Nov. 1, 1949 H. L. BARNEY 2,486,776

SELF-BIASED ELECTRIC TRANSLATING DEVICE

Filed April 21, 1948 2 Sheets-Sheet 1

FIG. 1

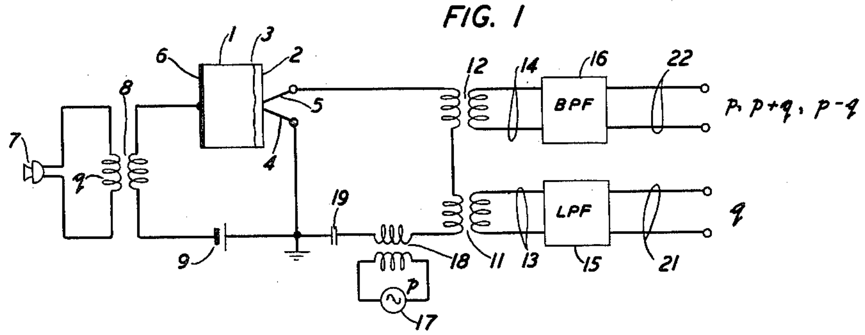

FIG. 2

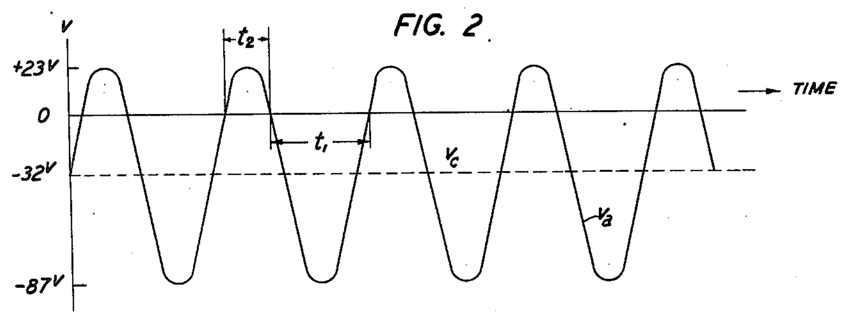

FIG. 3

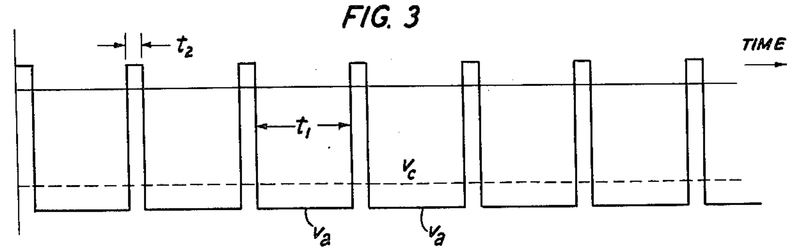

FIG. 4

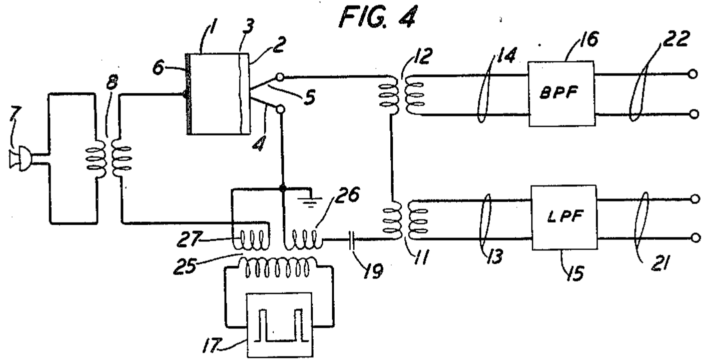

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FIG. 5

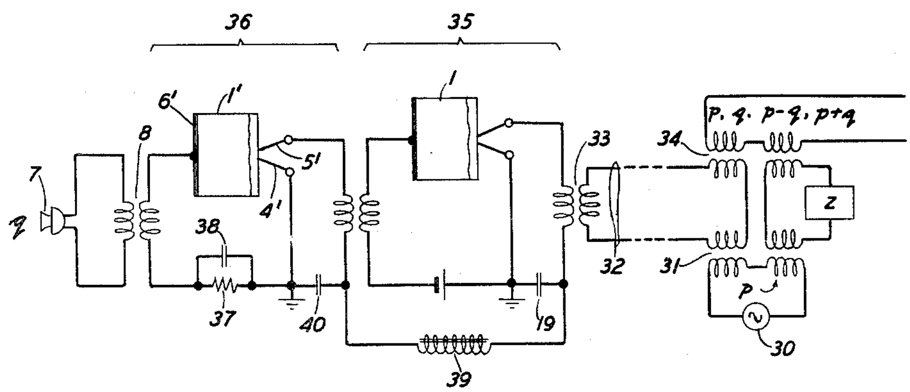
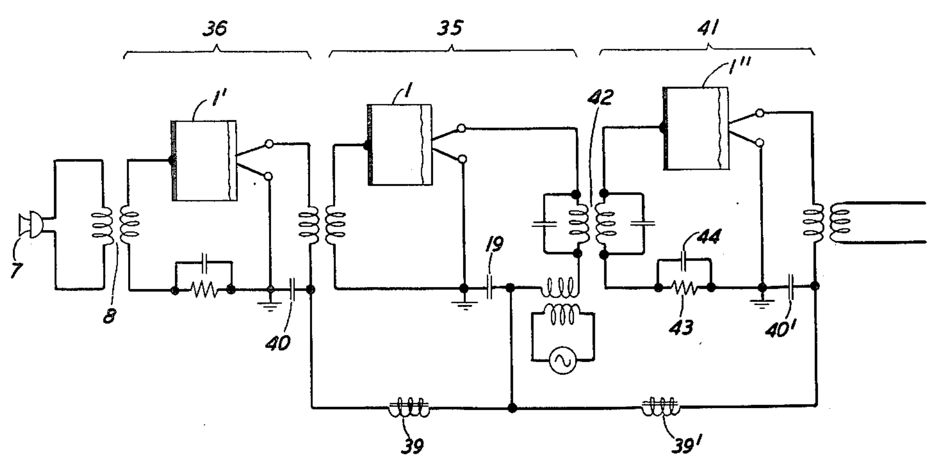


FIG. 6



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SELF-BIASED ELECTRIC TRANSLATING DEVICE

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Application April 21, 1948, Serial No. 22,276

13 Claims. (Cl. 332—52)

This invention relates to signal translation circuits including semiconductive elements.

The general object of the invention is to translate electric signals without the assistance of a source of steady potential.

A particular object of the invention is to modulate carrier energy by signal energy without resort to special power supplies or bias sources for the electrodes of the modulator apparatus. A related object is to furnish operating potentials to a signal amplifier without resort to a special power supply.

Another object is to adapt semiconductor modulators and amplifiers for service at unattended repeater stations.

A related object is to enable a plurality of translating devices to be coupled in tandem, all supplied with operating potential from one of them.

Another related object is to enable a plurality of translating devices, one of which is a semiconductor modulator, to be coupled in tandem, all supplied with energy from a carrier source only, which carrier source may be located at a remote point.

In an application of John Bardeen and W. H. Brattain, Serial No. 11,165, filed February 26, 1948, now superseded by a continuation-in-part application Serial No. 33,466, filed June 17, 1948, and thereafter allowed to become abandoned, there is described a circuit element comprising a small block of a semiconductive material such as germanium of which the body is of one conductivity type, for example, N-type, while one surface has been given a sensitizing treatment which is believed to alter the conductivity of a thin surface layer to P-type, which layer is believed to be separated from the body of the block by a high resistance barrier. Two electrodes, hereinafter denoted the emitter and the absorber, make contact with the treated surface. The absorber contact is of the rectifier type, while the emitter contact may be. A third electrode, which may be a plated metal film, makes low resistance contact with the opposite face, namely, the base of the block.

