

Feb. 24, 1942.

N. M. RUST ET AL

2,274,347

NEGATIVE RESISTANCE CIRCUIT ARRANGEMENT

Filed April 10, 1939

3 Sheets-Sheet 1

Fig. 1

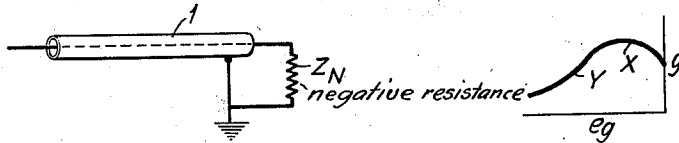


Fig. 3

Fig. 2

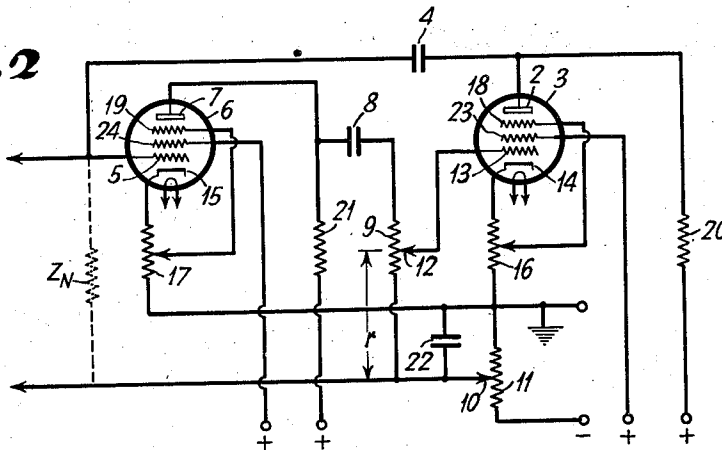


Fig. 4

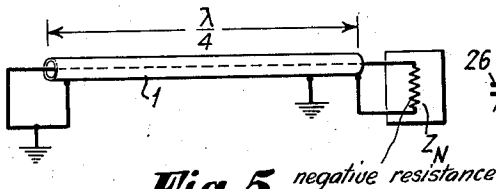


Fig. 5

negative resistance

Fig. 7

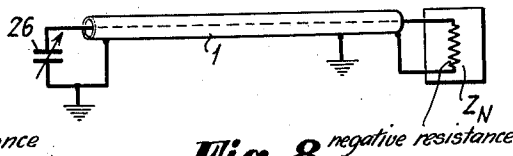


Fig. 8

negative resistance

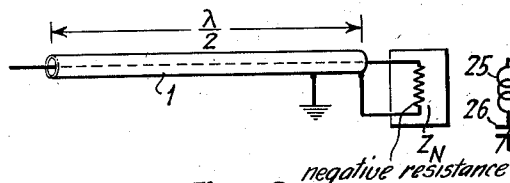
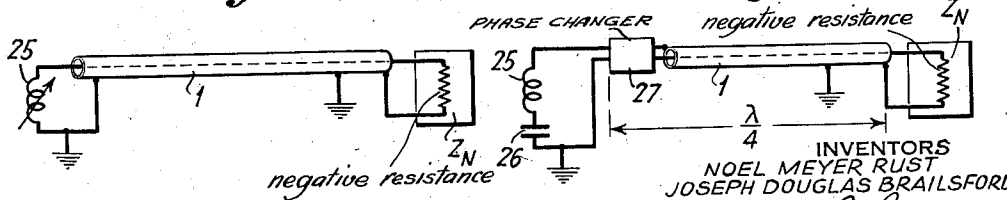


Fig. 6

negative resistance

Fig. 9

negative resistance



INVENTORS
NOEL MEYER RUST
JOSEPH DOUGLAS BRAILSFORD
BY *H.S. Snover*
ATTORNEY

Feb. 24, 1942.

