United States Patent

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[54] **NEGATIVE RESISTANCE ANTENNA AMPLIFIER ARRANGEMENT**
11 Claims, 4 Drawing Figs.

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[50] Field of Search .... 179/170 T, 170 HF, 170 U; 325/373, 374, 375, 384, 318, 365; 330/4.5, 4.9, 61 A; 331/132, 3, 4

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ABSTRACT: An oscillator circuit is kept at a predetermined stable-operating point below the onset of oscillations by high-resistance feedback in the emitter circuit. The tuned circuit of the oscillator has one winding of a transformer whose second winding is connected either in series between the antenna and the receiver, or in parallel with the receiver. The impedance seen looking into the second winding is a negative resistance.

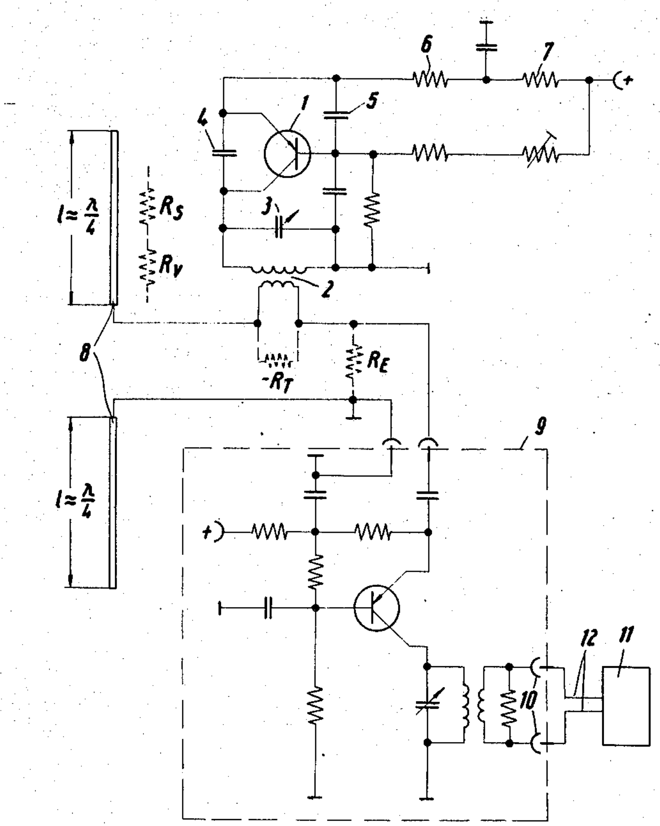

Fig.1

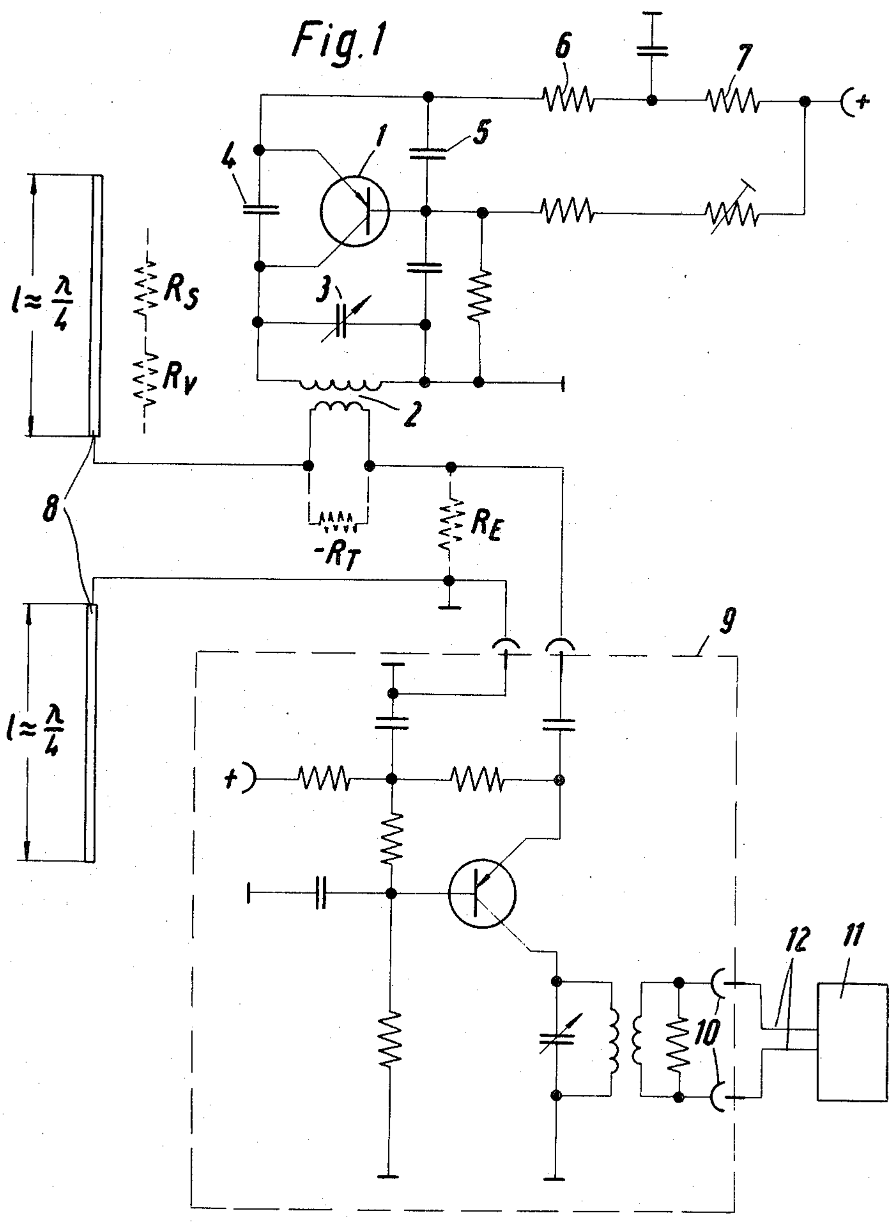

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Fig. 2

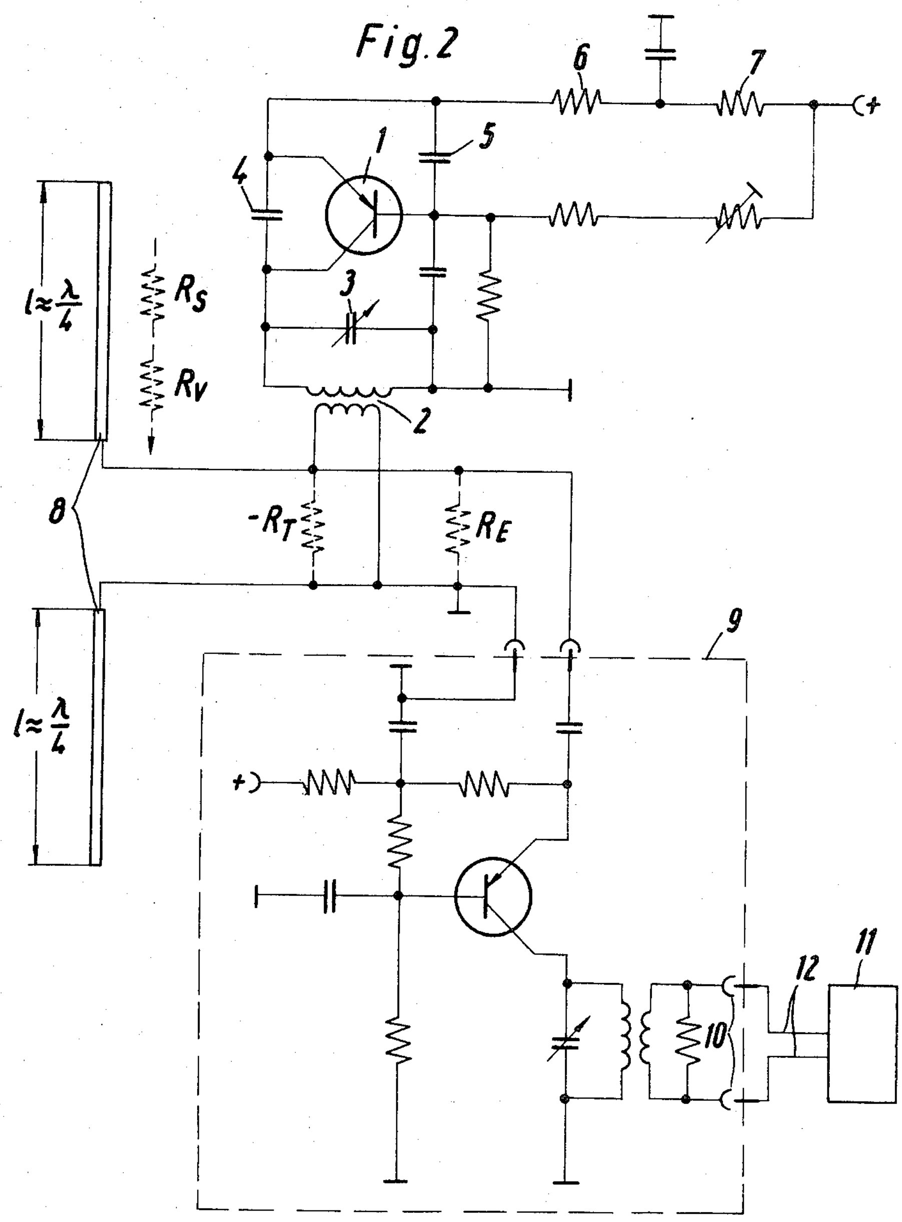

