Oct. 21, 1930. P. H. CRAIG 1,778,796

SYSTEM AND APPARATUS EMPLOYING THE HALL EFFECT

Original Filed July 9, 1926 2 Sheets-Sheet 1

FIG. 1

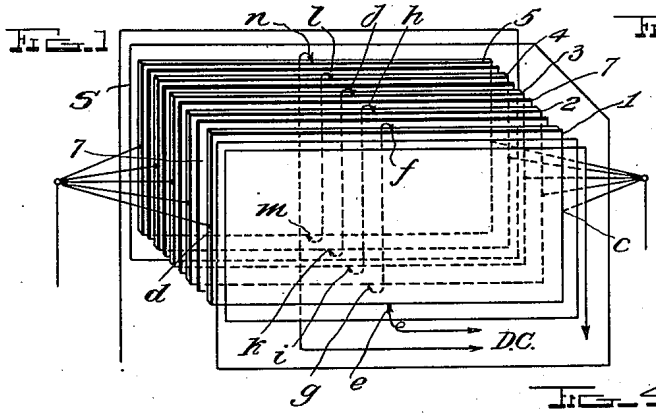


FIG. 2

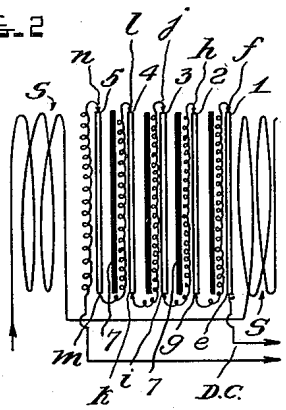


FIG. 4

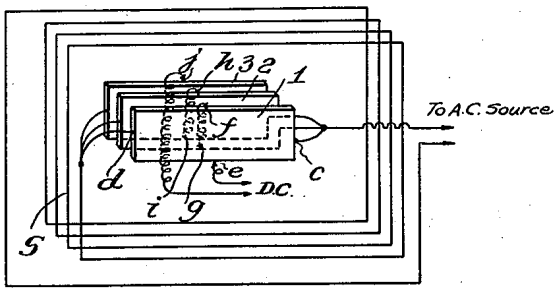


FIG. 3

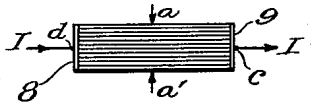


FIG. 9

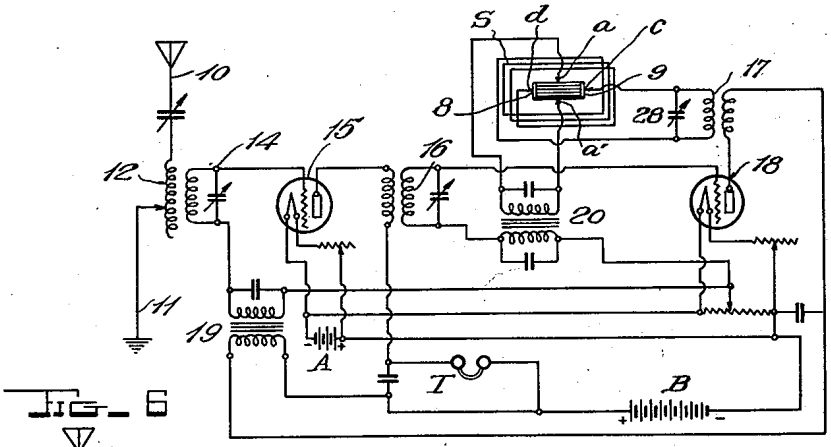
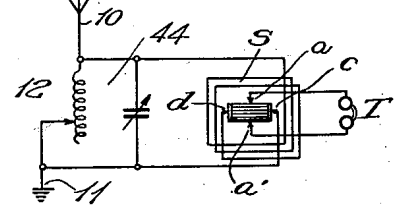


FIG. 6



INVENTOR.
Palmer H. Craig
BY
John B Brady
ATTORNEYS.