A small bias battery of one sign is applied from the control electrode to the emitter, and a larger bias battery of opposite sign is applied to the absorber. When the body material is of N-type, the emitter is biased positively, the absorber negatively. When it is of P-type, the signs are reversed. Thus the absorber rectifier contact is operated in its reverse direction.

It has been discovered that this circuit element displays remarkable amplification properties, in that when a signal to be amplified is applied between the emitter and the control electrode, an amplified replica appears across a load connected in series with the absorber.

In an application of H. L. Barney and R. C. Mathes, Serial No. 22,854, filed April 23, 1948, there is described a self-bias circuit arrangement which comprises a resistor in series with the control electrode, across which a bias voltage is developed by flow of current due to the collector bias potential source. The resistor may be bypassed for signal frequencies by a condenser. This permits the emitter-control electrode bias battery to be dispensed with. The present invention has to do with the elimination of the absorber bias battery.

The circuit arrangement of the Bardeen-Brattain application presents certain obvious similarities to a conventional amplifier circuit including a vacuum tube triode, the parallel being between emitter and cathode, control electrode and grid, absorber and anode. But the similarity holds only when the operating biases are as prescribed, and breaks down otherwise. Thus, when a negative voltage is applied to the anode of a vacuum tube triode, amplification disappears because anode current ceases to flow. When, on the other hand, a voltage of the wrong polarity is applied to the absorber electrode of the circuit element in question, amplification ceases because the control electrode loses control of the absorber current which, far from being cut off, flows more strongly than ever, by virtue of the fact that the absorber is now being operated in the forward direction. Heretofore this forward-direction current in the absorber circuit has been regarded as a disadvantage of the circuit element in question as compared with a vacuum tube triode, and as imposing limitations on the magnitude of the absorber voltage swing which can be tolerated, since with a voltage swing whose nominal peak value exceeds the bias battery voltage, the large, undesired forward-direction current would flow, limiting the voltage and destroying the amplification.

By the present invention the forward direction current is turned to advantage in the following manner. An alternating voltage, for example of carrier frequency, is applied to the absorber, and a condenser is included in the absorber circuit. The forward direction current which flows at the voltage peaks of one sign charges the condenser, and the resulting condenser voltage serves as a bias for the absorber on the voltage swings of opposite sign. The circuit element operates in alternation as a rectifier, when the condenser is charged, and as an amplifier, when the charged condenser furnishes the absorber bias. Inasmuch as the amplification of the input signal is dependent in part on the net instantaneous absorber potential, the unit operates both as a signal amplifier, a carrier translator, and a modulator, delivering at its output terminals energy having components of signal frequency, of carrier frequency, and of their various modulation products. The desired output components may be selected, and undesired ones may be rejected, by filtering.

Because the forward-direction current is much larger, for a given potential, than the reverse current, it need flow only for a small fraction of the carrier frequency period and can still charge the condenser to a substantial voltage. Amplifier operation takes place throughout the greater fraction of the carrier period, so that the duty cycle is favorable.

The invention will be fully apprehended from the following detailed description of certain preferred embodiments thereof taken in connection with the appended drawings in which:

Fig. 1 is a schematic circuit diagram of a signal translator embodying the invention;

Figs. 2 and 3 are wave form diagrams illustrating certain principles of the invention;

Fig. 4 is a schematic diagram of an alternative to Fig. 1;

Fig. 5 is a schematic diagram illustrating the extension of Fig. 1 to a system including an amplifier and a modulator which may be located remotely from a power source; and

Fig. 6 is a schematic diagram illustrating the extension of Fig. 1 to a system including a signal amplifier, a modulator, and a sideband amplifier.