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Fig. 3

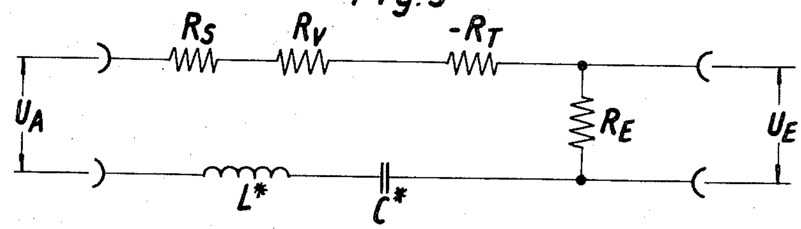
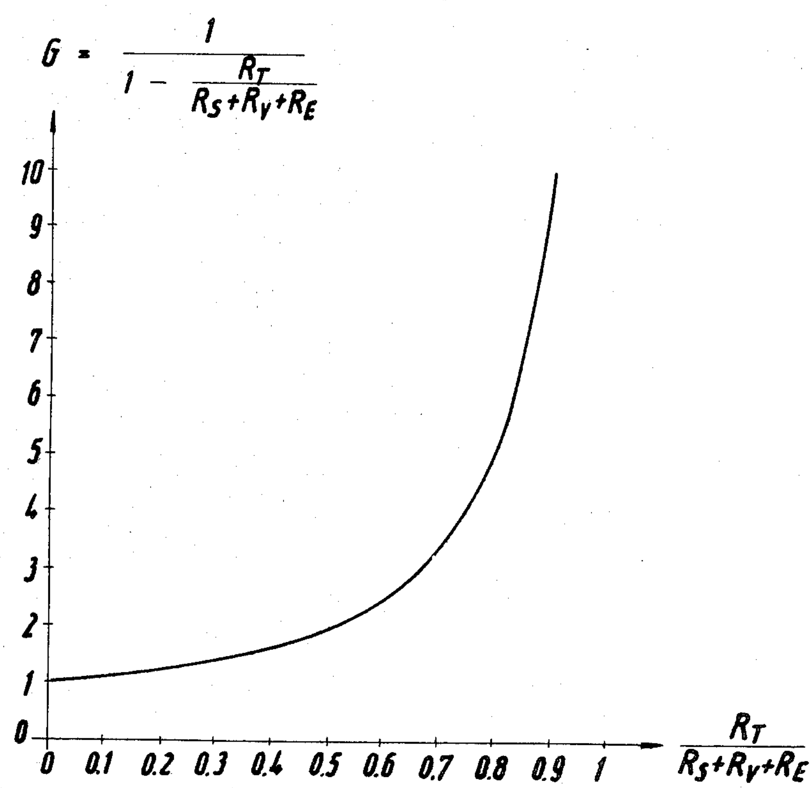


Fig. 4



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NEGATIVE RESISTANCE ANTENNA AMPLIFIER ARRANGEMENT

BACKGROUND OF THE INVENTION

This invention relates to antenna amplifiers. In particular, it relates to antenna amplifiers wherein an equivalent negative resistance is connected in series with said antenna by coupling an amplifier element in an oscillator-type circuit to said antenna.