Oct. 21, 1930. P. H. CRAIG 1,778,796

SYSTEM AND APPARATUS EMPLOYING THE HALL EFFECT

Original Filed July 9, 1926 2 Sheets-Sheet 2

Fig. 7

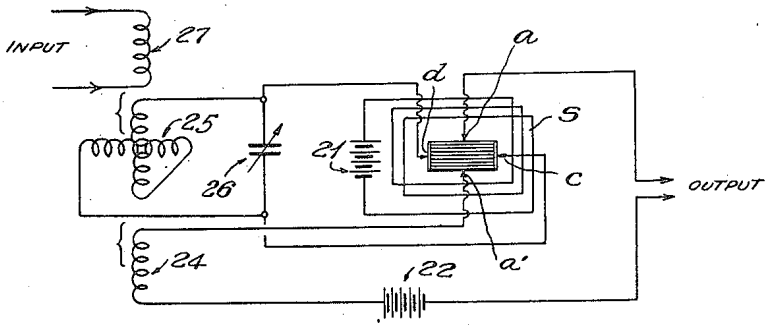


Fig. 8

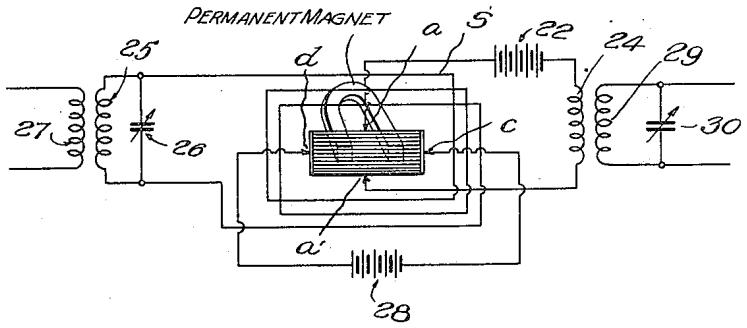


Fig. 9

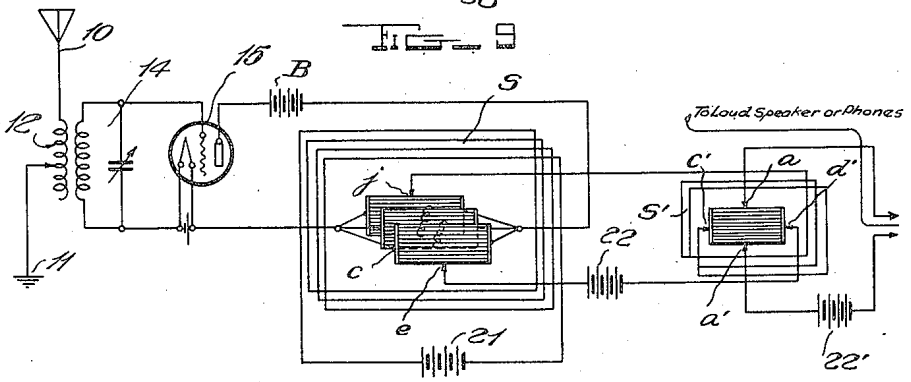
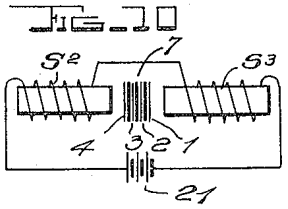


Fig. 10



INVENTOR.
Palmer H. Craig
BY
John C. Brady
ATTORNEYS.

Patented Oct. 21, 1930 1,778,796

UNITED STATES PATENT OFFICE

PALMER HUNT CRAIG, OF CINCINNATI, OHIO

SYSTEM AND APPARATUS EMPLOYING THE HALL EFFECT

Original application filed July 9, 1926, Serial No. 121,394. Divided and this application filed January 14, 1929. Serial No. 332,544.

My invention relates broadly to electrical apparatus for modifying the character of electrical current and more particularly an apparatus for effectively employing the transverse potential difference in certain metallic plates when subjected to the action of a longitudinal current and the influence of a magnetic field.

This application is a division of my application S. N. 121,394, filed July 9, 1926 for system and apparatus employing the Hall effect.

One of the objects of my invention is to provide a device consisting of a plurality of rectangular metallic foil sheets or metallic alloy plates in stacked arrangement insulated one from another and electrically connected in parallel at opposite ends thereof and in series along the transverse axis thereof, whereby current of direct current characteristic may be secured in a circuit which connects to points along the transverse axes of the plates when alternating current is supplied to the opposite end of the plates and a magnetic field created around the plates.

Another object of my invention is to provide a construction of fixed rectifier for alternating current which remains in permanent adjustment and does not require resetting from time to time.

Another object of my invention is to provide a device for modifying electrical current of alternating characteristic for rectifying, amplifying or causing the generation of electrical oscillations of any selected frequency.

Still another object of my invention is to provide an electrical apparatus particularly adapted for operation in conjunction with the circuits of a radio receiving system for rendering feeble signal currents observable.

A still further object of my invention is to provide an apparatus unit which may be connected in circuit with electron tube apparatus for facilitating the operation of the electron tube apparatus in the reception of signaling energy.

