

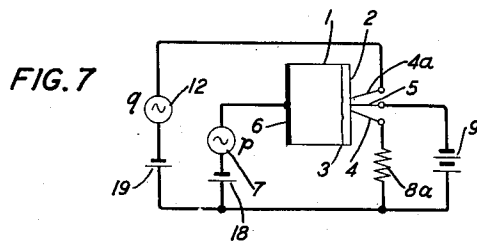
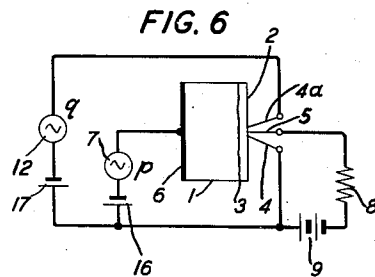
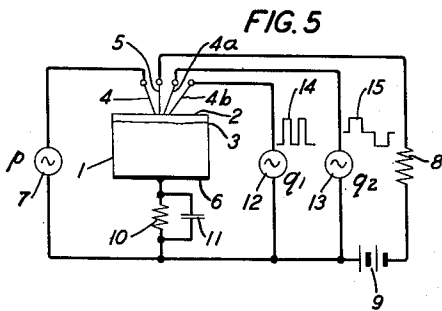
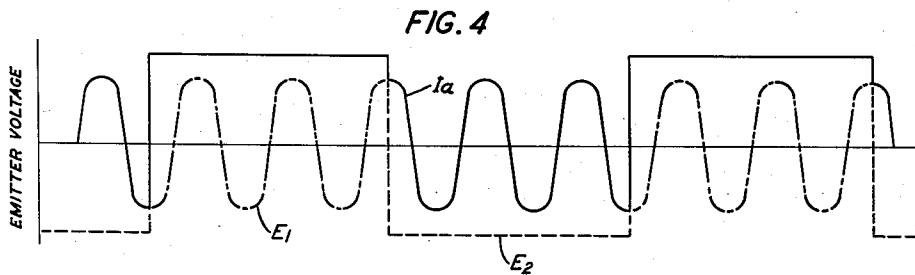
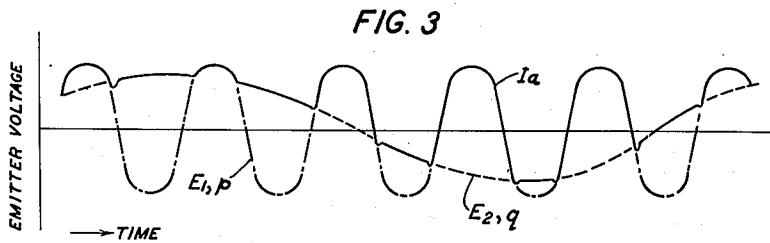
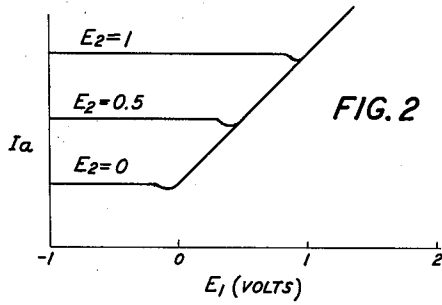
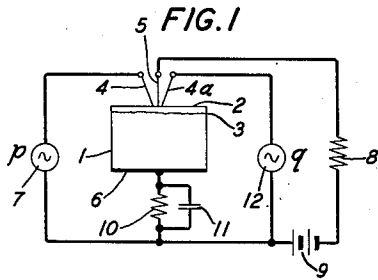
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MULTIELECTRODE MODULATOR

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MULTIELECTRODE MODULATOR

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7 Claims. (Cl. 332-52)

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This invention relates to signal translation circuits including semiconductive elements.

The general object of the invention is to modulate one electric signal by another. A particular object is to gate or switch one electric signal by another or by a plurality of others.

In an application of John Bardeen and W. H. Brattain, Serial No. 11,165, filed February 26, 1948, now superseded by a continuation-in-part application Serial No. 33,466, filed June 17, 1948, and thereafter allowed to become abandoned, there is described a circuit element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 face 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 (or collector), make contact with the treated surface. The absorber contact is of the rectifier type while the emitter contact may be similar. A third electrode, termed the control (or base) 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 of one sign is applied from the control electrode to the emitter and a larger bias 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 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.