The basic advantage of an antenna amplifier which presents an equivalent negative resistance and is connected in a two terminal configuration between the antenna and the receiver as compared to the conventional antenna amplifiers connected in a four-terminal connection is, that the antenna current and therefore the equivalent antenna absorption surface are increased, thus greatly increasing the signal-to-noise ratio. The negative resistance increases the figure of merit (Q) of the circuit and thus decreases the bandwidth of the antenna. The only limitation on the advantage to be gained by the arrangement set forth in the present invention is that a minimum bandwidth is prescribed for each transmission channel. However, it will be demonstrated below that an increase in gain of 29 db. for a frequency of 480 MHz. and 39 db. in the UHF region may be obtained even considering the regulations for minimum bandwidth mentioned above. Thus the increase in antenna gain by an antenna amplifier in accordance with the present invention is of great value when the fact is considered that an additional gain of 20 db. is sufficient to solve the reception problem in most fringe areas.

Antenna amplifiers using a tunnel diode as a negative resistance are known. However, the stability problems associated with these circuits are such that they cannot be used in a series or two terminal connection as is the amplifier of the present invention.

SUMMARY OF THE INVENTION

It is an object of this invention to furnish a negative resistance antenna amplifier which is sufficiently stable for use in a series connection.

This invention comprises an antenna receiving arrangement comprising antenna means and receiver means and circuit means series connected between said antenna means and said receiver means. Said circuit means are designed to provide an equivalent negative resistance between said antenna means and said receiver means, thus increasing the gain of the arrangement.

The circuit means for creating said above-mentioned equivalent negative resistance comprise an amplifier element and feedback means interconnected with said amplifier element in such a manner that the operating point of said amplifier element is kept just below onset of oscillations. These negative feedback means may for example comprise a very high resistance in the emitter circuit of the amplifier element. The circuit means also comprise coupling means, which may for example be a tank circuit, for coupling the interconnected amplifier element and its feedback means serially between the antenna means and the receiver means.

The circuit of the amplifier element may be further stabilized by providing high-frequency feedback by means of a voltage divider, said high-frequency feedback being designed to keep the operating point of the amplifier element in a region of relatively small variation in amplification.

Phase shift in the feedback circuit, and thus a lack of symmetry relative to the center frequency of the receiving arrangement is avoided by causing the voltage divider used for the high-frequency feedback to have a low leakage resistance compared to the input resistance of the control electrode of the amplifier element which is in parallel with said leadage resistance.

Capacitive diodes may be used as tuning elements. In a particularly advantageous embodiment of the present invention, the tuning elements and the operating point of the amplifier element are chosen in such a combination that the feedback remains the same over the whole tuning range.

A further improvement in stability of the receiving arrangement may be achieved by inserting a conventional antenna amplifier in a four pole arrangement between the antenna with the series connected antenna amplifier with negative resistance on the one hand, the the receiver means on the other hand. The distance between the antenna and said second, four-pole amplifier should be small relative to the wavelength of the receiving channel or alternatively a multiple of half of said wave length, so that a definite terminal resistance is formed at the input of this four-terminal network for the antenna circuit.

The output of the second antenna amplifier is matched to the wave impedance of the high-frequency cable leading to the receiver input in the conventional fashion. This matching eliminates reflections between the second amplifier and the receiver input. Furthermore, the second amplifier serves as a decoupling element and thus prevents the high-frequency cable and the impedance of the receiver from being reflected into the antenna circuit. Thus any receiver may be connected to the output of the second amplifier without requiring a change in the feedback arrangement of the series connected antenna amplifier.

The high stability achieved by the above means permit the series connection of the new antenna amplifier. The coupling elements coupling the amplifier element with its associated feedback means to the antenna and the receiver means may for example comprise tank circuits.

Conventional high-pass filters may be used for protecting the amplifier elements against overvoltages caused by lightning.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a first embodiment of a circuit in accordance with the present invention;

FIG. 2 is a second embodiment of a circuit in accordance with the present invention;

FIG. 3 is an equivalent circuit for the circuits shown in FIGS. 1 and 2; and

FIG. 4 is a plot of antenna gain as a function of the resistance elements in said circuits.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred embodiment of the present invention will now be discussed with reference to FIG. 1. The circuit of FIG. 1 has antenna means denoted by **8**, receiver means denoted by reference numerals **11** and **12**, where **12** denotes the high-frequency cable leading into the receiver proper which is denoted by **11**, a four-terminal amplifier circuit denoted by reference numeral **9**, and two-terminal circuit means which comprise the remainder of the circuitry shown in FIG. 1 and will be discussed in detail below.