Other and further objects of my invention will be understood from the specification hereinafter following by reference to the accompanying drawings in which:

Figure 1 represents in perspective view the arrangement of parts in the apparatus of my invention; Fig. 2 is an end view of the apparatus showing more clearly the direction of the magnetic field perpendicular to the plane of the metallic plates; Fig. 3 is a schematic view showing the arrangement of the metallic films which comprise the apparatus of my invention; Fig. 4 is a diagrammatic view showing the wiring arrangement of the apparatus of my invention when used as a rectifier; Fig. 5 shows one of the applications of my invention in a reflex signaling receiving circuit; Fig. 6 illustrates an application of my invention as a detector in a radio receiving circuit; Fig. 7 shows a circuit arrangement which makes use of the principles of my invention in the amplification of signal energy, provision being made for facilitating the production of oscillations; Fig. 8 shows a circuit arrangement wherein the longitudinal current which passes through the plates of the apparatus of my invention is derived from a source independent of the source which creates the magnetic field about the plates; Fig. 9, illustrates a circuit arrangement employing a plurality of the devices of my invention as an amplifier of incoming signaling energy and as a rectifier of the amplified energy; and Fig. 10 shows the fundamental arrangement of the magnetic field transverse to the plane of the several metallic films in the apparatus for developing the principles set forth herein.

My invention makes use of the "Hall", "Corbino" and similar electromagnetic phenomena for the rectification or amplification of alternating currents, and the generation of sustained electrical oscillations in electrical circuits.

The "Hall" effect consists, briefly, of an electromagnetic phenomena observable when a strip or film of metal carrying a longitudinal current I, (Fig. 3) is placed in a magnetic field perpendicular to the plane of such a strip, a transverse potential difference being set up between the edges a, a', of the strip, this difference of potential being ap-

proximately, under normal conditions, represented by the formula:

$$E=\frac{HI}{d}$$

where { E=the transverse potential difference; I=the current (longitudinal) through the strip; d=the thickness of the strip. H=the magnetic field strength.

The "Corbino" effect is similar to the "Hall" effect, wherein a radial current through a circular disc subjected to a magnetic field perpendicular to the plane of the disc, produces a "circular" current through the disc.

I have discovered that if plates or films of metal such as bismuth, tellurium, bismuth-antimony alloy, or other metal or alloy, be connected as shown in the drawings, the device will act as a practical rectifier of impressed alternating currents. Referring to the drawings in Fig. 4, the alternating current is sent through the strip 1 from *c* to *d*, in one-half of the cycle, and from *d* it enters the solenoid S, being an air core or a core of magnetic material, thence after passing through the solenoid it returns to the alternating current source. In the other half of the cycle the operation is, of course, reversed.

Fig. 4 also shows the method of stacking many plates 1, 2 and 3 on top of one another, with suitable insulation between, and then connecting the positive "Hall" effect potential point of one plate to the negative "Hall" effect potential point of the one below, as represented in the drawings at *e*, *f*, *g*, *h*, *i* and *j*. In other words, the transverse potential of all of the plates 1, 2 and 3 are put in series in order to add up to larger values of potential than would be obtained with a single plate.

It is obvious, that since the polarity of the "Hall" effect potential difference changes in synchronism with either the change in polarity of the points *e* and *d*, or with the change in direction of the magnetic flux through the plate, the polarity of the points *e*, *j*, (Fig. 4) will always be the same with respect to each other when both the magnetic flux and also the longitudinal current through the plates change in phase and synchronously with each other. The arrangement shown in Fig. 4 will then obviously give a pulsating direct current at the points *e*, *j*.

The construction of the apparatus of my invention is more clearly illustrated in Fig. 1 where the metallic films have been represented at 1, 2, 3, 4 and 5 separated by insulated sheets 7. Opposite ends of the films are tapped as represented at *c* and *d*. The transverse axes of the films are connected in series as represented at *e*, *f*, *g*, *h*, *i*, *j*, *k*, *l*, *m*, and *n* for delivering a direct current. The end view of the apparatus in Fig. 2 shows more clearly the arrangement of the films and the dielectric sheets. The solenoid winding has been divided into two sections for producing a transverse magnetic field through the metallic films.

In Fig. 3 I have shown a stacked arrangement of metallic films separated by insulated sheets in accordance with my invention, where the alternating current I passes along the longitudinal axes of the films from *d* to *c*. I provide copper end contacts 8 and 9 which bridge all of the metallic films enabling the films to be connected in the electrical circuit in parallel. The point contacts across the transverse axes of the films have been represented at *a* and *a'*.