Referring now to the figures, Fig. 1 is a schematic diagram showing a circuit for translating the voltage of a voice signal of frequency q. The translation may be both amplification of this voice signal and modulation of it onto a carrier signal of frequency p. The heart of the circuit is a three electrode semiconductor unit which may be of the type which forms the subject-matter of the aforesaid Bardeen-Brattain application. As a preferred example it may be a small block 1 of germanium prepared in accordance with the teachings of an application of J. H. Scaff and H. C. Theuerer, Serial No. 638,351, filed December 29, 1945, and to one surface 2 of which a sensitizing treatment has been applied, for example, an anodic oxidation process as described and claimed in an application of R. B. Gibney, Serial No. 11,167, filed February 26, 1948. Two electrodes 4, 5 which may be metal points make rectifier contact with the sensitized surface of the block 1, preferably close together. They may be denoted the emitter and the absorber, respectively. A third electrode 6 denoted the control electrode makes low resistance contact with the opposite face of the block. It may be a plated metal film. A signal to be translated, arising in a signal source here symbolically represented by a telephone transmitter 7 may be applied to the circuit by way of an input transformer 8 whose secondary winding is connected between the emitter 4 which may be at ground potential, and the control electrode 6. The output circuits of the device include the primary windings of two transformers 11, 12 by which output voltages are delivered to outgoing lines 13, 14. These primary windings are connected in the circuit of the absorber 5 and the emitter 4. Filters 15, 16 may be included in the outgoing lines 13, 14, to pass desired components of the output of the device and reject unwanted ones.

In accordance with the invention, the voltage of an alternating source, here symbolically represented by an oscillator 17 is applied by way of a transformer 18 in series with a condenser 19 between the absorber 5 and the emitter 4. The source 17 may, for example, be a source of carrier frequency which is high compared with the frequency of the signal to be translated.

The device as described in the aforementioned Bardeen-Brattain application does not include this carrier source 17 or the condenser 19. Rather, it includes a battery in the circuit of the absorber electrode, by way of which an operating bias of approximately —40 to —100 volts is applied to the absorber. According to current theory as to the operation of the device as an amplifier, the surface treatment to which the semiconductor block has been subjected results in the formation on the surface 2 of a thin layer of P-type material, perhaps 10^{-5} centimeters in thickness, separated from the body of the block by a high resistance barrier 3. With the emitter 4 biased positively with respect to the body of the block 1 by a volt or so, as by a battery 9, and the absorber 5 negatively by 40 to 100 volts, the emitter 4 operates in the forward direction and the absorber 5 in the reverse direction. These terms are familiar in the point contact rectifier art. As a consequence, mobile positive charges flow from the emitter 4 to the block 1, but because of the transverse resistance of the barrier 3 which is considerably higher than the lateral resistance of the surface layer 2, these mobile positive charges travel laterally in the surface layer away from the emitter rather than immediately crossing the barrier. In the course of this lateral spread of current it comes within the influence of a strong electric field which exists in the neighborhood of the absorber 5, i. e., between it and fixed charges in the body of the material. The mobile charges are here collected and flow out of the layer by way of the absorber electrode. A signal applied between the emitter 4 and the body of the block produces an electric field whose strength is greatest across the barrier 3. This field modifies the current of mobile charges flowing from the emitter to the surface layer and so the current in the external absorber circuit and the voltage across a suitable load. Thus amplification is obtained.

In the Bardeen-Brattain application, the control of the emitter current by a signal applied between the emitter and the body of the block is exerted only when there is applied to the absorber 5 a bias of substantial magnitude and of a sign such as to cause the absorber to operate in its reverse direction; that is to say with a negative bias on the absorber in the case of a block of N-type material and a positive bias in the case of a block of P-type material. When the bias is applied with the wrong sign, the absorber operates in its forward direction, a large current flows and control of the absorber current by a voltage applied to the control electrode is lost.

When an alternating voltage derived, for example, from the carrier source 17 is applied by way of the transformer 18 to the absorber electrode 5, it is of the right polarity to work the absorber in its reverse direction and produce amplification during one half of each cycle, while during the other half of the cycle it is of the opposite polarity and a large uncontrolled current flows in the absorber circuit. Thus modulation of the carrier by the signal takes place during alternate half cycles, but this result is obtained at the cost of dissipation of large amounts of carrier frequency power in the semiconductor block 1 during the intervening half cycle, and the system is therefore not efficient. When, however, in accordance with the present invention, a condenser 19 is included in the circuit, the forward direction current flows only during the short time necessary to charge the condenser. Because of the low forward resistance of the barrier 3 of the semiconductor block, the condenser 19 is charged to a substantial fraction of the peak voltage of the carrier. On the ensuing half cycle, its voltage is added to the applied carrier voltage. Thus the condenser, charged in the fashion described, serves as a bias source for the absorber 5.