The transistor denoted by reference numeral **1** serves as an amplifier element. This transistor **1** together with the primary winding of transformer **2** which furnishes an inductivity and the tuning capacitor **3**, in addition to the capacitive voltage divider comprising capacitors **4** and **5**, form an oscillator circuit which is maintained below the onset of oscillation. The high-stability requirements of the arrangement are satisfied by the high-resistance value of the emitter resistors **6** and **7**, as well as by the value chosen for the voltage-divider means comprising capacitors **4** and **5**. The reasonant frequency of the oscillator circuit corresponds to the carrier frequency of the complete receiving channel, thus causing the circuit means embodied in this so-called oscillator circuit to present an equivalent negative resistance of value $-R_T$ at the secondary winding of transformer 2. As shown in FIG. 1, this negative resistance is connected in series to the radiation resistance R_S and the resistance R_V representing the antenna losses on the one hand, and to a conventional four-terminal amplifier circuit, circuit **9**, on the other hand. Under these conditions, the equivalent circuit for the arrangement is that shown in FIG. **3** which will be used as the basis for the theory to be presented below. A half-wave dipole is assumed to be the embodiment of antenna **8**. For the chosen coupling at peak current, this may be considered as a series resonant circuit for the carrier frequency in the received signal.

Other antennas as for example multiple dipole antennas, dipole with reflecting mirrors in half-wave or full wave configurations, or short dipoles ($1<<\lambda/4$) may be substituted with whatever additional matching elements may then be required.

The only difference between the circuit shown in FIG. **2** and the circuit shown in FIG. **1** is that the negative resistance $-R_T$ is in parallel to the input resistance R_E for FIG. **2**, while it is in series with said resistance in FIG. **1**. The winding ratio of transformer **2** must in general have a different value for the circuit configuration shown in FIG. **2** as that for the circuit configuration shown in FIG. **1**. However, either circuit will lead to the same antenna gain for a proper choice of components.

In accordance with the present invention, four-terminal amplifier circuit, **9**, decouples the antenna circuit comprising resistors $R_S+R_V+R_E-R_T$ from the high-frequency cable and the receiver input so that a perfect match between the amplifier output **10** having a positive resistance to the wave resistance of the high-frequency cable **12** leading to the input receiver **11** is achieved. Any mismatch at the receiver input does not cause any back coupling to the antenna circuit and thus cannot influence the stability of said antenna circuit.

An analysis of the negative-resistance circuit and the antenna arrangement as a whole now follows.

Let it be assumed that the received carrier frequency is denoted by f. A series resonant circuit resulting from a half-wave dipole antenna is assumed. It is assumed that this antenna has radiation resistance R_S, a resistance R_V representing the antenna losses. The input resistance of the receiver means is denoted by R_E, while the equivalent negative series resistance coupled into the circuit in a two-terminal arrangement is denoted by $-R_T$. Thus the equivalent circuit of FIG. **3** is derived. Below onset of oscillations, the magnitude of R_T must be less than $R_S+R_V+R_E$. This results in an efficiency:

$$\eta=R_E/(R_S+R_V+R_E-R_T)$$

It will be noted that this is greater than 1 when R_T is greater than R_S+R_V.

Let the gain G of the antenna amplifier be defined as the ratio of the efficiency of $\eta(R_T)$ for any given negative resistance $-R_T$ to the efficiency $\eta(R_T)$ for $R_T=0$.

Then the following equation results:

$$G=\frac{1}{1-\frac{R_T}{R_S+R_V+R_E}}$$

The curve denoting this equation is shown in FIG. **4**.