N. M. RUST ET AL

2,274,347

NEGATIVE RESISTANCE CIRCUIT ARRANGEMENT

Filed April 10, 1939

3 Sheets-Sheet 2

Fig. 10

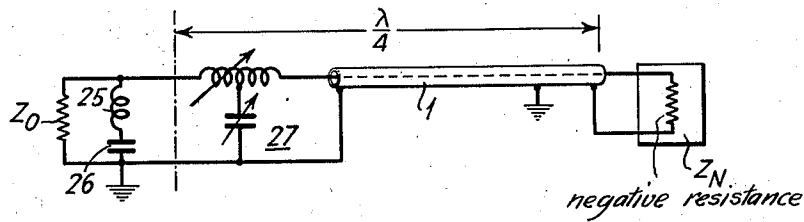


Fig. 11

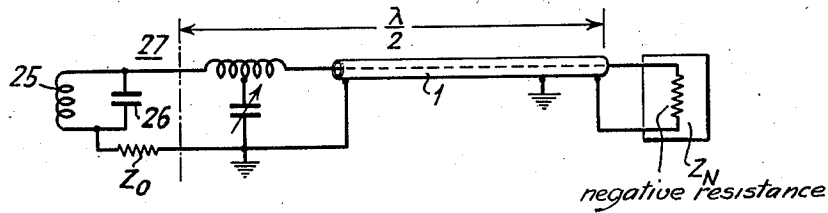


Fig. 12

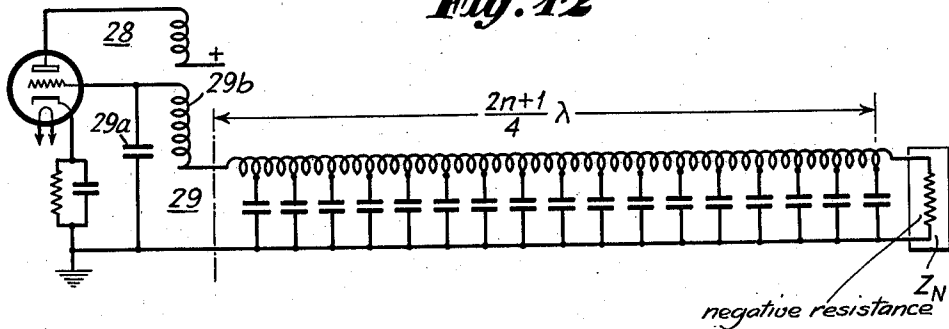
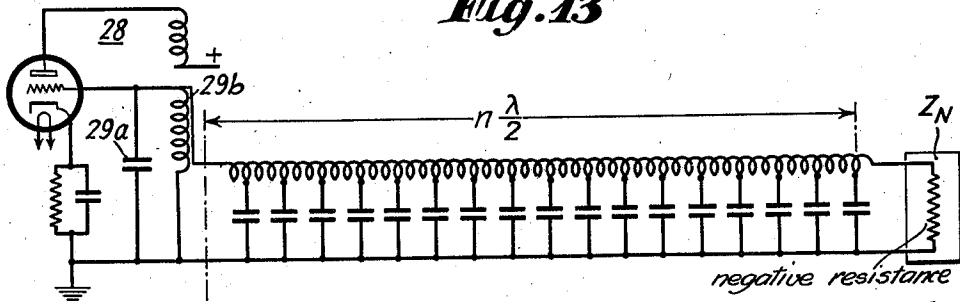


Fig. 13



INVENTORS
NOEL MEYER RUST
JOSEPH DOUGLAS BRAILSFORD
BY *H.S. Snover*
ATTORNEY

Feb. 24, 1942.