The condenser charge once applied leaks off only slowly by way of the high reverse resistance of the absorber contact. Therefore, on later positive half cycles of the carrier voltage, still less current is required to charge the condenser. Indeed, only that small current flows which is required to replace the small fraction of the condenser charge which may have leaked off during the prior cycle.

Fig. 2 is a voltage-time diagram illustrating the foregoing in the steady state after the initial transient conditions which arise when the system is first turned on have died away. The curve V_a represents the wave form of a sinusoidal carrier voltage of frequency p derived from the carrier source 17 and applied from the emitter 4 to the absorber 5. Were it not for the addition of the condenser 19 in the absorber circuit, the voltage would be symmetrically located about the zero voltage axis. Due, however, to the charging of the condenser 19 in the manner described above, the carrier voltage wave form is displaced in a negative direction so that it lies symmetrically about a negative voltage. In the illustration shown which is based on experimental results, the negative condenser voltage V_c about which the carrier wave form is symmetrically distributed is -32 volts, so that the carrier voltage, whose peak to peak magnitude is 110 volts, swings from $+23$ volts to -87 volts. It has positive values greater than zero only for a fraction t_2, approximately one-fifth, of each period. Therefore, the system operates as an amplifier throughout the fraction t_1, while the smaller fraction t_2 is utilized for maintaining the condenser charge. During the working fraction t_1, the absorber voltage is being changed from 0 to a negative voltage of -87 volts and back to zero in approximately sinusoidal fashion. Therefore, the amplification of the unit is correspondingly varied. As a result, the output of the system which appears on the output transformers 11, 12 and is delivered to the outgoing lines 13, 14 contains, in addition to the signal frequency q, components of the carrier frequency p and of the modulation products between them, for example, upper and lower side frequencies $p+q$ and $p-q$. Any desired frequency band, or several together, may be supplied to a load circuit. Thus a low pass filter 15 blocks all components of frequencies higher than the voice frequencies, passing these to an outgoing line 21, while a band pass filter 16 passes the carrier and the two sidebands to another outgoing line 22, and blocks all other frequencies.

With a sinusoidal carrier, the signal frequency output is low. Furthermore, any control electrode bias battery is a compromise between the correct bias values for the various absorber voltages occurring in the absorber cycle. These defects may be overcome by the use of a square wave carrier as indicated in Fig. 3, which comprises swings of one polarity and of short durations t_2, alternating with swings of the opposite polarity and of longer durations t_1. As before, the polarities are so chosen that the longer times are in reverse direction with respect to the absorber rectifier contact. As before, the condenser is charged by the forward direction current which flows during the fraction t_2 of each cycle, and the resulting charged condenser voltage is added to that of the carrier during the longer fraction t_1 of each cycle. Now, however, the absorber voltage is substantially constant throughout the fraction t_1, so that the control electrode bias may be selected at the best value for this particular absorber voltage, without compromise.

A further advantage of the square wave carrier is that the signal frequency output of the device is increased as compared with the carrier and side frequency output. Therefore the square wave is to be preferred for an amplifier while, unless the control electrode bias compromise is too great, the sine wave is generally to be preferred for a modulator.

Instead of a control electrode bias battery, the control electrode bias may be supplied from the carrier source 17, whether the wave form of the latter be sinusoidal or square. Fig. 4 shows such a system wherein the carrier source 17 is applied by way of one winding 26 of a transformer 25 to the absorber 5 and by way of another winding 27 of the transformer 25 to the control electrode 6. The windings 26, 27 are so poled that the absorber 5 and the control electrode 6 are simultaneously positive and simultaneously negative with respect to the emitter 4, and the transformer 25 is wound to apply one or two volts through winding 27 to the control electrode 6 and 50 to 100 volts through winding 26 to the absorber 5. During the working fractions t_1 of the cycle, the magnitude and polartiy of the control electrode bias are then correct while during the fractions t_2 of the cycle, it is incorrect, but at these times the condenser 19 is being charged by the carrier source 17, the unit is not translating the signal, and the sign of the control electrode bias is of no importance.

