Feb. 22, 1949. E. S. GRIMES 2,462,093

MODULATOR

Filed Sept. 22, 1945 5 Sheets-Sheet 1

FIG. 1

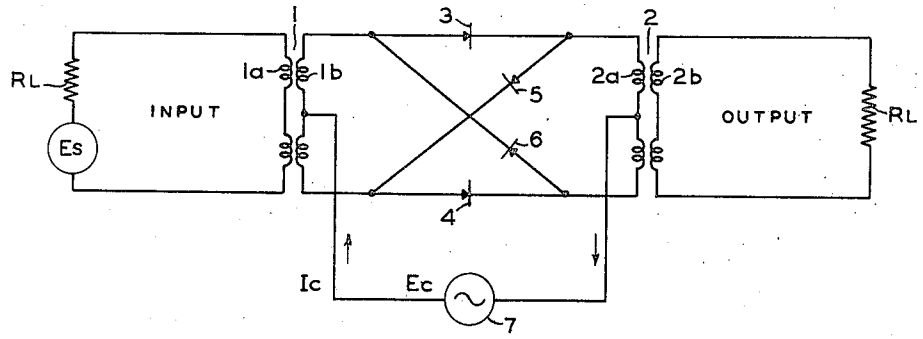


FIG. 2

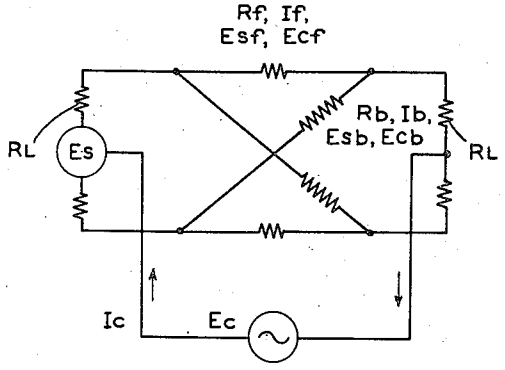
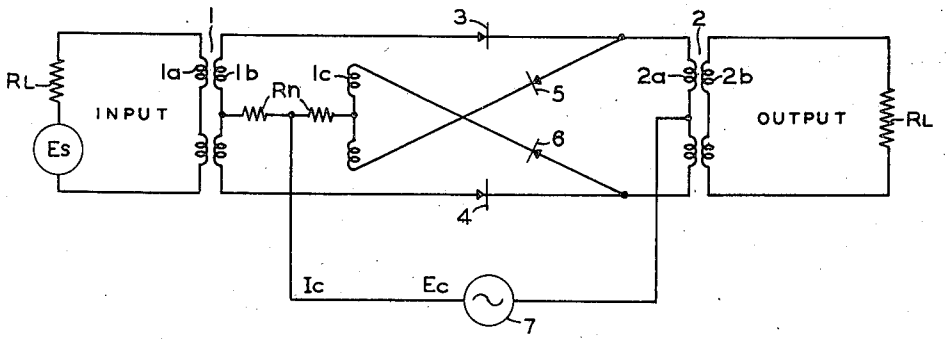


FIG. 4



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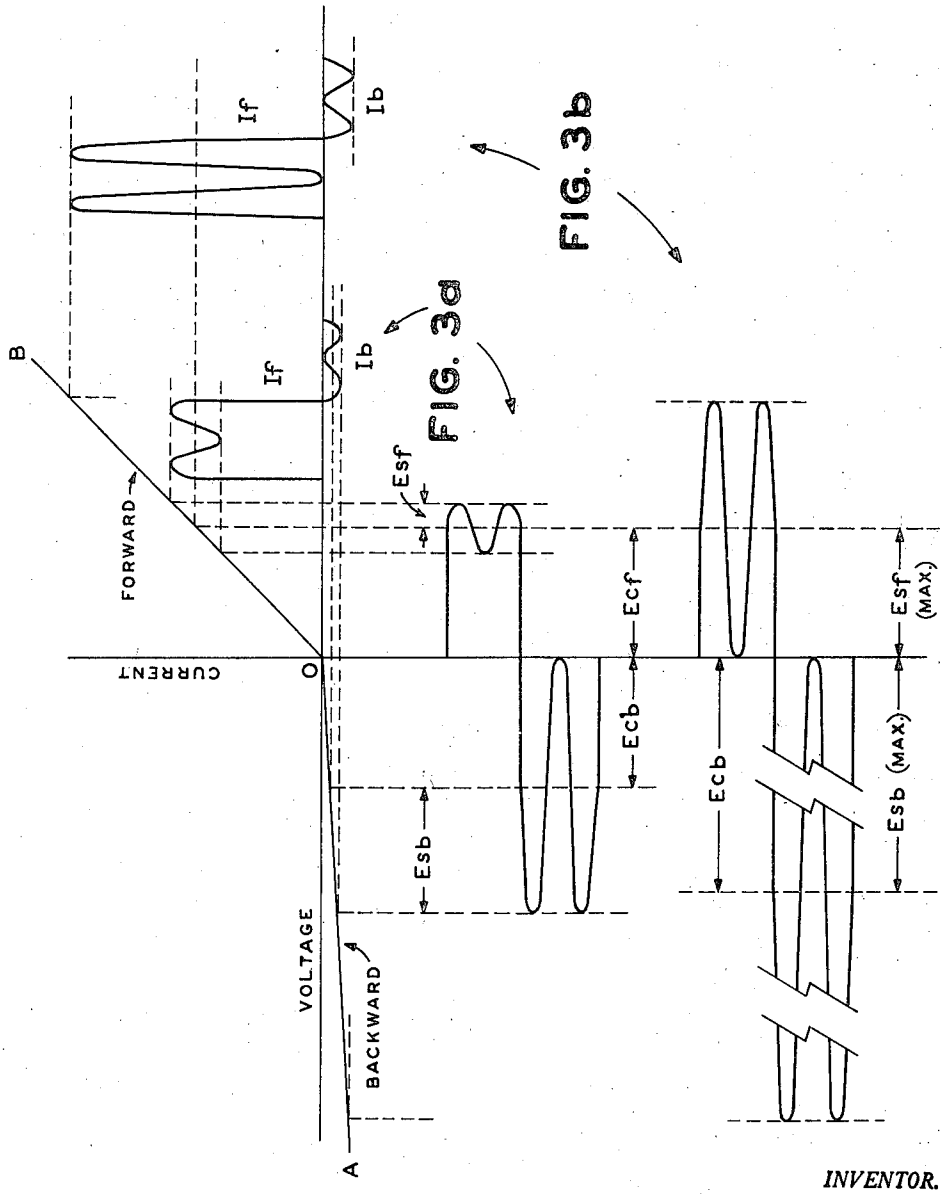