N. M. RUST ET AL

2,274,347

NEGATIVE RESISTANCE CIRCUIT ARRANGEMENT

Filed April 10, 1939

3 Sheets-Sheet 3

Fig. 14

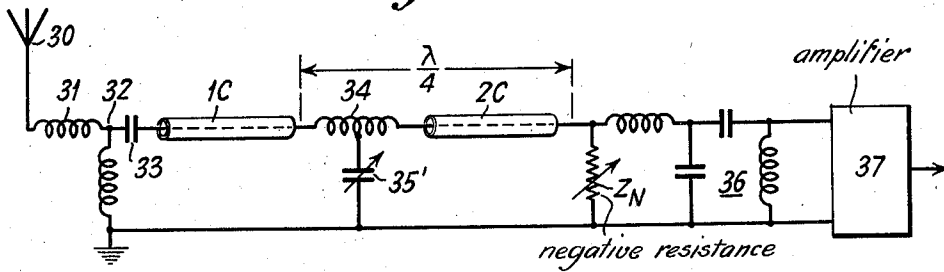


Fig. 15

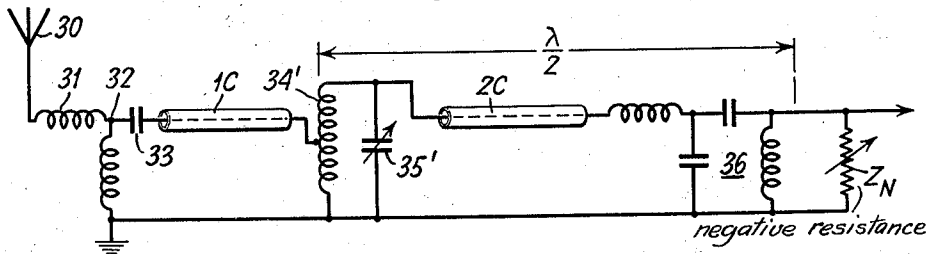


Fig. 16

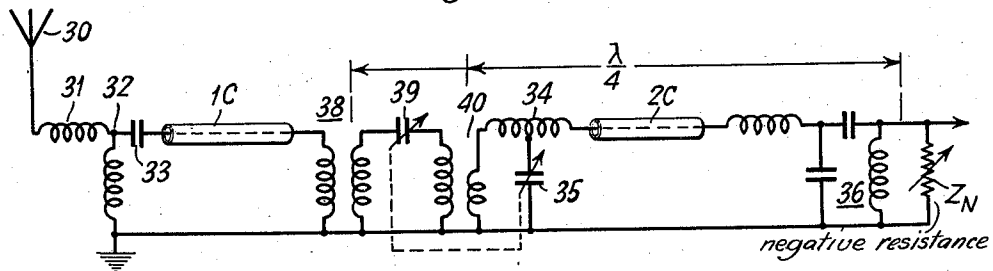
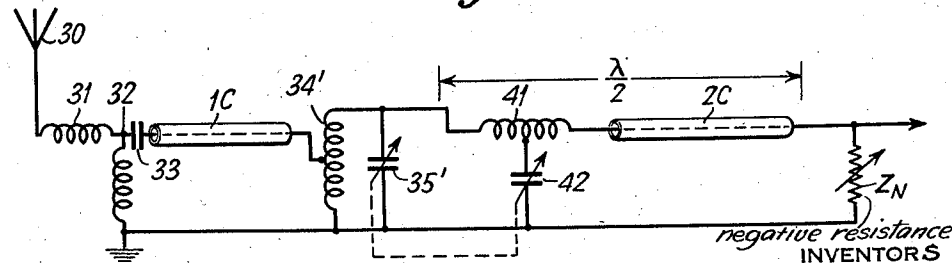


Fig. 17



INVENTORS
NOEL MEYER RUST
JOSEPH DOUGLAS BRAILSFORD
BY *H. S. Grover*
ATTORNEY

UNITED STATES PATENT OFFICE

2,274,347

NEGATIVE RESISTANCE CIRCUIT
ARRANGEMENT

Noël Meyer Rust, Chelmsford, and Joseph Douglas Brailsford, London, England, assignors to Radio Corporation of America, a corporation of Delaware

Application April 10, 1939, Serial No. 267,062
In Great Britain April 14, 1938

10 Claims. (Cl. 250—36)

This invention relates to negative resistance circuit arrangements. Although the said invention is of wide application its main applications are to electrical oscillation generators, reaction circuit arrangements and oscillator stabilising circuits.

According to this invention in its broadest aspect a negative resistance circuit arrangement comprises in combination a line, which may be an actual cable or an artificial line, and a negative resistance which is connected to act as a termination to said line.

The invention is illustrated in and further explained in connection with the accompanying drawings wherein Figure 1 shows an application of the present invention; Figure 2 shows a circuit organization for obtaining negative impedance in accordance with the present invention; Figure 3 is a characteristic curve of the operation of the circuit of Figure 2; Figures 4 and 5 illustrate oscillator circuits utilizing the negative impedance circuit of the present invention; Figures 6 to 11 and 14 to 17 illustrate applications of the present invention to remote tuning of radio receivers while Figures 12 and 13 illustrate the application of the present invention to long line controlled oscillators.