For a $\lambda/2$) of dipole of length 2H and radius r_o, the following equations result:

a. the inductivity L:

$$L=(\mu_0/2\pi)\cdot \ln(2H/r_o) \text{ per kilometer}$$

b. the capacitance C:

$$C=\frac{2\pi\epsilon_0}{\ln\frac{2H}{r_o}} \text{ per kilometer}$$

c. the wave impedance Z:

$$Z=\sqrt{\frac{L}{C}}=\frac{Z_0}{2\pi}\cdot\ln\frac{2H}{r_o}Z_0=\sqrt{\frac{\mu_0}{\epsilon_0}}=377\Omega$$

$$Z=60\cdot \ln(2H/r_o)\Omega$$

d. the equivalent inductivity L*:

$$L^*=L\cdot 2/\pi\cdot H; H=\lambda/4$$

e. the equivalent capacitance C*:

$$C^*=C\cdot 2/\pi\cdot H;\ H=\lambda/4$$

f. the figure of merit of Q of the antenna then is:

$$Q=\frac{Z}{R_S+R_V+R_E-R_T}=\frac{60\cdot\ln\frac{2H}{r_0}}{R_S+R_V+R_E-R_T}$$

g. If the value Q_0 for the figure of merit without an antenna negative resistance amplifier ($R_T=0$) and the gain G as defined above are introduced into this expression for the figure of merit Q, the following results are obtained:

$$Q_0=\frac{60\cdot\ln\frac{2H}{r_o}}{R_S+R_V+R_E}$$

$$Q=G\cdot Q_0=\frac{Q_0}{1-\frac{R_T}{R_0+R_V+R_E}}$$

h. For a $\lambda/2$ dipole having a reflector R_S+R_V may be assumed to be 60Ω. Furthermore R_E is also 60Ω.

For these values:

$$Q=\frac{60\cdot\ln\frac{2H}{r_o}}{120-R_T}$$

i. For $R_T=0$, that is without the two terminal negative resistance amplifier of the present invention:

$$Q_0=0.5\cdot \ln(2H/r_o)$$

j. If now $f_1=480$ MHz., $2H=0.9\cdot 62=56$ cm., and $r_o=0.5$ cm.:

$$Q_{01}=0.5\cdot \ln 112=0.5\cdot 4.72=2.35$$

k. For $f_2=90$ MHz., $2H=0.95\cdot 333=317$ cm. $r_o=0.6$ cm:

$$Q_{02}=0.5\cdot \ln 528=0.5\cdot 6.27=3.13$$

l. For $f_1=480$ MHz., and a bandwidth $\Delta f_1=7$ MHz. the required figure of merit:

$$Q_1=f_1/\Delta f_1=480/7=68.6$$

m. The maximum resulting gain then is:

$$G_{max}^{(1)}=Q_1/Q_{01}=68.6/2.36=29.1=29.2 \text{ db.}$$

n. For $f_2=90$ MHz., and a bandwidth $\Delta f_2=0.3$ MHz. the following figure of merit results:

$$Q_2=f_2/\Delta f_2=90/0.3=300$$

o. This results in a maximum gain of:

$$G_{max}^{(2)}=Q_2/Q_{02}=300/3.1395.8=39.8 \text{ db.}$$

p. The above-mentioned gains are theoretically obtainable if the optimal value of R_T is used. If these values are denoted $-R_T^{(1)}$ and $-R_T^{(2)}$, the respective values may be computed as follows:

from:

$$G_{max}=\frac{1}{1-\frac{R_T}{R_S+R_V+R_E}}$$

$$R_T^{(1)}=(R_S+R_V+R_E)\cdot\left(1-\frac{2}{G_{max}^{(1)}}\right)=120\left(1-\frac{1}{29.1}\right)=115.88$$

$$R_T^{(2)}=120\left(1-\frac{1}{95.8}\right)=118.75$$

q. The effective surface of the antenna having a height H, a wave impedance $Z_0(=377\Omega)$, resistances R_S, R_V, R_E, and $-R_T$ in the presence of the receiver may be computed as follows:

$$F_a=\frac{H^2\cdot Z_0}{R_S+R_V+R_E-R_T}=\frac{H^2\cdot Z_0}{(R_S+R_V+R_E)}\cdot\frac{1}{1-\frac{R_T}{R_S+R_V+R_E}}$$

r. Since the maximum gain equals:

$$G_{max}=\frac{1}{1-\frac{R_T}{R_S+R_V+R_E}}$$

both the effective surface area F_a of the antenna as well as the figure of merit Q are proportional to the maximum gain.

Thus it will be seen that the effective absorption surface of the antenna, the gain G, and the figure of merit all are considerably increased because of the effective negative resistance $-R_T$ introduced by the two-terminal amplifier of the present invention.