FIG. 3b

FIG. 3d

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MODULATOR

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FIG. 5

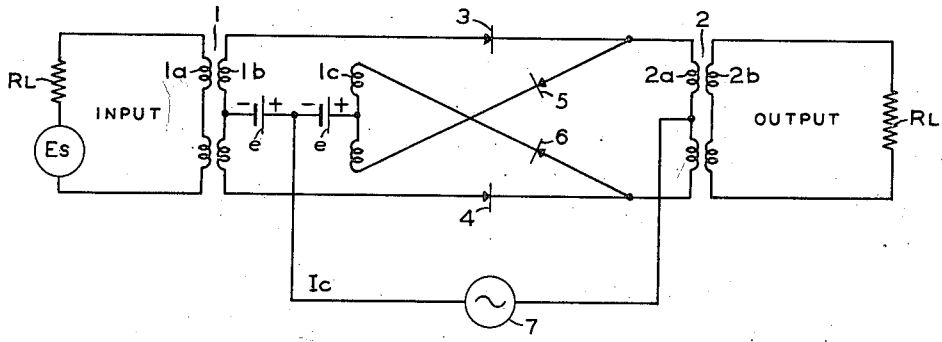


FIG. 6

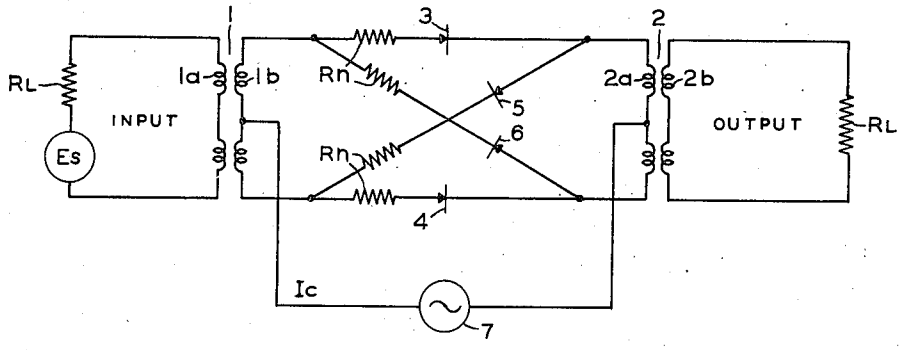
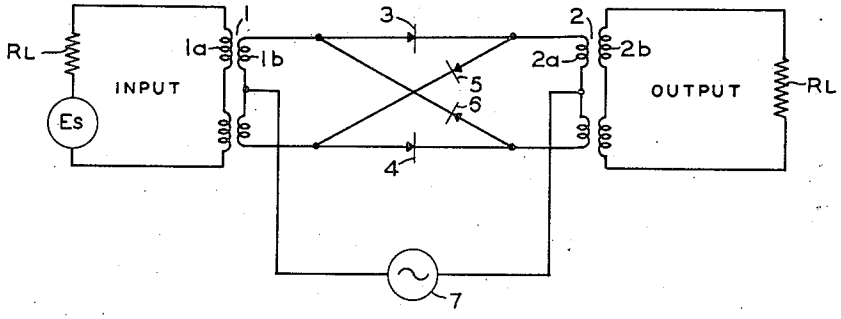


FIG. 7



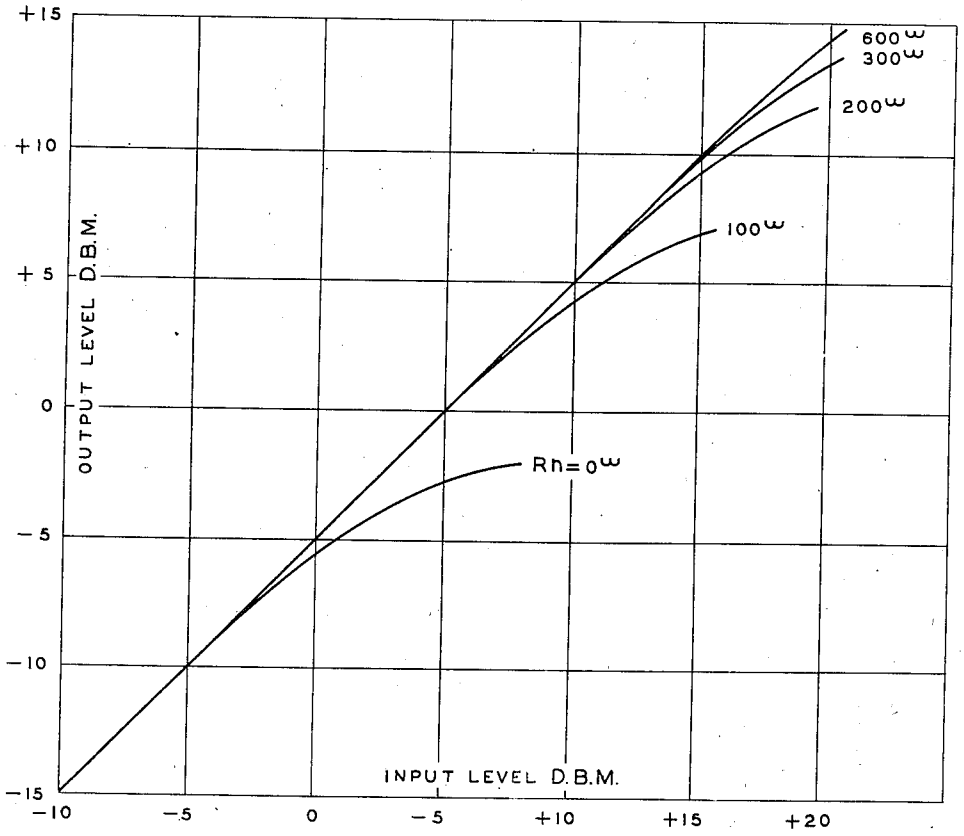
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MODULATOR

