily capacitively loaded antenna in accordance with the present invention. This circuit is designed for use in the broadcast band and the FM band while rejecting atmospheric noise suuch as automobile ignition noise which is largely above 1.6 Mhz and below 88 Mhz. The antenna **84** is connected through a resistor **85** to the gate electrode of the amplifier **86.** Resistors **87** and **88** act as a voltage divider to provide an appropriate bias level and also have high values to provide the desired high total input impedance in accordance with the present invention. As in the circuit of FIG. **9,** amplifier **86** may be a conventional high impedance device, such as, for example, the 2N4416 field effect transistor. Resistor **85** acts as a filter directly on the input signal to remove atmospheric noise, such as automobile ignition noise, before it enters the amplifier **86.**

The drain of amplifier **86** is connected through a resistor **89** to an appropriate d.c. voltage source, and, via coupling capacitor **90,** to the emitter of the second amplifier **91** which may be a junction transistor such as for example the 2N706 transistor. The source of amplifier **86** is connected through resistor **92** to ground and to the base of amplifier **91.** In addition, the antenna **84** is coupled directly through capacitor **93** to the emitter of amplifier **91** in order to provide FM reception. The emitter of amplifier **91** is connected through a resistor **94** to ground and, via coupling capacitor **95** to the remainder of the receiver system. Specific values for the circuit components of FIG. **10** are as follows:

Resistor **85** = 15Kω
Resistor **87** = 22Mω
Resistor **88** = 10Mω
Resistor **89** = 3.3Kω
Resistor **92** = 100Kω
Resistor **94** = 390ω
Capacitor **90** = 0.05μf
Capacitor **93** = 5pf

It will be appreciated that, while for purpose of illustration, specific values have been given for the components of the specific circuits shown in FIGS. **9** and **10,** the principles of the present invention are not limited to such circuit values or circuit designs, but embrace a wide range of circuit designs and component values depending upon the parameters within which the antenna-input circuit combination is intended to operate.

Although, in accordance with the principles of the present invention, the signal-to-noise ratio at the input amplifier can be improved generally by providing the input amplifier with a bias resistance network having a high resistance value as seen from the antenna, it will be appreciated that it is the total input resistance as seen from the antenna that determines the signal-to-noise ratio. Therefore, inasmuch as the inherent input resistance of the amplifying device is connected in parallel with the bias resistance network, it will be seen that total input resistance is limited by the inherent resistance of the amplifying device and that diminishing advantages are obtained by increasing the values of the bias resistors beyond the amplifier's inherent resistance. Further, as a practical matter, the amplifying device itself will have an inherent, and usually rather low noise figure, so that no practical advantage is gained by reducing the effect of the thermal noise of the input resistors below the inherent noise figure of the amplifying device.

It will further be apparent that the total input resistance of the input circuit as seen from the antenna should be increased by increasing the values of the physical resistors rather than by means of a feedback arrangement. If feedback is used to increase the apparent total input resistance, both noise and signal will be amplified so that no advantage is obtained.

The scope of our invention is not limited to vertical monopoles and vertical as well as horizontal dipoles. It obviously includes horizontal monopoles and any existing or conceivable antenna forms which can be heavily, capacitively loaded. Neither are passive tuning circuits which are advantageously used with our antenna limited to the two examples shown in FIGS. **4** and **7.**

Our invention can best be summarized by stating that we are using capacitive loading of linear antennas in excess of a degree where maximum effective lengthening or increase of aerial height is obtained, that such excessive loading has heretofore been considered meaningless, and that we have made it meaningful by taking into consideration the advantages of additional radiation capacity and the desirable influence which it has

upon resonant gain, signal-to-noise ratio and niose figure. In recognizing these previously not entirely understood relationships we have created a new approach to antenna concepts and designs, which includes the often desirable aspect of antenna miniaturization.

What is claimed is:

1. Radio receiver apparatus comprising:

an antenna comprising a stem, and a termination mounted on an end of said stem, the length of said stem being less than one eighth of the shortest wavelength at which the antenna is to be operated, and the maximum dimension of said termination being less than one eighth of the shortest wavelength at which the antenna is to be operated, the radiation capacity of said termination being at least one and one-half times that which would increase the effective electrical length of said antenna to 180 percent of the physical length of said stem; and

an input circuit comprising an amplifying device having a high inherent input impedance, said amplifying device having its input connected to said stem of said antenna and a bias resistance network connected to said input of said amplifying device to provide an appropriate bias level for said input of said amplifying device, the total resistance of said bias resistance network being less than the inherent input resistance of said amplifying device, the total input resistance of the combination of said amplifying device, and said bias resistance network being at least an order of magnitude greater than the capacitive reactance of said antenna whereby said capacitive reactance of said antenna acts as a sink for the inherent noise of said amplifying device.

2. The radio receiver apparatus of claim **1** wherein the total input resistance of the combination of said amplifying device and said bias resistance network is at least two orders of magnitude greater than the capacitive reactance of said antenna.

3. The radio receiver apparatus of claim **1** wherein said amplifying device comprises a field effect transistor.

4. The radio receiver apparatus of claim **1** further comprising a resistor in series between said stem of said antenna and said input of said amplifying device.

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