Physically this increase in the effective absorption surface of the antenna may be explained as follows. For a constant antenna voltage determined by the product of the transmitted field strength and the effective antenna height, the negative resistance of the antenna amplifier of the present invention results in an increase in antenna current corresponding to the above-defined gain. Thus the field established in the vicinity of the receiving antenna is increased correspondingly, thus weakening the transmitted field.

The power required for establishing the receiving antenna field is furnished by the negative resistance. This intercoupling of the amplifier of the present invention with the antenna field is the basic assumption underlying the generation of a true gain as compared with conventional antenna amplifiers.

Thus with conventional antenna amplifiers having a $R_T=0$, an increase in the effective absorption surface area of the antenna may only be obtained by the use of multiple dipole antennas or dipoles having reflectors. However, with use of a negative-resistance amplifier as proposed by the present invention, it is possible to effectively increase the surface area of the antenna and thus the gain of the receiving system electrically, without requiring additional antennas. Of course the arrangement according to the present invention may also be used to increase the gain of the multiple dipole arrangement, or dipoles with reflectors which should then have an arrangement which has as broad a bandwidth as possible so that the phase characteristic of the antenna impedance within the transmission channel is relatively flat and the figure of merit Q_0 without amplifier ($R_T=0$) is low, that is that the maximum gain obtainable by the antenna amplifier of the present invention is as great as possible.

In practice, the obtainable gains G depend first on the stability of the circuit means used to generate the equivalent negative resistance and further on the minimum bandwidth required.

While the invention has been illustrated and described as embodied in a negative resistance amplifier using a transistor, it is not intended to be limited to the details shown, since various modifications, structural and circuit changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended

1. Receiving arrangement, comprising, in combination, antenna means; a negative-resistance circuit means connected to said antenna means, said negative-resistance circuit means comprising oscillator circuit means having an amplifier element, said amplifier element having a first and second output electrode and a control electrode; high-resistance passive feedback means connected to said first output electrode for maintaining the operating point of said amplifier element at a predetermined stable point below onset of oscillations; and high-frequency voltage divider means connected to said amplifier element for furnishing additional feedback in such a manner that the operating point of said amplifier element lies in a region of relatively small changes in amplification; and receiver means connected to said negative-resistance circuit means.

2. An antenna arrangement as set forth in claim 1, further comprising four-terminal amplifier circuit means having a pair of input terminals connected to said interconnected antenna and negative-resistance circuit means, said four-terminal amplifier circuit means further having a pair of output terminals; and receiver means connected to said pair of output terminals of said four-terminal amplifier circuit means.

3. An antenna arrangement as set forth in claim 1, further comprising receiver means connected to said interconnected antenna means and negative-resistance circuit means.

4. Antenna arrangement as set forth in claim 3 wherein said circuit means is connected in series between said antenna means and said receiver means.

5. Antenna arrangement as set forth in claim 3 wherein said antenna means, said negative-resistance circuit means and said receiver means are connected in parallel to each other.

6. Antenna arrangement as set forth in claim 1 wherein said voltage-divider means comprise a first and second capacitor, each of said capacitor having a leakage resistance, the value of said leakage resistance in parallel to said control electrode of said amplifier element being small compared to the input impedance of said control electrode.

7. An antenna arrangement as set forth in claim 1, wherein said amplifier element is a transistor and wherein said first output electrode is the emitter of said transistor.

8. Receiving arrangement, comprising, in combination, antenna means; a negative-resistance circuit means connected to said antenna means, said negative-resistance circuit means comprising oscillator circuit means having an amplifier element, said amplifier element having a first and second output electrode and a control electrode; high-resistance feedback means connected to said first output electrode for maintaining the operating point of said amplifier element at a predetermined stable point below onset of oscillations, said oscillator circuit further comprising tuning means for the remote tuning thereof and receiver means connected to said negative-resistance circuit means.

9. An antenna arrangement as set forth in claim 8, wherein said oscillator circuit further comprises transformer means having a first winding connected in parallel with said tuning means and a second winding, inductively coupled to said first winding, connected to said antenna means and said receiver means.

10. Antenna arrangement as set forth in claim 8 wherein said tuning means comprise capacitive tuning means.

11. Antenna arrangement as set forth in claim 10 wherein said capacitive tuning means comprise capacitive diodes.

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