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FIG. 8



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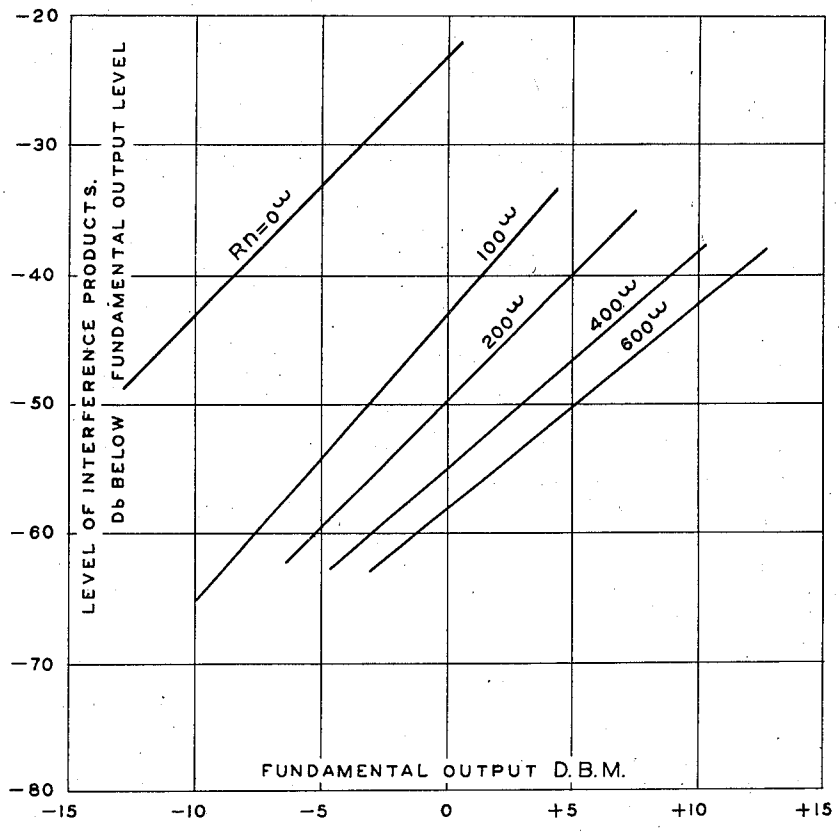
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MODULATOR

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FIG. 9



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Patented Feb. 22, 1949

2,462,093

UNITED STATES PATENT OFFICE

2,462,093

MODULATOR

Edgar S. Grimes, Ridgewood, N. J., assignor to The Western Union Telegraph Company, New York, N. Y., a corporation of New York

Application September 22, 1945, Serial No. 617,993

22 Claims. (Cl. 179—171.5)

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This invention relates to modulators, demodulators or frequency translators of the double-balanced type. When operated under optimum conditions a double-balanced modulator suppresses to a high degree in the modulator output, the applied carrier frequency, the applied signal frequency, the harmonics of both, and in addition certain other spurious frequencies.

In modulators used in multichannel carrier communication systems the requirement of high fidelity is essential in order to prevent the production of interference products which would fall within the frequency space of adjacent channels. Such modulators are frequently but not necessarily made up of variable resistance devices such as rectifier units composed of copper oxide discs because of the small size, economy and long life of these rectifiers. However, output levels from these modulators are quite low because, if distortion is to be avoided, the summation of the signal and carrier voltages, as impressed upon the rectifier elements, must remain within the linear portion of the rectifier characteristic. Neglect of these limitations quickly results in intolerable interchannel interference. Further, it is necessary to provide a very high level of carrier frequency relative to signal frequency in order to minimize distortion, but again this carrier current level is limited by the heat radiating capacity of the rectifier units. It follows, therefore, since the signal level must be considerably less than the carrier level, that the available output of undistorted modulated signal is inconveniently low. The low level input and output signal is then not only subject to noise pickup but in most cases necessitates an accompanying high gain amplifier in order to raise the output signal to a level suitable for transmission purposes. Since amplifiers are inherently one-way devices, a modulator followed by a directly connected amplifier cannot serve as a combined modulator-demodulator in a two-way circuit. If the low-level requirement could be overcome so that the amplifier could be dispensed with, a modulator-demodulator device suitable for most circuits would result.

The general object of this invention is to improve modulator and demodulator devices in the following respects: to increase power output; to reduce the levels of distortion products; to improve efficiency; to operate all the units comprising the modulator or demodulator at their full capacity.

A particular object is to provide a modulator of the double-balanced type in which the signal and carrier voltages across both the conducting and non-conducting units will bear the same relation to each other so that the non-conducting units will not be subject to overloads while the conducting units are still operating within their safe capacity.

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Another particular object of the invention is to provide a modulator composed of a plurality of elements arranged so that when the carrier and signal voltages impressed across the conducting elements are approximately equal, the corresponding voltages applied to the non-conducting elements will also be substantially equal.

Still another object is to provide a frequency translator eminently adapted to serve as a modulator-demodulator.

A further specific object is in a modulator of the class described to make the carrier voltage as impressed on the non-conducting units greater than that impressed upon the conducting units.

Fig. 1 illustrates a common type of double-balanced modulator built up of variable resistance units which may, for example, be of the copper-oxide rectifier type.

Fig. 2 is a theoretical diagram of Fig. 1 to explain the operation of the modulator.

Fig. 3 in two parts, Figs. 3*a* and 3*b*, illlustrates relationships between carrier and signal voltages in the modulators of Fig. 1 and Fig. 4, respectively.

Figs. 4, 5, 6, and 7 illustrate different modifications of the modulator of this invention.

Fig. 8 represents curves indicating the permissible safe increase in operating power level of the improved modulator; and

Fig. 9 represents the reduction in typical disturbing modulation products in the modulator of the invention.

In the operation of ordinary modulators of the type herein referred to and comprised of balanced pairs of rectifier units which are alternately conducting and non-conducting, the voltages impressed upon the respective pairs of units vary considerably under the two conditions. For safe operation it is necessary that the summation of the applied signal and carrier voltages under both conditions must remain within the linear portion of the characteristic of the rectifier units. The voltage applied across the rectifiers in the non-conducting direction will be known hereinafter as the backward acting voltage while the voltage drop across the conducting rectifiers will be known as the forward acting voltage. It is known that in the voltage aggregate impressed upon the individual rectifier units the component due to the applied signal must not exceed the component due to the applied carrier frequency if distortion is to be avoided. I have discovered, however, that ordinarily the signal voltage component will exceed the carrier voltage component impressed upon the backward acting rectifiers long before this condition occurs for the forward acting rectifiers. It follows, therefore, that the capacity of the modulator may be increased if this overloading in the backward direction may

be deferred until full safe capacity is also reached in the forward direction. This simultaneous balancing of carrier and signal voltages across the forward and backward acting rectifiers has been accomplished by relatively simple expedients.