In order that the invention may be the better understood, the general basic underlying theory will first be briefly described. In any transmission line system the correct voltage impedance or admittance at any given point may be defined in terms of the image or characteristic impedances of the elements of the system and their image transfer constants or "line angles" (see Kenelly's text book "Electric lines and nets"). The line angle is a hyperbolic angle with a real part defining attenuation and an unreal part defining phase change. In accordance with the technique adopted in the text books referred to, reflection actions due to "mismatches" at junctions in the transmission system are defined in terms of another hyperbolic angle which may be termed the "reflection angle." In general, in setting out line angles and characteristic impedances of the elements another quantity termed a "position angle" is derived by calculating from one end of the system, summing up the reflection angles, defining the reflection effects at the terminal load and at junctions in the system, and the line angles of the elements progressively. The effect at any part of the system of an alteration in the terminal load can thus be assessed. An alteration in termination necessarily produces some effect right through the

system although, in some circumstances, the effect may be very small.

If a line of characteristic impedance Z_0 is terminated by an impedance (real or complex) Z the reflection angle θR is given by

$$\tanh \theta R = \frac{Z}{Z_0}$$

If Z is real then $\tanh \theta R$ and θR are also real and the effect of terminating the line by Z is to increase the attenuation terms of all the position angles all along the system. If Z is wholly unreal its use as a termination will cause the reflection angle to express a phase change which may be either positive or negative. If Z is complex θR will be complex and the effect of the termination will manifest itself both in attenuation and phase change.

Now if Z be negative and real, the attenuation term added in with the reflection angle will also be negative and real and, in dependence upon the value of the negative resistance in relation to the characteristic impedance of the element it "loads," the negative attenuation reflection factor may be made less than, equal to, or greater than the positive attenuation term of the line angle of the section concerned, the losses of the section being, in any case, reduced. If Z be complex with the real component of negative sign the resultant reflection angle will reduce the attenuation factor of the total position angle of the system, the unreal component of course producing a line lengthening or shortening effect as defined by a change of the phase factor or unreal part of the total position angle. If the negative term is quantitatively greater than the positive term the section, taken by itself with the terminating load, will oscillate. If the section considered is joined to another, a resistance reducing effect will be carried through to the said other section . . . and so on, through the system. The system as a whole will oscillate if the total position angle, as made up by the negative term introduced by the negative resistance termination, is at least equal to the positive attenuation terms due to losses and reflections at junctions. The relation

$$\tanh \theta R = \frac{Z}{Z_0}$$

still holds quantitatively when Z is negative. Referring now to Figure 1 consider the case of a line l—e. g. a concentric cable as shown—of characteristic impedance $Z_0=100$ and having a line angle

$$\theta = 0.05 + j^{1.0}$$

i. e. having an attenuation constant of 0.05 neper and a phase constant of one quadrant or

$$\frac{\pi}{2}$$

radians—in other words, a quarter wave line. Now terminate this line at the far end with a negative resistance Z_N which will introduce to the system a reflection angle θ_R where $\tanh$

$$\theta_R = \frac{Z_N}{Z_0}$$

the attenuation term of this angle being negative. The total position angle at the near end will therefore be $\theta + \theta_R$. Then if Z be the impedance looking in at the open end of the line, its value, for various values of Z_N is as given in the following table:

Z_N	$\tanh \frac{Z_N}{Z_0}$	θ_R	$\theta + \theta_R$	$\tanh (\theta + \theta_R)$	$Z = Z_0 \tanh (\theta + \theta_R)$
Infinity	Infinity	$0 + j1$	$0.05 + j2.0$	0.05	5
-10,000	-100	$-0.01 + j1$	$0.04 + j2.0$	0.04	4
-2,500	-25	$-0.04 + j1$	$0.01 + j2.0$	0.01	1
-2,000	-20	$-0.05 + j1$	$0 + j2.0$	0	0
-1,500	-15	$-0.0667 + j1$	$-0.067 + j2.0$	-0.067	-1.67

Thus, taking the last horizontal line of the table it would depend upon how the cable was connected whether or not it would oscillate; with 2 ohms connected across it, it would not oscillate, with 1.65 ohms across it, it would oscillate feebly and the oscillations would become more and more free with decrease in the resistance connected across it. If a second system were connected on the open end of the cable, then, if Z_N were made less than 2,000 ohms quantitatively a negative attenuation effect would be carried through and the system as a whole would oscillate if this exceeded, quantitatively, the positive attenuation defined by the rest of the circuit.