The device may be used as a rectifier in ordinary electrical circuits where the power drawn from the rectifier is of sufficiently low value so as to render the method practicable. The arrangement can also be used as a rectifier in radio transmitters and receivers, especially to replace the crystal detector or the triode vacuum tube detector in radio reception. It could be used either alone or in combination with electron tubes, a typical circuit diagram of the latter method being given in Fig. 5.

Referring to the drawing in more detail the receiving antenna system is represented at 10 which connects to a ground system at 11 with a coupling inductance 12 therein coupled to the tuned input circuit 14 of the electron tube 15 which functions as a radio frequency amplifier. The output of the radio frequency amplification circuit 15 connects through a tuned circuit 16 with the input circuit of a second stage of radio frequency amplification constituted by electron tube 18, the output circuit of which includes transformer system 17 tuned as represented at 28 for supplying exciting current to the solenoid S through a series circuit which passes through the longitudinal axes of the metallic films from points *d* to *c*. A direct current is derived across the points of contact *a* and *a'* which is directly proportional to the incoming signaling energy. The rectified current is delivered through a transformer system 20 to the input circuit of the electron tube 18 which also functions as an audio frequency amplification system delivering its audio frequency output through transformer 19 with the input circuit of electron tube 15 which serves also to amplify at audio frequency delivering its output to telephones T. Battery A supplies filament heating current for the several tubes while battery B supplies space current for the tubes. The tuned system 17—28 permits a relatively large value of current to pass through the metallic films and thereby secures maximum direct current energy across the transverse axes of the metallic films. My invention may be applied to all standard circuits as well as as to the reflex system of Fig. 5.

Referring to Fig. 6 a simplified circuit is illustrated showing the application of the principle of my invention to a simple radio receiving apparatus. In this circuit the incoming signaling energy delivered from tuned circuit 14 passes through the longitudinal axes of the metallic films from *d* to *c* at the same time setting up a magnetic field by means of solenoid S for deriving direct current across the transverse axes of the metallic films at *a* and *a'* proportionate to the incoming signaling energy. This direct current directly actuates the telephone responsive device T.

It should be noted that, due to the fact that this system is a perfect rectifier (that is, it admits of no inverse potential or currents in the output) it will produce no distortion in the reproduction of radio telephone signals and voice, and is, therefore, far superior to either the crystal detector or the electron tube from the standpoint of faithful reproduction, in addition to its superior qualities of stability, ease of operation and lower cost of maintenance.

Fig. 7 illustrates a circuit arrangement which I employ in the amplification of signaling energy by means of the apparatus of my invention. An input circuit has been illustrated in the form of an inductive coupler 25 tuned by variable condenser 26 and connected through the longitudinal axes of the metallic films at *d* and *c*. A permanent magnetic field may be established about the metallic films by means of a local source 21 connected in circuit with the winding S. An iron core may be provided for this solenoid S. Incoming signaling energy is supplied through winding 27 coupled with the windings 25. The transverse axes of the films at *a* and *a'* are connected in series with a local source 22 and an inductance 24 which couples with the inductance system 25. A desired degree of regenerative amplification is thus introduced for increasing the amplitude of the impulses of signaling energy delivered to the output circuit. The principle of my invention may be applied to an oscillator where the input coil 27 connects to a small local exciter of alternating current and the output connected through a transformer system. By employing selected values of inductance, capacity and resistance the system may be arranged to oscillate at either audio or radio frequencies.

Fig. 8 illustrates a method of obtaining greater energy amplification in the apparatus of my invention. A permanent magnetic flux is set up through the thickness of the plates and also a permanent longitudinal current is established along the horizontal axes of the plates from a battery 28. A tuned input circuit system 27—25—26 is arranged to excite the winding S which encloses the stack of alternately positioned films and dielectric sheets. The longitudinal axes of the films are connected at points *a* and *a'* with an output circuit including a source of potential 22 and inductance 24. The inductance 24 is inductively coupled to an inductance 29 tuned by means of condenser 30 in the output circuit of the electrical system. The fluctuating magnetic field from the winding S which varies in proportion to the amplitude of the signaling energy is superimposed on the permanent field which is established.

The input may also be superimposed on the longitudinal current instead of upon the magnetic field. The local battery for supplying longitudinal current to the conductive films may thus be eliminated. The local battery in the circuit of the electrical system is provided to boost the voltage of the output to the proper value for the operation of succeeding amplifier stages or the reproducing unit, the "Hall" fluctuating potential being then superimposed upon this steady potential. By increasing the number of conductive films in parallel the effective potential may also be increased.