A description of the modulator of this invention follows with reference to the several figures in which like symbols refer to like circuit elements.

Fig. 1 represents a common type of double-balanced modulator in which the two pairs of rectifier units **3**, **4** and **5**, **6** are rendered alternately conductive and non-conductive in pairs by the positive and negative half-waves of carrier current supplied by the generator **7**. A signal generator of voltage E_s and resistance R_L supplies signaling voltage to the primary **1***a* of the transformer **1**, and the modulated output current is supplied to a load resistance R_L by the transformer **2** comprised of primary winding **2***a* and secondary winding **2***b*. The carrier current generator **7** of voltage E_c is connected to midpoints of the transformer windings **1***b* and **2***a* of the input and output transformers, respectively. The input and output terminals in this figure as well as in the remaining modulator figures have been chosen arbitrarily. It is immaterial theoretically which terminals serve as input or output, or whether the device is operating as a modulator or demodulator.

With this modulator the carrier voltage serves as a means for cyclically varying the impedance of the rectifier elements in pairs between the conducting and non-conducting conditions. Hence this circuit in its ideal form may be considered as acting as a reversing switch operated at carrier frequency. So long as the applied signal and carrier voltages together lie within the region where the characteristics of the rectifier units are linear, the signal frequency and its harmonics are absent in the circuit output provided the longitudinal rectifiers **3** and **4** are perfectly balanced against the diagonal rectifiers **5** and **6**. Furthermore, the carrier frequency and its harmonics will be absent in the output circuit if both the longitudinal rectifiers and the diagonal rectifiers are balanced in pairs.

In order to secure rapid action of the reversing switch function it has been customary to employ carrier levels that are very high with respect to signal levels so that the carrier potential passes through the zero period almost instantaneously. This effect may be enhanced by the use of a square wave in place of a sinusoidal carrier. Such a square wave may be conveniently obtained by using a carrier wave so large as to have a practically instantaneous reversal from positive to negative polarity but with the peak values cut off so as to avoid overheating of the rectifier units. The carrier sources indicated in the figures, therefore, are considered as square wave generators although the application of the invention is not limited thereto.

A simplified analysis of the performance of the modulator of Fig. 1 may be made by assuming that the rectifier impedance is either a constant low resistance R_f or a constant high resistance R_b, depending upon whether the polarizing carrier voltage is in a forward or a backward direction. These conditions are illustrated in the simplified equivalent circuit of Fig. 2 for the condition where the carrier voltage has such a direction as to render the longitudinal rectifiers conducting, i. e., of low resistance. Referring to the forward acting rectifiers, the resistance will be designated as R_f, the total current due to both carrier and signal

voltages is I_f, the voltage drop due to signal current is E_{sf}, and the voltage drop due to the carrier current is E_{cf}. The like quantities for the diagonal or non-conducting rectifiers are R_b, I_b, E_{sb}, and E_{cb}, respectively. Upon reversal of the carrier voltage, the longitudinal rectifiers will assume a high resistance while the diagonal rectifiers will have a low resistance to give a reversal in direction of the modulated output current. In the following description consideration will be given to the case where the carrier current flows in the direction indicated so as to render the longitudinal rectifiers conducting and the diagonal rectifiers non-conducting. However, the same reasoning applies when the carrier current reverses to render the longitudinal rectifiers non-conducting and the diagonal rectifiers conducting.

In order to illustrate in detail the functioning of the rectifiers, an idealized rectifier voltage-current characteristic AOB is shown in Fig. 3*a*, along with the current and voltage wave shapes produced in both the conducting and non-conducting branches by a single cycle of high frequency signal and low frequency carrier. This figure should be studied in conjunction with Figs. 1 and 2. For clearness in illustration, a single cycle of carrier voltage is being treated along with a signal voltage wave of 3 cycles length. This is for the reason that we are concerned here principally with the behavior of the rectifier units through the conducting and non-conducting phases of a single carrier cycle. The simplification is further enhanced by considering that the transition from the forward to the backward conducting condition is effected instantaneously by means of a perfectly square-topped carrier. The rectifier characteristic includes a forward or conducting portion OB, and a backward or non-conducting portion OA, which are presented respectively under the influence of forward or backward acting carrier voltages. Both portions of the characteristic are represented in an idealized linear form; actually some curvature exists in both parts and the bend does not occur exactly at the origin. The carrier wave impresses the voltage E_{cf} across the forward acting longitudinal rectifiers and an equal voltage E_{cb} across the backward acting diagonal rectifiers. At the same time a signal voltage is superimposed upon the carrier voltage to produce a voltage E_{sf} across the forward acting rectifiers and a much larger voltage E_{sb} across the backward acting rectifiers. Under the combined influence of these two voltages a current I_f flows through the forward acting rectifiers and a very much smaller current I_b flows through the backward acting rectifiers.

It is seen that when the signal voltage E_{sb} has a peak value which is equal to the carrier voltage E_{cb} across the backward acting rectifiers, any further increase in the signal voltage will cause a reversal of current in these rectifiers, thus thwarting the regular reversing switch action. In other words, the peak signal voltage must not exceed the carrier voltage. The reason that E_{sb}, the signal voltage in the backward direction, is so much the larger is that a non-conducting rectifier is subject to one-half of the applied signal voltage whereas the voltage drop E_{sf} across a conducting rectifier is relatively small. The significance of this excessive back signal voltage appears to have been overlooked in the past. By recognizing this tendency and remedying its consequences, the improved modulator of this description has been devised.

It has been stated that the modulator will

overload, or distort, when the peak signal voltage across the rectifier elements exceeds the carrier voltage. But, as indicated in Fig. 3*a*, this overloading will occur first in the backward direction. In this modulator, therefore, the back signal voltage E_{sb} determines the load limit of the modulator. To determine the voltage at which overloading will occur, consider again the simplified equivalent circuit of Fig. 2, along with the curves of Figs. 3*a* and 3*b*. In these figures E_s represents the signal voltage applied to the modulator, I_c represents the total carrier current and is constant in value, and R_L represents input or output resistances which for convenience are made equal. The remaining symbols, as previously explained, represent voltage, current, or resistance in respect to individual rectifier elements in either the forward or backward directions and have the significance hereinbefore mentioned and indicated in the figures. Under the influence of the biasing carrier voltage the two longitudinal rectifiers are rendered conductive to provide a series circuit comprising these two rectifiers and the input and output resistances R_L. The other two rectifiers are at this time non-conducting and do not influence the flow of current in the circuit.