A negative resistance for use in carrying out this invention may take any of a variety of different forms but, preferably, comprises a two-pentode circuit connected as shown in Figure 2. The anode 2 of the second pentode 3 is capacity coupled by a condenser 4 to the first grid 5 of the first pentode 6 and the anode 7 of said pentode 6 is connected through a condenser 8 and a resistance 9, in series in the order stated, to an adjustable tap 10 on a second resistance 11 one end of which is earthed, and the other end of which is connected to a suitable source (not shown) of negative bias potential. An adjustable tap 12 on the resistance 9 is connected to the first grid 13 of the pentode 3 so that, in effect, the anodes and first grids of the two pentodes are cross coupled. The earth point is connected to the cathodes 14, 15, of the two pentodes through cathode leg resistances 16, 17 (one for each), and the suppressor grids 18, 19, of the pentodes are adjustably tapped upon these cathode leg resistances as shown. Each pentode receives anode potential through a separate anode resistance 20 or 21, a condenser 22 is connected between earth and the tap 10, and each pentode screen grid 23 or 24 is positively biased. With this arrangement, properly adjusted, negative resistance is manifested between the tap 10 and the first grid 5 of the first pentode 6. This negative resistance is represented in broken lines at Z_N . The advantage of this form of negative resistance network, which constitutes a feature of this invention is that, since the suppressor grids are connected to points on the cathode leg re-

sistance, it is possible, by suitably choosing the parameters of the circuit, to obtain a mutual conductance grid bias curve as shown in Figure 3 in which the mutual conductance g rises to a broad maximum and then tails off with increase in negative grid bias *eg.* By choosing a grid bias corresponding to a point such as X on the comparatively flat top portion of this curve it can be ensured that the negative resistance does not vary greatly with variation of signal amplitude over a quite considerable range of amplitudes. This is of considerable practical advantage in that, in a reaction arrangement in accordance with the invention, it enables the reaction to be taken quite close to the oscillation point without danger of bursting into oscillation as a result of a strong signal. Indeed, by operating on the downwardly sloping part of the curve, *e. g.* at Y, it can actually be arranged that the advent of a strong signal reduces the reaction. Control of the amount of negative resistance manifested is preferably effected by varying the position of the tap 12. In general the negative resistance will be equal to

$$\frac{1}{r g_1 g_2}$$

where g_1 and g_2 are the mutual conductances of the first and second pentodes respectively, and r is the resistance between the first grid of the second pentode and the first mentioned adjustable tap. Thus if $r=100$ ohms and $g_1=g_2=2$ milliamps. per volt, the negative resistance is

$$\frac{1}{100 \times \frac{2}{1000} \times \frac{2}{1000}} = 2500 \text{ ohms}$$

It is possible to obtain resistances down to about 100 ohms which are substantially non-reactive for frequencies of over 10 megacycles and consequently the arrangement (which may be used to provide the negative resistance in any of the embodiments to be described later herein) is satisfactorily operable at very high frequencies of the order stated.

There will now be described a number of oscillator embodiments of the invention. In one embodiment shown in Figure 4 a length l of concentric cable which is $\lambda/4$ long (λ being the wave length) has a negative resistance Z_N (provided preferably by an arrangement as shown in Figure 3) connected between its inner and outer conductors at one end, the said conductors being connected together and to earth at the other. This embodiment will have possible modes of oscillation at the quarter wave length frequency and at frequencies corresponding to odd multiples of $\lambda/4$.

In the modification shown in Figure 5 the cable is $\lambda/2$ long and is left open at the end remote from the negative resistance. This modification will have modes at frequencies corresponding to multiples of $\lambda/2$.

Either of these embodiments may be arranged for remote control of tuning (remote as respects the negative resistance network) by including a variable reactance between the cable conductors at the end remote from the negative resistance network. Such arrangements are represented in Figures 6, 7 and 8 where (respectively) a variable inductance 25; a variable condenser 26; and an inductance 25 and a variable condenser 26 in series; are shown connected at the place indicated.