The device has subsequently come to be known as a "transistor."

The Bardeen-Brattain application suggests that a plurality of absorber electrodes (termed collector electrodes in that application) may surround the emitter, being connected together, to increase the fraction of emitter current which is collected by them as compared with that which results with a single absorber electrode. By the present invention, the opposite course is followed. One or more auxiliary emitter electrodes are employed in conjunction with the original emitter electrode and with a single absorber electrode, and signal voltages are applied to the several emitter electrodes individually. It has been discovered that whichever one of the emitter electrodes is most positive takes full control, the unit behaving as though the other emitters were absent. As the signal voltages change, therefore, first one emitter

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takes control, then another, the control function being passed from one to another as their voltages change.

This behavior of the multi-emitter unit adapts it to use as a modulator and a time coincidence gate. When it is employed as a modulator a carrier voltage, for example of sinusoidal wave form, may be applied to one of the emitter electrodes, a signal voltage being applied to another. The output, in addition to other modulation products which may be rejected by known techniques, contains a component of the carrier frequency and upper and lower side frequencies. When employed as a time coincidence gate, a signal to be translated may be applied to one emitter electrode and gating pulses may be applied to others. As long as the pulse voltage applied to any of these other emitter electrodes exceeds the signal voltage, the signal voltage is not translated. When the auxiliary emitter electrodes are all more negative in potential than the signal emitter electrode, the unit translates the signal. Thus it produces a translated signal when, and only when, voltages of suitable magnitude, applied to the auxiliary emitter electrodes, coincide in time.

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

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

Fig. 2 is a set of characteristic curves of the unit illustrated in Fig. 1;

Figs. 3 and 4 are wave form diagrams illustrative of the performance of the apparatus of Fig. 1;

Fig. 5 is a schematic circuit diagram of a time coincidence gate embodying the invention; and

Figs. 6 and 7 are schematic circuit diagrams showing alternatives to Fig. 1.

Referring now to the drawings, Fig. 1 is a schematic diagram showing a circuit for translating the voltage of a first signal of frequency p and for modulating it by a second signal of frequency q . For example, the frequency q may be that of a voice signal, in the range 100 to 4,000 cycles per second, while the frequency p may be that of a carrier, for example, 8,000 cycles per second. The heart of the circuit is a semiconductor unit which may be of the type which forms the subject-matter of the aforesaid Bardeen-Brattain application with the electrode arrangement modified in accordance with the present invention. In brief and 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 2 of the block 1, preferably close together. They may be denoted the first emitter electrode and the absorber, respectively. A third electrode, denoted the control electrode, makes low resistance contact with the opposite face of the block 1. It may be a plated metal film 6. A signal of frequency p , derived from a signal source 7 may be applied between the control electrode 6 and the first emitter 4. The output circuit of the device may include a suitable load such as a resistor 8 and a bias battery 9. When the body of the block 1 is of N-type material, the bias battery 9 is poled as shown, with its negative terminal connected by way of the load resistor to the absorber electrode 5. For best operation, the first emitter electrode 4 should be biased positively by a volt or so with respect to the body of the block. This may be accomplished by the use of a battery, or preferably by a self-bias resistor 10 which may be shunted by a by-pass condenser 11 as described in an application of H. L. Barney and R. C. Mathes, Serial No. 22,854, filed April 23, 1948.

In accordance with the present invention, an auxiliary emitter electrode 4a is added, which may be structurally similar to the first emitter electrode 4 and makes contact with the block 1 in similar fashion. The auxiliary emitter 4a may be spaced from the absorber electrode 5 by a distance approximately equal to that which separates the absorber 5 and the first emitter 4. For example, the two emitter electrodes 4, 4a may be equally spaced on either side of the absorber electrode 5. A suitable voltage, derived from a source 12 is applied between this auxiliary electrode and the control electrode.