In the forward direction, the signal voltage across a rectifier element is

$$E_{sf}=E_s\left[\frac{R_f}{2(R_L+R_f)}\right]$$

The carrier voltage across a rectifier element in the forward direction is

$$E_{cf}=\frac{I_c}{2}R_f$$

where I_c is the total carrier current.

Since the forward acting rectifiers will overload when the signal voltage exceeds the carrier voltage, at the overload point:

$$E_{sf}=E_{cf}, \quad \text{or} \quad E_s\left[\frac{R_f}{2(R_L+R_f)}\right]=\frac{I_cR_f}{2}$$

and the peak value of the maximum permissible input signal voltage to the modulator is:

$$E_s(\text{max.})=I_c(R_L+R_f)$$

at the overload point of the forward acting rectifiers. This value of input signal voltage will produce the voltage across the forward acting rectifiers designated as $E_{sf}(\text{max.})$ in Fig. 3*b*.

Now consider the maximum permissible input signal voltage insofar as the backward acting rectifiers are concerned. The signal voltage across each of the two non-conducting rectifiers is:

$$E_{sb}=\frac{E_s}{2}$$

The carrier voltage across the backward acting rectifiers, due to the symmetry of the circuit, remains the same as for the forward acting rectifiers, or:

$$E_{cb}=E_{cf}=\frac{I_c}{2}R_f$$

Equating the signal and carrier voltages in this direction, as before,

$$E_{sb}=E_{cb}, \quad \text{or} \quad \frac{E_s}{2}=\frac{I_c}{2}R_f$$

and the peak value of the maximum permissible input signal voltage to the modulator in the back direction is found to be:

$$E_s\ (\text{max.})=I_cR_f$$

Comparison of the two expressions for E_s (max.), as developed for the forward and backward directions respectively, indicates that the latter is much the smaller and so will be the first to be exceeded as the signal input E_s is increased. For example, R_L may be as much as 600 ohms and R_f only about 30 ohms, so that the backward acting rectifiers will overload under a signal which is only about one-twentieth of that required to overload the forward acting rectifiers.

Reference again to Fig. 3*a* suggests a method which will permit greatly enlarging the value of E_s but without overloading the rectifiers in the backward direction. It has already been shown that $E_{sb}=E_{cb}$ at the overload point. It is only necessary, therefore, to increase E_{cb} apace with E_{sb} until, finally, the accompanying increase in E_{sf} causes overloading to occur in the forward direction instead, and nothing is gained by further increasing the load capacity in the backward direction. The associated Fig. 3*b* illustrates the voltage and current relationships that will prevail under this condition for the idealized rectifier of Fig. 3*a*. The forward acting rectifiers are now operating at their full capacity, i. e., $E_{sf}\ (\text{max.})=E_{cf}$, yet in the backward direction the carrier voltage E_{cb} has been sufficiently enlarged so that the signal voltage E_{sb} (max.) although now greatly increased, does not exceed the biasing carrier voltage to cause these diagonal rectifiers to become conducting, with consequent distortion and limitation of available modulator output. A greatly enlarged useful current I_f now flows through the forward acting rectifiers but the current I_b through the backward acting rectifiers does not reverse.

The circuit modification shown in Fig. 4 provides a means for increasing the carrier voltage in the back direction without altering the other voltages, so that the overload point in the backward direction will not be reached before it is reached in the forward direction. This figure differs from Fig. 1 only in that terminals of the diagonal rectifiers have been brought out to a separate but identical transformer secondary winding at one end of the modulator, and a center tapped resistance R_n has been inserted between the center taps of the two secondaries. The carrier supply is then connected to the center tap of the resistance R_n, and the voltage of the source is raised sufficiently so that I_c is the same as before. The presence of R_n in Fig. 4 increases the carrier back voltage across the non-conducting rectifier elements to:

$$E_{cb}=I_c\left[\frac{R_f}{2}+\frac{R_n}{2}\right]=I_c\frac{(R_n+R_f)}{2}$$

while the signal voltages are not changed.

Again equating signal and carrier voltages in the back direction, we have:

$$\frac{E_s}{2}=I_c\frac{(R_n+R_f)}{2} \quad \text{and} \quad E_s\ (\text{max.})=I_c(R_n+R_f)$$

for the maximum permissible signal input (peak value).

In the forward direction, the signal voltage E_{sf} impressed upon the rectifiers in Fig. 4 remains the same as in Fig. 2, and since I_c was maintained constant, the carrier voltage E_{cf} is likewise unchanged. Therefore, for the forward acting rectifiers, the peak value of the maximum signal is $E_s(\text{max.})=I_c(R_L+R_f)$, as before.

It is now apparent that as the input signal voltage to the modulator is increased up to the per-

missible maximum value in the forward direction, the load capacity in the backward direction has been increased at the same time by introduction of the resistance R_n. Finally the permissible maximum loading is reached when the carrier voltage is made equal to the peak value of the signal voltage in the case of both the forward and backward acting rectifiers. But since at this time the signal input voltage E_s(max.) is the same for both the conducting and non-conducting paths of the modulator,

$$I_c(R_n+R_f)=I_c(R_L+R_f), \text{ or } R_n=R_L$$

No additional improvement follows from further increase of R_n.

The foregoing development has revealed certain inherent limitations in a common type of double balanced modulator and in Fig. 4 has illustrated a satisfactory means for substantially overcoming these limitations. Similar results may be secured by certain other circuit arrangements which will now be described.

Since it is the function of the two halves of the resistance R_n of Fig. 4 to present a biasing potential as current flows therethrough, and always in the same direction, this function may be performed by a steady biasing battery poled to oppose the rectifiers. Fig. 5, which is otherwise identical to Fig. 4, illustrates such an arrangement. The value of the biasing batteries e in terms of R_n as previously determined may be derived as follows.