In all the above embodiments the actual cable

need not be itself of the length ($\lambda/4$ or $\lambda/2$) mentioned but may be different from said length, the said lengths being, in effect, achieved by connecting a suitably dimensioned phase changing network in series with the actual cable. An example of this nature is represented in Figure 9 where 27 is the phase changing network. In Figure 9 the elements 25, 26, are together series tuned to the wave length λ .

Although the above embodiments have several modes, in general oscillation will occur at one only and a required mode may be selected by providing suitable termination at the end remote from the negative resistance network. Thus a cable (or cable and phase changing network) which is $\lambda/4$ long will have a predominant but not exclusive mode at $\lambda/4$ if a series tuned circuit resonant at the frequency corresponding to $\lambda/4$ is connected between the cable conductors at the end remote from the negative resistance. Thus, as shown in Figure 10, if the cable or (as represented) the cable and phase changing network 27 is $\lambda/4$ (or an odd multiple thereof) long is terminated by a series tuned circuit 25, 26, resonant at $\lambda/4$ (or the corresponding odd multiple) and a resistance of value Z_0 is connected across the series tuned circuit, all spurious modes will be avoided and oscillation will occur only at $\lambda/4$ (or the corresponding odd multiple). Similarly as shown in Figure 11, if the cable or cable and phase changer 27, is $\lambda/2$ (or a multiple thereof) long and is terminated at the end remote from the negative resistance by a resistance Z_0 in series with a parallel tuned circuit 25, 26, resonant for $\lambda/2$ (or the corresponding multiple) oscillation will occur only at $\lambda/2$ (or the corresponding multiple).

The invention is also applicable to long line stabilisation of oscillators. Thus, in one embodiment of this nature, illustrated in Figure 12, an oscillator 28—e. g. a back coupled oscillator as shown—includes, in series in its frequency determining circuit 29 a long line (which may be an artificial line) which is an odd multiple of $\lambda/4$ long, and which is terminated by a negative resistance Z_N manifested by a network as hereinbefore described. Thus the terminals at one end of the line are connected between one side of the condenser 29a in said frequency determining circuit and one side of the inductance 29b therein, the remaining condenser and inductance terminals being, of course, connected directly together and the negative resistance Z_N being connected between the terminals of the line at the end remote from the oscillator valve. If the long line were $\lambda/2$ or a multiple thereof, long the terminals thereof adjacent the oscillator valve would be connected as shown in Figure 13 one to one side and the other to the other, of the normal parallel tuned frequency determining circuit 29 of the oscillator. These long line stabiliser embodiments avoid—by virtue of the negative resistance—the difficulty met with in known long line stabiliser circuits, namely that long lines involve high attenuation and therefore impaired stability unless indeed, the physical dimensions of the line are so big as to be inconvenient and ill-suited to temperature control.

In order to facilitate selection of the required harmonic frequency in oscillator stabiliser circuits as above described, it is advantageous to modify the negative resistance network of Figure 2 by replacing that portion (r) of the resistance which is between the first grid 13 of the

pentode 3 and the tap 10 by a damped tuned circuit tuned to the desired frequency. A considerable alteration of tune of this circuit will produce only a small change in the frequency at which the minimum impedance occurs. The provision of variable tuning in the negative resistance arrangement is, however, of advantage in that it provides a means of making small changes of frequency.

Clearly in such oscillator stabiliser circuits the valves in the negative resistance network must be reasonably proportioned, as to size, to the oscillator valve or valves. Thus a high power oscillator involves the use—if good stabilisation is to be obtained—of reasonably large valves in the negative resistance network. Where high constancy of frequency is required thermostatic temperature control of the long line, effected in any convenient known way, is advisable.

The invention is also applicable to the provision of controlled reaction—which may be remotely controlled, if desired—for example to improve selectivity in a radio receiver, and the invention obviously lends itself to the obtaining of such control automatically, in dependence upon signal strength, by any suitable automatic selectivity control network, as known per se. In such embodiments negative resistance variation for reaction control is preferably obtained by varying the resistance portion r in the negative resistance network hereinbefore described although it can be obtained by potentiometer control of the grid bias voltage on either or both valves in said network.