According to current theory as to the operation of the device described in the aforementioned Bardeen-Brattain application, the surface treatment to which the semiconductor block 1 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 first emitter 4 biased positively with respect to the body of the block by a volt or so and the absorber electrode 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 first emitter 4 to the block, 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 first emitter 4 rather than immediately crossing the barrier 3. 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 electrode 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 5. A signal applied between the first 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 4 to the surface layer 2 and so the current in the external absorber circuit and the voltage across a suitable load 8. Thus amplification is obtained.

The present invention is based on the discovery that when similar emitter electrodes make contact with the block, substantially equally spaced from the absorber electrode, and signal voltages are applied to them individually, the emitter electrode to which the greater of the two voltages is applied takes full control of the unit, which behaves substantially as though the emitter having the lesser of the two voltages were removed. This situation is graphically depicted in Fig. 2 which shows characteristic curves of the device in which the absorber current I_a is plotted as a function of the voltage E_1 applied to the first emitter 4, for various values of the voltage E_2 applied to the auxiliary emitter 4a. It will be seen that, as long as the voltage E_1 is in excess of the voltage E_2 , the unit operates as an approximately linear amplifier of the voltage E_1 , translating this voltage into an absorber current which is substantially proportional thereto. However, when the voltage E_2 exceeds the voltage E_1 , the amplification properties of the device disappear, the absorber current I_a now having a value dependent on the voltage E_2 , but independent of the voltage E_1 .

From the foregoing explanation, the effect of the joint application of two sinusoidal signals of different frequencies to the two emitter electrodes will be clear. Referring to Fig. 3 as an example, if a sinusoidal voltage E_1 of a higher frequency p be applied to the first emitter electrode, while another sinusoidal voltage E_2 of a lower frequency q is applied to the auxiliary emitter electrode, the unit will translate the signal of frequency p at times when the first emitter electrode is at a higher potential than the auxiliary emitter electrode and not otherwise. The wave form of the resulting absorber current I_a is indicated in the figure. This wave form evidently differs from the symmetrical modulated wave which is familiar as the output of a vacuum tube modulator. Nevertheless, it contains, in addition to miscellaneous modulation products which can be rejected, if desired, by filters or otherwise, a component of the frequency p and upper and lower side frequencies $p+q$ and $p-q$, respectively. Thus the unit operates as a modulator.

There is, of course, no necessity that either or both of the input voltages to the device be sinusoidal. For example, a voltage E_1 of a high frequency may be applied to the first emitter electrode 4, while a voltage E_2 of lower frequency and square wave form and amplitude exceeding that of the high frequency voltage both on its positive and negative swings may be applied to the auxiliary emitter 4a as indicated in Fig. 4, in which case the resulting output wave form of the absorber current I_a is as indicated by the solid curve. This consists of a substantial replica of the signal E_1 during intervals in which the voltage E_2 applied to the auxiliary emitter 4a is negative, and of a current which is substantially constant in magnitude and proportional to the magnitude of the square wave voltage E_2 at other times. The latter may be rejected by the use of filters or otherwise as desired, in which case the output of the device consists of a current of frequency p which is gated or switched on and off by the square wave E_2 .

If desired, more than one auxiliary electrode may be employed in conjunction with the first emitter electrode. Such a system is useful as a gate circuit in which a signal is to be translated only during the joint temporal coincidence of pulses from two different sources. Fig. 5 shows such a system, in which various elements of simi-

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lar structure and function to those of Fig. 1 are designated by the same reference characters. In addition, however, to the auxiliary emitter electrode 4a of Fig. 1, there is provided a second auxiliary emitter electrode 4b of similar structure and disposition with respect to the absorber 5. A signal of frequency p may be applied to the first emitter 4, as before, while gating pulses derived from sources 12, 13, may be applied to the two auxiliary emitters 4a, 4b. These may be rectangular pulses 14, 15 of different frequencies or different durations or both. From the foregoing description it will be understood that, with the choice of suitable magnitudes for the pulse voltages q_1 and q_2 , the signal p is translated into an absorber current when, and only when the potentials of both of the auxiliary emitter electrodes 4a, 4b are negative with respect to the first emitter electrode 4.