The carrier back voltage across the non-conducting rectifiers will now be,

$$E_{cb}=\left(e+\frac{I_c}{2}R_f\right)+e=2e+\frac{I_c}{2}R_f$$

where the symbols have the same significance as before. Equate this to E_{cb} as previously determined, i. e.,

$$2e+\frac{I_c}{2}R_f=I_c\frac{(R_n+R_f)}{2}$$

and

$$2e=\frac{I_c}{2}R_n+\frac{I_c}{2}R_f-\frac{I_c}{2}R_f$$

$$4e=I_cR_n$$

$$e=\frac{I_cR_n}{4}$$

For this value of e, Figs. 4 and 5 are exactly equivalent. The optimum value is:

$$e=\frac{I_cR_L}{4}$$

Another circuit arrangement which produces an improvement in the power carrying capacity of the modulator is illustrated in Fig. 6, which is identical with Fig. 1 except for the addition of a resistance R_n in series with each rectifier unit. In the backward direction, the carrier and signal voltage relations for this circuit are the same as for Fig. 4 and overloading occurs when the input signal voltage reaches the value:

$$E_s(\text{max.})=I_c(R_n+R_f)$$

In the forward direction the signal voltage across a rectifier element is:

$$E_{sf}=E_s\left[\frac{R_f}{2(R_L+R_n+R_f)}\right]$$

and equating this voltage to the forward acting

carrier voltage across the rectifier element we have:

$$E_s\left[\frac{R_f}{2(R_L+R_n+R_f)}\right]=\frac{I_c}{2}R_f$$

and, for Fig. 6,

$$E_s(\text{max.})=I_c(R_L+R_n+R_f)$$

As before, the rectifiers will overload first in the backward direction and it is not possible in this case by adjustment to cause the forward and backward overload voltages to coincide. However, the addition of the resistors does increase the load capacity, the overload point obtainable being even higher than with the circuit of Fig. 4.

An additional means for increasing the undistorted power output of the basic modulator of Fig. 1 is illustrated in Fig. 7. In connection with Fig. 1 it was found that overloading occurred when the input signal voltage reached the value $E_s(\text{max.})=I_cR_f$. It is apparent that by means of a stepdown input and a stepup output transformer the rectifier units may be operated at lower levels of signal voltage, thus reducing the backward acting signal voltage across these units. Fig. 7 is identical with Fig. 1 except for the non-unity ratio input and output transformers. In this modulator the carrier voltages impressed upon both pairs of rectifiers remain equal but it is, of course, possible to supplement the modulator of Fig. 7 with the expedients of Figs. 4, 5, or 6 to further increase the rectifier load capacities.

The curves of Fig. 8 illustrate the degree to which the undistorted power output may be increased in a typical modulator of this invention, as the value of R_n in Fig. 4 is increased. The abscissae represent the level in decibels referred to one milliwatt, of an input signal frequency f_s applied to a modulator provided with a carrier frequency f_c. The ordinates represent the level of single sideband output of frequency f_c-f_s or f_c+f_s. When R_n equals 0 ohms, the sideband output ceases to be proportional to the signal input as soon as the input level exceeds — 5 dbm. However, an increase in the value of R_n extends the linear range of the modulator so that, for example, if R_n is made equal to R_L (600 ohms), the output remains linearly proportional up to input levels of +15 dbm., representing an increase in permissible loading of 20 db. It will be noted that the increment of improvement decreases progressively as R_n approaches R_L. Values of R_n somewhat smaller than 600 ohms are in fact quite satisfactory. It will also be noted that the minimum loss of 5 db which occurs in the modulator is not affected by the value of R_n.

Another aspect of the invention appears at this point. When R_n equals zero and with a signal input of —5 dbm., an input carrier level of +13.5 dbm. was found to be necessary to prevent distortion. However, with R_n equal to 400 ohms and the input signal level increased to +15 dbm., the carrier power required was only increased to +23 dbm. In other words, a modulator of this invention produced substantially undistorted output with the carrier level only 8 db greater than the signal input level as compared with the differential of 18.5 db required in modulators of the prior art.

This reduction in ratio between the power levels of carier and signal which will still permit a distortionless modulated output may be explained as follows. It has already been shown that the

maximum permissible signal input voltage for the improved modulator of Fig. 4 is:

$$E_s \text{ (max.)} = I_c(R_n + R_f) \text{ peak value}$$

or

$$E_s \text{ (max.)} = \frac{I_c(R_n + R_f)}{\sqrt{2}} \text{ effective value}$$

The signal input power delivered to the modulator is:

$$P_s = \left[\frac{E_s}{2(R_L + R_f)}\right]^2 (R_L + 2R_f)$$

If R_f is considerably smaller than R_L,

$$P_s = \left[\frac{E_s}{2(R_L + R_f)}\right]^2 (R_L + R_f)$$

approximately, or

$$P_s = \frac{E_s^2}{4(R_L + R_f)}$$

The carrier input power is,

$$P_c = I_c^2\left(\frac{R_n + R_f}{2}\right)$$

but

$$I_c = \frac{\sqrt{2}E_s}{R_n + R_f}$$

for maximum signal. So

$$P_c = \left[\frac{2E_s^2}{(R_n + R_f)^2}\right]\frac{(R_n + R_f)}{2} = \frac{E_s^2}{R_n + R_f}$$

and

$$\frac{P_s}{P_c} = \frac{R_n + R_f}{4(R_L + R_f)}$$

When R_n has the optimum value of R_L,

$$\frac{P_s}{P_c} = \frac{1}{4}$$

that is, the carrier level theoretically required is only 6 db higher than the signal level. When $R_n = 0$, as in the modulator of Fig. 1, the differential is much greater since

$$\frac{P_s}{P_c} = \frac{R_f}{4(R_L + R_f)}$$

That these equations confirm the example cited in connection with the curves of Fig. 8 may be shown by computation, using the numerical values previously given of $R_f = 30$ ohms, $R_L = 600$ ohms, $R_n = 400$ ohms.

For Fig. 4,

$$\frac{P_s}{P_c} = \frac{R_n + R_f}{4(R_L + R_f)} = \frac{430}{4 \times 630} = \frac{1}{5.85}, \text{ or } 8 \text{ db}$$

For Fig. 1,

$$\frac{P_s}{P_c} = \frac{R_f}{4(R_L + R_f)} = \frac{30}{4 \times 630} = \frac{1}{84}, \text{ or } 19 \text{ db}$$

Fig. 9 illustrates the reduction in the level of certain of the prominent distortion products for a representative modulator of the type shown in Fig. 4. The abscissae represent the level of single sideband output of frequency $f_c - f_s$ or $f_c + f_s$ expressed in dbm. The ordinates then represent the level of spurious frequency $f_c - f_s$ or $f_c + 3f_s$ in decibels below the level of $f_c - f_s$ or $f_c + f_s$. It is apparent that by the use of a resistance R_n of 600 ohms the interference level may be reduced about 35 db. For example, with an output level of zero dbm., the distortion level is only 23 db below the useful sideband level when R_n is zero, but drops to a level of 58 db below the useful sideband level when R_n is made 600 ohms. Stated somewhat differently, it may be seen that the introduction of a resistance R_n of 600 ohms permits the operating level to be raised 20 db without exceeding a tolerable distortion level. In the case of Fig. 9 this increase is from −8.5 dbm. to +11.5 dbm., assuming that interference 40 db below the useful sideband level may be tolerated.