The translator of Fig. 1 which, as above explained, draws all its required operating power from the carrier source 17, is adapted to be located at an unattended repeater station, drawing carrier power from a remotely located point. Furthermore, inasmuch as the condenser 19 of Fig. 1 serves as a bias potential source, the potential of this condenser may be applied to provide the bias potential for other units, for example amplifiers. Fig. 5 shows a system in which both of these features are included. A translator unit 35 which may be identical with that of Fig. 1 and which may serve, for example, to modulate a carrier p by a signal q, is supplied with carrier power derived from a remotely located oscillator 30 by way of a hybrid coil 31 and a transmission line 32 which is terminated at the modulator in the winding of a transformer 33. Modulated output likewise passes over the transmission line 32 and is fed to an output circuit by way of a second hybrid coil 34. A terminal impedance Z is included in the circuit in well-known fashion.

The input to the modulator 35 is derived from an amplifier 36 such, for example, as the semiconductor amplifier which forms the subject-matter of the aforementioned Bardeen-Brattain application. Its electrodes are designated by the same reference numerals as are used in Fig. 1, distinguished by primes. Control electrode bias may be provided by inclusion of a self-bias resistor 37 in the control electrode-emitter circuit, by-passed by a condenser 38, in the manner described in the aforementioned application of H. L. Barney and R. C. Mathes, Serial No. 22,854, filed April 23, 1948.

The input signal to this amplifier may be derived from any desired source, for example, a telephone transmitter 7 which delivers a voltage of frequency q to the primary winding of a transformer 8 whose secondary winding is connected in the control-emitter circuit.

The amplifier of the aforementioned Barney-Mathes application includes a battery as a bias source in the absorber circuit. In accordance with the present invention, however, a suitable negative voltage is applied to the absorber electrode 5′ of the amplifier 36 by way of a choke coil 39 or other decoupling impedance which permits the application of steady voltages but prevents the flow of signal energy. A signal frequency by-pass condenser 40 may be included in the circuit.

Any number of amplifier stages may be connected ahead of the modulator 35, the limit being determined only by the amount of forward current which can safely be drawn through the absorber contact of the modulator. On the other hand the translator unit 35 may, if preferred, serve principally as an amplifier. In the general case the output contains all of the components indicated on the figure.

This aspect of the invention is equally applicable to a sideband amplifier. Fig. 6 shows a signal amplifier 36 and a modulator 35 similar to those of Fig. 5 and similarly coupled, with the amplifier 36 drawing its absorber bias voltage from the charged condenser 13 of the modulator 35. The modulator output instead of being transmitted directly over an outgoing line is first amplified by a sideband amplifier 41 which may be identical in construction with the signal amplifier and receives carrier and sideband energy from the modulator by way of the interstage transformer 42. The latter may be tuned to pass the desired frequencies and reject unwanted ones. As in the case of the signal frequency amplifier 36 its control electrode may be negatively biased by a self-bias resistor 43 and the latter may be shunted by a condenser 44 as a sideband frequency by-pass.

The necessary operating bias potential for the absorbers of all stages may be derived from the charged condenser 19 and applied to the absorbers by way of choke coils 39, 39′ or other decoupling impedance elements. By-pass condensers 40, 40′ may be included in the circuit in each case.

The invention has been shown, described and explained in connection with a semiconductor amplifier unit, connected in the fashion of a conventional triode; that is to say, with the emitter electrode grounded. It is equally applicable to other triode circuits such as the grounded grid circuit and the grounded anode or cathode follower circuit. Furthermore, it is not restricted to use in connection with the semiconductor amplifier specifically shown in the aforementioned Bardeen-Brattain application, but is equally applicable to similar units whose operation is based on the same principle.

Still other modifications within the spirit of

the invention will be apparent to those skilled in the art.