The invention is generally applicable to circuit arrangements of other configurations. Whereas Figs. 1 and 5 are analogous to the so-called "grounded grid" circuit arrangement which has become well known in connection with triode amplifiers, Fig. 6 is analogous to the conventional grounded cathode circuit and Fig. 7 is analogous to the conventional grounded anode or cathode follower circuit. In each case elements similar to those of Fig. 1 are designated by similar reference characters. The mean voltages about which the signals p and q oscillate may be adjusted to appropriate values by the use of bias batteries 16, 17, 18, 19 as indicated or, if preferred, the resistor-condenser combination shown in Figs. 1 and 5 may be employed.

The multi-electrode structure of Fig. 5 may also be connected in the alternative circuits of Figs. 6 and 7, if desired.

It is explained in the aforementioned application of John Bardeen and W. H. Brattain that if a semiconductor block of P-type conductivity bearing a surface layer which is of N-type be employed, the polarities of all voltages are to be reversed. The same holds for the present invention. Thus, if such interchange were to be made, the most negative of all the emitter electrodes 4, 4a, 4b would be the controlling one.

The invention has been described as applied to the structure described and claimed in the aforementioned Bardeen-Brattain application as a preferred example. It is, however, not necessarily restricted thereto, but is also applicable to semiconductor amplifier units of other materials, other configurations, and other electrode arrangements.

What is claimed is:

1. A modulator which comprises a semiconductor body, an absorber electrode making rectifier contact with said body, a control electrode making low resistance contact with said body, at least two additional electrodes making contact with said body, each of said additional electrodes being so biased and disposed with respect to said body as to act as an emitter of electric charges into said body within the influence of said absorber electrode, connections for applying a signal to be modulated to one of said additional electrodes, and connections for applying a modulating signal to another of said additional electrodes.

2. A modulator which comprises a semiconductor body, an absorber electrode making rectifier contact with said body, at least two additional electrodes making contact with said body, each of said additional electrodes being so biased and

disposed with respect to said body as to act as an emitter of electric charges into said body within the influence of said absorber electrode, connections for applying a signal to be modulated between said body and one of said additional electrodes, and connections for applying a modulating signal between said body and another of said additional electrodes.

3. Signal translation apparatus which comprises a semi-conductive body, an absorber electrode making rectifier contact with said body, at least two additional electrodes making contact with said body, each of said additional electrodes being so biased and disposed with respect to said body as to act as an emitter of electric charges into said body within the influence of said absorber electrode, connections for applying a signal to one of said additional electrodes, and connections for applying gating pulses to another of said additional electrodes.

4. Signal translation apparatus which comprises a semiconductor body, an absorber electrode making rectifier contact with said body, a plurality of additional electrodes making contact with said body and symmetrically disposed with respect to said absorber electrode, each of said additional electrodes being so biased as to act as an emitter of electric charges into said body within the influence of said absorber electrode, connections for applying a signal to one of said additional electrodes, and connections for applying gating pulses individually to others of said additional electrodes.

5. Signal translation apparatus which comprises a semi-conductive body, an absorber electrode making rectifier contact with said body, a control electrode making low resistance contact with said body, at least two additional electrodes making contact with said body, each of said additional electrodes being so biased and disposed with respect to said body as to act as an emitter of electric charges into said body within the influence of said absorber electrode, a plurality of separate alternating signal sources of different characteristics, and connections for applying the voltages of said sources individually to said additional electrodes, whereby said additional electrodes take control of the absorber current in alternation.

6. Signal translation apparatus which comprises a semi-conductive body, a control electrode making low resistance contact with said body, at least three additional electrodes making contact with said body, one of said additional electrodes being biased for conduction in the reverse direction, others being biased for conduction in the forward direction, connections for applying a first signal to one of said additional electrodes, and connections for applying a second signal to another of said additional electrodes.

7. A modulator which comprises a semiconductor body, an absorber electrode making rectifier contact with said body, a control electrode making low resistance contact with said body, at least two additional electrodes making contact with said body, each of said additional electrodes being so biased and disposed with respect to said body as to act as an emitter of electric charges into said body within the influence of said absorber electrode, connections for applying a signal to be modulated to one of said additional electrodes, and connections for applying a modulating signal to the other of said additional electrodes.

ALOIS J. RACK.

No references cited.