In the modulators of Figs. 4 and 5 it is, of course, more convenient to provide only the one triple winding transformer as at 1, and to concentrate resistance R_n or the batteries e at one point. However, the operation of the modulator will not be changed if a third winding is included on the transformer 2 as well and connected as in the case of transformer 1, except that the values of the resistance R_n or the batteries e will be halved so that the total resistance or biasing potential remains the same as before. Modulators built in this manner are entirely symmetrical.

The foregoing explanation has referred altogether to the modulator function of the various circuit assemblies embodying the rectifier devices. The same results, however, are realized when the device serves as a demodulator. As previously pointed out, the device of the invention is particularly suited to serve as a modulator-demodulator because of its high load carrying capacity.

While rectifier units of the copper-oxide type have been specifically referred to, other types of rectifiers or variable resistance devices may serve equally well, and the invention is intended to encompass the use of such equivalent devices.

To repeat the broad principles of the invention: It was known that for distortionless operation the signal voltage impressed upon the variable resistance elements of a modulator should not exceed the carrier voltage. It has been discovered, however, that in conventional modulator circuits the signal voltage is normally much greater on the non-conducting elements than on the conducting elements, and consequently overloading will first occur on the non-conducting elements. To compensate this, means has been devised for increasing the carrier voltage applied across the non-conducting elements to enlarge their load capacity so that these elements will not overload before the full load capacity of the conducting elements is reached. Therefore, when at full load the signal voltage becomes just equal to the carrier voltage as impressed upon the conducting elements, the signal voltage impressed upon the non-conducting elements will, at the same time, have just reached but not exceeded the carrier voltage impressed upon these elements. At all lower levels the signal voltages impressed upon both the conducting and non-conducting elements will continue to bear the same relationship to each other. These statements apply exactly in the case of the modulators of Figs. 4 and 5 and approximately to Fig. 6.

These modulators described herein differ from the conventional devices apparently only in small degree. However, it is clear that I have discovered the controlling limitations of the conventional circuit and by comparatively simple expedients have remedied these limitations and hence greatly extended the performance range. This basic improvement of the modulator has led to the very substantial operational advantages emphasized in Figs. 8 and 9, and further has greatly enlarged the useful applications of such devices.

Several embodiments of the invention have

been described but it is apparent that the principles of the invention may be practised by many other means while still lying within the scope of the appended claims.

What is claimed is:

1. A modulator of the reversing switch type comprising at least two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and adjusted at full load to be approximately equal thereto when impressed upon the resistance units while they are in the conducting condition, and means for also maintaining approximate equality of said voltages when impressed upon the resistance units while they are in the non-conducting condition.

2. A modulating device operating between two external circuits and comprising two pairs of two terminal variable resistance elements poled oppositely with respect to a source of carrier current, said pairs of elements being symmetrically connected on one side to a common pair of balanced terminals on a center-tapped impedance device associated with one external circuit, the other side of each of said two pairs of variable resistance elements being connected respectively to balanced terminals on separate center tapped impedances, associated with the other external circuit, a resistance connected between the respective center taps of said last-named separate impedances, and a source of carrier current connected between an intermediate point on said resistance and the center tap of said first-mentioned impedance.

3. A modulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units connected in bridge relationship and adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves respectively of an applied carrier voltage, means for applying a carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a predetermined relationship thereto as impressed upon said variable resistance units when they are in the conducting condition, and resistance means connected symmetrically with respect to said variable resistance units and inherently operative to increase the carrier back voltage across the non-conducting pair of said variable resistance units for continuously maintaining the same relationship of said signaling and carrier voltages as impressed upon the variable resistance units when they are in the non-conducting condition.

4. A frequency translating device terminating in two impedance elements, one of said elements having outer terminals and a center tap and the other of said elements having first and second identical portions each with outer terminals and center taps, a pair of similarly poled variable resistance elements connected between the outer terminals of said one impedance element and the outer terminals of the first portion of said other impedance element, a second pair of variable resistance elements connected between the same outer terminals of said one impedance element and the outer terminals of said second portion of the other impedance element but poled oppositely to the first pair of variable resistance elements, a resistance connected between the center taps of said first and second portions, and a source of carrier current connected between an intermediate point on said resistance and the center tap of said one impedance element.

5. A modulator-demodulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves of applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and adjusted at full load to be approximately equal thereto as impressed upon the resistance units when they are in the conducting condition, and resistance means for maintaining approximate equality of said voltages when they are impressed upon the resistance units in the non-conducting condition thereof.

6. A modulator-demodulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves of a carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a certain relationship thereto as impressed upon the resistance units when they are in the conducting condition, and additional means in series with each resistance unit and inherently operative to increase the back carrier voltage across the non-conducting pairs of said variable resistance units for continuously maintaining a similar relationship of said signaling and carrier voltages when they are impressed upon the resistance units in the non-conducting condition thereof.

7. A frequency translating device terminating in two impedance elements connected respectively to input and output circuits having similar predetermined resistive value, one of said elements having outer terminals and a center tap and the other of said elements having first and second identical portions each with outer terminals and center taps, a pair of similarly poled variable resistance elements connected between the outer terminals of said one impedance element and the outer terminals of the first portion of said other impedance element, a second pair of variable resistance elements connected between the same outer terminals of said one impedance element and the outer terminals of said second portion of the other impedance element but poled oppositely to the first pair of variable resistance elements, a resistance connected between the center taps of said first and second portions, and a source of carrier current connected between an intermediate point on said resistance and the center tap of said one impedance element, the value of said resistance being at least one half the resistance of said input and output circuits.

8. A modulator-demodulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves of an applied carrier voltage, means for applying said carrier voltage

to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a certain relationship thereto as impressed upon the resistance units when they are in the conducting condition, and means comprising sources of biasing potential effective to increase the carrier back voltage across the non-conducting pairs of said variable resistance units to such values as will continuously maintain the same relationship of said signaling and carrier voltages when impressed upon the resistance units in the non-conducting condition thereof.

9. A modulator-demodulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a random relation thereto when impressed upon the variable resistance units while they are in the conducting condition, and means comprising resistance connected symmetrically with respect to said variable resistance units and inherently operative to increase the carrier back voltage across the non-conducting pairs of said variable resistance units for continuously maintaining the same random relationship of said signaling and carrier voltages when impressed upon the variable resistance units while they are in the non-conducting condition.