One embodiment of the invention as applied to a radio receiver with controllable reaction is shown in Figure 14. Here a receiving aerial 30 is connected to earth through an inductance 31 a tap 32 upon which is connected through a condenser 33 to the inner conductor of a first concentric cable K with an earthed outer conductor. At the far end of the first cable its "inner" is connected through an inductance 34 to one end of the "inner" of a second cable 2C the middle point of said inductance being earthed through an adjustable condenser 35 which, with said inductance, constitutes a series tuning circuit. The "outer" of the second cable 2C is earthed and at the far end of said second cable the "inner" is connected to earth through a negative resistance Z_N provided as hereinbefore described and which may be remotely controlled and if desired ganged with condenser 35. The negative resistance is followed by a transmission line transformer 36 consisting, for example, of an inductance and condenser in series, in the order stated, in the "live" wire, a shunt condenser connected to earth from the junction of said inductance and condenser and a shunt inductance connected from the far side of said condenser to earth. This transformer is followed by a wide band amplifier 37 and then by the remainder of the receiver, i. e. detector and L. F. amplifier (not shown). The electrical length between the far ends of the two cables is approximately $\lambda/4$ or an odd multiple thereof. Alternatively, and as shown in Figure 15, the said electrical length may be $\lambda/2$ or a multiple thereof in which case the series inductance 34 and shunt condenser 35 between the two cables 1C and 2C being replaced by a parallel tuned circuit 34' 35' connected between the "inner" of the second cable and earth, the inner of the first cable being tapped on to the inductance 34' of said parallel tuned circuit. Both these embodiments are "one circuit tuner" embodiments.

Either of these embodiments may be modified so as to be a "two circuit tuner" embodiment. For example, Figure 16 shows the embodiment of Figure 14 so modified. Here the far end of the first cable is earthed through the primary of a transformer 38 whose secondary is connected between earth and one side of an additional tuning condenser 39 the other side of said condenser being earthed through the primary of a second transformer 40. The secondary of this second transformer is connected between earth and one end of the series inductance 34. The two tuning condensers 35, 39 are ganged and the remainder of the arrangement is as before. Similarly Figure 17 shows the "half-wave" embodiment of Figure 15 modified so as to constitute a "two circuit tuner." Here there is interposed between the parallel tuned circuit 34', 35' and the beginning of the second cable 2C a second tuned circuit 41, 42, which is gang controlled therewith, and consists of a series inductance 41 connected between the "live" end of the parallel tuned circuit and the "inner" of the second cable 2C and an adjustable condenser 42 connected between earth and the midpoint of said inductance 41.

The principle applied in the four last described embodiments consists in so terminating and adjusting the length of the cable (the second cable) connecting the control point with the remote receiver, that a substantially non-reactive high impedance condition is presented to the negative resistance network. In the simple "one circuit tuners" the line and termination adjustments are compromised in a single adjustment; in the "two circuit tuners" provision may be made for effecting those adjustments separately or, alternatively, these two adjustments may be "ganged" mechanically.

The negative resistance devices herein described may be applied to lines which are not exactly a quarter or a multiple of the quarter wave length long. Fundamentally there are two applications:

(1) Application to obtain reactive effects.

(2) Application of complex negative resistance to obtain resistive or variable reactance effects.

Dealing with (1) in a line terminated with pure negative resistance and of a length other than the quarter or half wave (or multiples) there is at the remote end a complex impedance with a resistance component depending on the line losses.

Again a line terminated with a variable reactance is a means of throwing a reactance varying effect to a remote point but a resistance component is introduced due to line losses. Application of negative resistance is a means of reducing these losses and therefore securing a more effective reactance control.

In this arrangement the pure negative resistance is applied in parallel with the variable terminating reactance.

By replacing the quantity r of the two valve negative resistance device (Figure 2) by a complex impedance, any desired complex negative impedance may be supplied to a cable. In some cases it may be desired to obtain at a remote end a high or low resistance effect at some definite frequency, sharply varying as the frequency varies. This may be produced by the combination of other than the quarter or half wave (or multiples) long line, in conjunction with a complex negative impedance, the negative resistance component of which reduces the line losses to any

desired degree, whilst the reactive component lengthens or shortens the line system to obtain the resistance effect at the required frequency. Using the same symbols as before in this specification the formulae for a complex impedance element replacing r and having impedance Z or admittance Y are

$$Y_1 N = -g_1 g_2 Z$$

$$Z_1 N = \frac{-1}{g_1 g_2} Y$$

where $Y_1 N$ and $Z_1 N$ define the complex impedance given by the arrangement. It will be seen that owing to the minus sign these will be negative, i. e. resistance components will be negative. Thus it is possible not only to throw a low loss reactance effect along a line, but by suitably varying the impedance Z_N to vary this in any way required.