In Fig. 9 I have shown an application of my invention to an electron tube circuit where the conductive films have their longitudinal axes connected in series in the output circuit of electron tube 15. A constant magnetic field is supplied from battery 21 to the winding S. In this manner the device operates as a radio frequency amplifier, delivering amplified energy to an output circuit across the transverse axes of the conductive films in series as represented at *e* and *j*, the output circuit including battery 22 and solenoidal winding S'. The solenoidal winding S' connects in series with the longitudinal axes of conductive films as represented at *c'* and *d'* and across the transverse axes at *a* and *a'* I connect the output circuit which includes the battery 22'. The arrangement of the conductive films within the solenoidal winding S' serves as a rectifier of amplified energy delivered by the conductive films within the solenoidal winding S'.

Fig. 10 shows a method I may employ for setting up the magnetic field which threads through the conductive films. A pair of compressed silicon steel filing cores or other suitable magnetic material or alloys are arranged on opposite sides of the stack of alternately positioned conductive films and dielectric sheets. On these coils are provided the windings S_2 and S_3 supplied from the local source 21. The stock of bismuth or metallic alloy conductive films may be quite thick but the magnetic field is concentrically normal to the plane of the conductive films. Permanent magnets may also be employed instead of electromagnets.

It will be understood that I may employ conductive films of alloys, metals, crystals or chemical salts in lieu of the bismuth films

mentioned herein. Photo-electric materials may be provided for the films. In some instances, I may produce the bismuth films by cathodic sputtering, thus making the films very thin. The transverse current effect is inversely proportional to the thickness of the film and when the films, which are often so thin as to be transparent to light, are deposited on thin mica approximately 100 films are connected in series transversely for securing desired operation. The magnetic field in some cases is produced by a solenoidal coil of approximately 1,000 turns on cores of compressed silicon steel filings. The resultant transverse pulsating direct current is several volts for only one milliampere flowing through the field coil and longitudinally through the conductive films in parallel. I have found that where four amperes alternating current at 60 cycle frequency is passed through a 12 turn coil and then through the conductive films connected in parallel with themselves longitudinally, the resulting pulsating direct current component across each conductive film is approximately 50-micro-volts. When the conductive films in the number above referred to are connected in series transversely 200 micro-volts may be obtained. The values obtainable may readily be used in the operation of electron tubes. The arrangement of the apparatus is such that connections may be readily made with electron tube circuits directly in the input circuit of an electron tube as represented at Fig. 9 without the interposition of transformer systems.

When an iron core is used with the device of my invention with the proper permeability curve an asymmetric characteristic curve may be obtained with the device similar to that obtained with a triode tube. This ability of the device of my invention facilitates the generation of self-oscillations in the device. The device when properly connected will, therefore, operate as an amplifier or as an oscillator in addition to its properties as a rectifier.

While I have described my invention in certain preferred embodiments, I desire that it be understood that various modifications may be made without departing from the spirit of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. In a system for generating electrical oscillations the combination of a plurality of conductive films each possessing Hall effect and insulated one from the other, each having longitudinally and transversely extending axes, separate circuits connected in series with said longitudinally and transversely extending axes, said circuits being mutually coupled for the generation of electrical oscillations and means for subjecting said conductive films to a magnetic field in a direction transverse to the plane thereof.

2. A signaling system comprising a tuned circuit a multiplicity of alternately positioned conductive and dielectric films disposed in planes parallel one to the other, said conductive films each possessing Hall effect, means connecting the longitudinal axes of said films with said tuned circuit, means for establishing a magnetic field normal to the planes of said films and connections across the transverse axes of said films including an inductance element magnetically coupled with a portion of said tuned circuit and connected to an output system for regeneratively amplifying incoming signaling current impressed upon said tuned circuit and delivering the same to said output system.

3. An oscillatory system comprising a multiplicity of alternately positioned conductive and dielectric films disposed in planes parallel one to the other, said conductive films each possessing Hall effect, a tuned circuit for supplying modulated signaling energy to the longitudinal axes of said films, an inductance positioned adjacent said films for establishing a magnetic field normal to the planes of said films and an output system connected across the transverse axes of said films and coupled with a portion of said tuned input circuit whereby current derived from Hall effect produced in accordance with the modulated signaling energy may be amplified and delivered to said output system.

4. A signal apparatus comprising a multiplicity of alternately positioned conductive and dielectric films each of said conductive films possessing Hall effect, a tuned input circuit, connections for delivering modulated signaling energy to the longitudinal axes of said films, means for establishing a magnetic field normal to the planes of said films, circuits extending from the transverse axes of said films and including a coupled element coupled with a portion of said tuned input circuit and connected with an output system, whereby current derived from Hall effect in accordance with said modulated signaling energy may be regeneratively amplified and delivered to said output system.

In testimony whereof I affix my signature.

PALMER HUNT CRAIG.