10. A frequency translating device terminating in two impedance elements, one of said elements having outer terminals and a center tap and the other of said elements having first and second identical portions each with outer terminals and center taps, a pair of similarly poled variable resistance elements connected between the outer terminals of said one impedance element and the outer terminals of the first portion of said other impedance element, a second pair of variable resistance elements connected between the same outer terminals of said one impedance element and the outer terminals of said second portion of the other impedance element but poled oppositely to the first pair of variable resistance elements, a source of potential connected between the center taps of said first and second portions, and a source of carrier current connected between an intermediate point on said source of potential and the center tap of said one impedance element, said source of potential having a voltage which together with the peak carrier voltage is approximately equal to the full load peak signal voltage as impressed upon both pairs of said rectifiers.

11. A modulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units connected in bridge relationship and adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves respectively of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a certain relationship thereto when impressed upon the variable resistance units while they are in the conducting condition, and biasing means effective to increase the carrier back voltage across the non-conducting pairs of said variable resistance units to such values as will continuously maintain the same relationship of said voltages when impressed upon the variable resistance units while they are in the non-conducting condition.

12. A frequency translator of the reversing switch type comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the alternating half waves of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and means effective to increase the carrier back voltage across the non-conducting pairs of said variable resistance units to such values as will continuously maintain the same relationship between said carrier and signaling voltages as impressed upon both pairs of said resistance units, respectively.

13. A frequency translating device operating between two external circuits and comprising two pairs of two terminal variable resistance elements poled oppositely with respect to a source of carrier current, said pairs of elements being symmetrically connected on one side to a pair of balanced terminals on a center-tapped impedance device associated with one external circuit, the other side of each of said two pairs of elements being connected respectively to balanced terminals on separate center-tapped impedances associated with the other external circuit, a source of biasing potential connected between the respective center taps of said last named separate impedances, and a source of carrier current connected between an intermediate point on said source of biasing potential and the center tap of said first mentioned impedance.

14. A modulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units connected in bridge relationship and adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves respectively of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing at any instant a certain relationship thereto as impressed upon the variable resistance units when they are in the conducting condition, and resistance means in series with each variable resistance unit inherently operative to increase the carrier back voltage across the non-conducting pair of said variable resistance units for maintaining a similar relationship between said signaling and carrier voltages when impressed upon the variable resistance units while they are in the non-conducting condition.

15. A frequency translator of the reversing switch type comprising at least two pairs of oppositely poled variable resistance units, means for rendering said variable resistance units cyclically conductive and non-conductive in pairs in alternating sequence by the application of alternating half waves of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage but impressed in different magnitudes upon the conducting and non-conducting pairs of variable resistance units and means inherently operative to increase the car-

rier back voltage across the non-conducting pair of said variable resistance units for maintaining the carrier voltage as impressed upon the conducting and non-conducting variable resistance units at a corresponding difference in magnitude.

16. A modulating device operating substantially without distortion between two external circuits of predetermined similar impedance value and comprising two pairs of two terminal variable resistance elements poled oppositely with respect to a source of carrier current, said pairs of elements being symmetrically connected on one side to a common pair of balanced terminals on a center-tapped impedance device associated with one external circuit, the other side of each of said two pairs of variable resistance elements being connected respectively to balanced terminals on separate center-tapped impedances associated with the other external circuit, a resistance connected between the respective center taps of said last named separate impedances, and a source of carrier current connected between an intermediate point on said resistance and the center tap of said first mentioned impedance, the value of said resistance being equal to at least one half the value of the impedance of said external circuits.

17. A modulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units connected in bridge relationship and adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves respectively of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and adjusted at full load to be approximately equal thereto when impressed upon the variable resistance units while they are in the conducting condition, and biasing means effective to increase the back voltage across the non-conducting pairs of said variable resistance units to such value as will maintain approximate equality of said voltages when impressed upon the variable resistance units while they are in the non-conducting condition.

18. A modulator comprising two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the alternating half waves of an applied carrier voltage, and resistance means connected symmetrically with respect to said variable resistance units and inherently operative to increase the carrier back voltage across the non-conducting pairs of said variable resistance units for causing the carrier voltage impressed upon the non-conductive units to exceed the carrier voltage impressed upon the conductive units.

19. A modulator-demodulator of the reversing switch type comprising two pairs of oppositely poled variable resistance units connected in bridge relationship and adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the positive and negative half waves respectively of an applied carrier voltage, means for applying said carrier voltage to said modulator, means for applying to said modulator a signaling voltage superimposed upon said carrier voltage and bearing a certain relationship thereto when impressed upon the variable resistance units while they are in the conducting condition, and resistance means connected symmetrically with respect to said variable resistance units and inherently operative to increase the carrier back voltage across the non-conducting pairs of said variable resistance units for continuously maintaining the same relationship between said signaling and carrier voltages when impressed upon the variable resistance units while they are in the non-conducting condition.

20. A frequency translator of the reversing switch type comprising at least two pairs of oppositely poled variable resistance units adapted to be rendered cyclically conductive and non-conductive in pairs in alternating sequence by the alternating half waves of an applied carrier voltage, and means connected symmetrically with respect to said variable resistance units and inherently operative to increase the carrier back voltage across non-conducting pairs of said variable resistance units for causing said carrier voltage as applied to the non-conducting units to be larger than that applied to the conducting units.

21. The method of operating a modulator of the reversing switch type having oppositely poled variable resistance units and provided with a signal input circuit and a carrier source, which comprises impressing a carrier voltage from said carrier source on said variable resistance units to alternately modify the conducting condition thereof, superimposing a signaling voltage from said signal input circuit upon said carrier voltage, proportioning the ratio of the power levels of the carrier source and signal input respectively as impressed on the modulator at a value between four and fifty and preventing distortion at such power levels by continuously maintaining substantially the same relationship between carrier and signal input voltages impressed upon said variable resistance units in both conducting conditions thereof.

22. In a modulator of the reversing switch type having at least two pairs of oppositely poled variable resistance units connected in bridge relationship, the method of operating the same without distortion which comprises impressing a carrier voltage on said modulator to render said pairs of variable resistance units alternately conducting and non-conducting in accordance with the positive and negative half waves of carrier voltage respectively, superimposing a signaling voltage upon said carrier voltage and continually maintaining substantially the same relationship between the carrier and signal input voltages impressed upon said pairs of variable resistance units in both the conducting and non-conducting condition thereof.

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