Although the preferred negative resistance device (Figure 2) is a two valve arrangement single valve arrangements are possible. For example, an ordinary reaction valve arrangement is a means of supplying negative resistance at one frequency, and such an arrangement with suitable "tap down" to fit a required cable impedance could be used. Again a single pentode arrangement in which the suppressor grid is connected to a point on a cathode resistance can be used to produce a required shape of mutual conductance curve to ensure stable operation just as already described in connection with the two valve arrangements of Figure 2. Again it is obvious that dynatron and other arrangements can be used. In the case of the dynatron, smooth and stable operation can be secured by adjusting the anode voltage so that operation is on the steepest part of the negative resistance curve.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed we declare that what we claim is:

1. A stabilized generator of high frequency waves comprising a section of transmission line having a length equal to an odd multiple of a quarter of the length of the wave to be generated, one end of said line being connected to a back coupled oscillator and the other end of said line being connected to a negative impedance, said negative impedance having a real component equal in magnitude and opposite in sign to the real component of the impedance of said transmission line.

2. A stabilized generator of high frequency waves comprising a section of transmission line having a length equal to an odd multiple of a quarter of the length of the wave to be generated, one end of said line being connected to a back coupled oscillator and the other end of said line being connected to a negative impedance, said negative impedance having a real component equal in magnitude and opposite in sign to the real component of the impedance of said transmission line, said negative impedance comprising a pair of thermionic discharge tubes each having at least an anode, a grid, a suppressor grid, and a cathode, said anodes and grids being cross-coupled, each of said cathodes being connected through resistances to a common point of zero reference potential, a source of anode potential, a resistance connected between said reference point and the negative end of said source of potential, said transmission line being connected to one of said grids and to a tap on said last

named resistance, said suppressor grids being connected to points on said cathode resistances whereby changes in amplitude of oscillations in said line are prevented from causing said thermionic discharge tubes from oscillating.

3. In combination with a back coupled oscillator circuit, a long line so coupled to frequency determining elements of said circuit as to stabilize generated oscillations and a negative resistance network coupled to said long line for compensating for attenuation in said line.

4. In combination with a back coupled oscillator circuit, a long line so coupled at one end to frequency determining elements of said circuit as to stabilize generated oscillations and a negative resistance network coupled to said long line at its other end for compensation for attenuation in said line.

5. In combination with a back coupled oscillator circuit, a long line connected in series with said circuit for stabilizing generated oscillations and a negative resistance network coupled to said long line for compensating for attenuation in said line.

6. A self-oscillatory circuit including lumped circuit elements, a long line connected in series with said circuit elements for stabilizing generated oscillations and a negative resistance network coupled to said long line for compensating for attenuation in said line.

7. In combination with an oscillator circuit having included therein elements for determining the frequency of the wave generated thereby, a long line so coupled to said frequency determin-

ing elements as to stabilize generated oscillators and a negative resistance network coupled to said long line to compensate for attenuation in said line.

8. In combination with an oscillator circuit having included therein elements for determining the generated frequency, a long line so coupled at one end to said frequency determining elements as to stabilize the generated oscillations and a negative resistance network coupled to said long line at its other end to compensate for attenuation in said line.

9. In combination with an oscillator circuit having included therein elements for determining the generated frequency, a line having a length equal to a multiple of half the operating wavelength connected in shunt to said frequency determining elements so as to stabilize generated oscillations and a negative resistance network coupled to said line to compensate for attenuation in said line.

10. In combination with an oscillator circuit having included therein elements for determining the generated frequency, a line having a length equal to an odd multiple of a quarter of the operating wavelength connected at one end in series with said frequency determining elements so as to stabilize generated oscillations and a negative resistance network coupled to said line at its other end to compensate for attenuation in said line.

NOËL MEYER RUST.

JOSEPH DOUGLAS BRAILSFORD.