What is claimed is:

1. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, means for impressing forward and reverse direction potentials in alternation on said absorber, and means for deriving a reverse direction bias for said absorber from forward direction absorber currents which flow in response to said forward direction potentials.

2. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, an alternating current source, means for causing absorber currents to flow through said rectifier contact in alternately opposite directions, means for utilizing the current flow in one of said directions to provide a bias voltage, and means for applying said bias voltage to said absorber in a sense to promote said reverse direction current flow.

3. In combination with signal translation apparatus comprising a block of semi-conductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, and an alternating voltage source and a condenser connected in series with said absorber electrode.

4. Apparatus as defined in the preceding claim, wherein the wave form of the source voltage is rectangular.

5. Apparatus as defined in claim 3 wherein the wave form of the source voltage is rectangular, having swings of short duration in the condenser-charging polarity and swings of longer duration in the amplifying polarity.

6. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which it variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, an alternating voltage source, a condenser, and a load impedance connected in series with said absorber, and a signal source connected to said control electrode.

7. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an ab-

sorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, a condenser in series with said absorber, a source of alternating voltage, and means for simultaneously applying the voltage of said source to said absorber and to said control electrode with like polarity.

8. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, impedance means for deriving a voltage drop from forward direction absorber current flow, and means for applying said voltage drop in a sense to aid said reverse direction absorber current flow.

9. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, means for applying an alternating voltage to said absorber, means for deriving a steady voltage from forward direction absorber current flowing under the action of said alternating voltage, and means for applying said steady voltage in a sense to aid said alternating voltage in producing reverse direction absorber current.

10. In combination with signal translation apparatus comprising a block of semiconductor material, an emitter electrode and a control electrode in contact with said block and an absorber electrode making rectifier contact with said block, said apparatus being characterized by reverse direction absorber current which is variable under control of a signal applied to the control electrode and a larger forward direction absorber current which is not so controllable, a signal source coupled to said control electrode, an impedance element and a condenser connected in series with said absorber, an alternating voltage source located at a remote point, a utilization circuit located at said remote point, a transmission line interconnecting said remote point with said impedance element, said line being coupled to said source and to said utilization circuit, and means for preventing substantial amounts of the energy of said source from being directly transmitted to said utilization circuit.

11. The combination which comprises a carrier source, a signal source, a plurality of signal translation stages coupled together, each stage

comprising a block of semiconductor material, an emitter electrode, an absorber electrode, and a control electrode in contact therewith, each of said stages requiring for proper operation a substantially steady bias potential on the absorber electrode, a carrier source, a signal source, at least one of said stages serving as a modulator of which the absorber electrode makes rectifier contact with the block, said modulator being characterized by a reverse direction absorber current which is variable under control of a signal applied to its control electrode and a larger forward direction absorber current which is not so controllable, connections for applying the voltage of said carrier source to said modulator absorber, means for deriving a steady voltage from forward direction modulator absorber current flowing under the influence of said carrier voltage, and means for applying said steady voltage as a bias potential to the absorber electrode of another stage.

12. In combination with a circuit element comprising a body of semiconductive material, an emitter electrode making contact with said body over an area which is small compared with the dimensions of said body, a control electrode making low resistance contact with said body, and an absorber electrode making rectifier contact with said body, an alternating current source connected to apply a potential to said absorber which is alternately in the forward direction and in the reverse direction with respect to said rectifier contact, a condenser connected in series with said source and said absorber, which condenser becomes charged by current flowing in the forward direction from said source, a signal source connected to said control electrode for influencing the magnitude of the reverse current flowing from said source, and an impedance element connected to carry said reverse current, whereby modulation product voltages between the frequencies of said sources are developed across said impedance element.

13. In combination with a circuit element comprising a semiconductive body, an emitter electrode making contact with said body, an absorber electrode making rectifier contact with said body, and a control electrode making low resistance contact with said body, a carrier source supplying energy to said absorber electrode, a signal source supplying energy to said control electrode, and a condenser connected in series with said carrier source and said absorber electrode, whereby a steady voltage appears across said condenser due to rectification of the current of said carrier source, said voltage being applied to said absorber as an operating bias.

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