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PHOTOELECTRIC PHONOGRAPH

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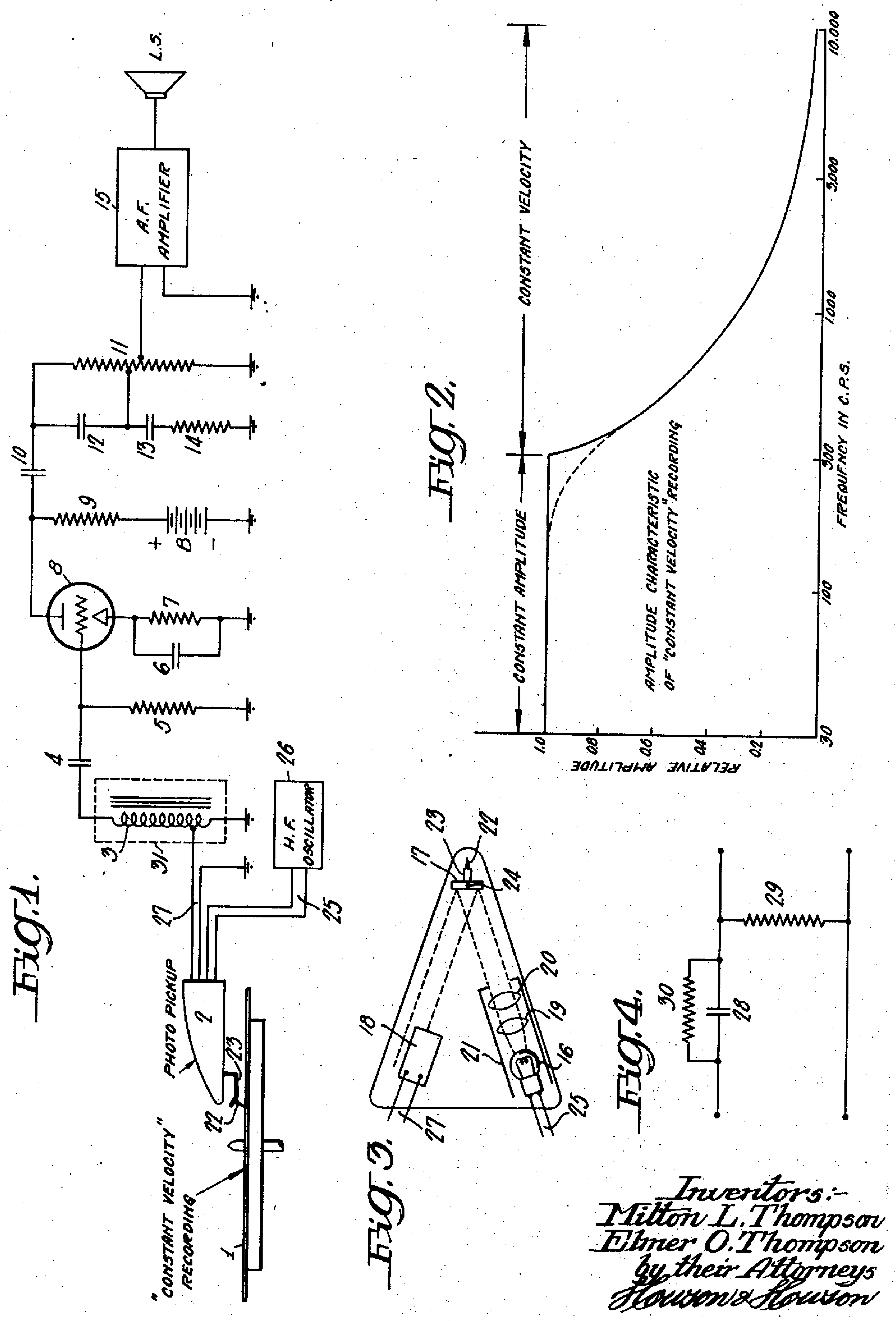

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PHOTOELECTRIC PHONOGRAPH

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2 Claims. (Cl. 179—100.4)

This invention relates to mechanical-optical-electrical sound reproducing systems in which mechanical recordings (e. g. sound on disk) are reproduced through the medium of an electro-optical pickup system. The invention relates more particularly to an amplitude-responsive photo-electric pickup for use with mechanical recordings of the constant velocity type, and having electric circuit means for converting, in effect, the constant velocity recording to a constant amplitude recording, whereby a true and faithful reproduction of the original recorded sound is secured.

Two general methods of mechanical or disk recording are well known in the art, namely "constant amplitude" and "constant velocity." A constant amplitude recording is one in which, for constant sound pressure at the recording microphone, the undulations cut in the record have a constant amplitude for all frequencies. A constant velocity recording is one in which, for constant sound pressure at the microphone, the vibrational velocity of the cutting (or reproducing) stylus is constant for all frequencies. In constant velocity recordings, the amplitude of the undulation cut in the record is inversely proportional to frequency.

Phonograph records at present available to the public are of a modified constant velocity type. They are recorded at constant amplitude over a relatively narrow low frequency range, say up to 300 cycles, but are recorded at constant velocity over the greater part of the audio range, i. e., from 300 cycles on up to the upper recorded limit, which may be as high as 8000 cycles or more, depending upon the design or excellence of the recording equipment.

When recordings of the constant velocity type are reproduced through a mechanical reproducer of the early mica or Duralumin diaphragm types, the proper sound values tend to be restored since constant energy over the frequency range is represented by constant vibrational velocity of the stylus. Similarly when such recordings are reproduced by means of a pickup of the magnetic type, the proper frequency characteristic is automatically restored, since the voltage generated in the magnetic pickup is proportional to the velocity of the stylus point, rather than to its amplitude. There is accordingly no problem in reproducing constant velocity recordings with velocity responsive pickup devices.

Electro-optical pickups, however, are inherently amplitude-responsive devices, and as such, have not heretofore been well adapted for use with recordings of the constant velocity type, particularly where a true and faithful reproduction of the original sound is desired. The present invention has for its purpose to provide novel means by which amplitude-responsive pickups of the photo-electric type can be satisfactorily and advantageously utilized in the high fidelity reproduction of constant velocity recordings.

Accordingly, it is one of the objects of this invention to provide a signal modifying network, and more particularly a signal differentiating network, which will permit the use of an amplitude-responsive photo-electric pickup in the high fidelity reproduction of constant velocity recordings.

Another object of the invention is to provide a photo-electric pickup circuit which makes possible the successful and economical use of the simpler types of photo-electric cells.

Still another object of this invention is to provide a relatively simple but effective signal differentiating circuit for obtaining a velocity responsive signal from an amplitude-responsive electro-optical phonograph pickup.

These and other objects of the invention and the manner of achievement thereof may best be understood by reference to the accompanying drawing, in which

Fig. 1 is a schematic diagram of a preferred embodiment of the invention;

Fig. 2 shows the amplitude characteristic of a typical constant velocity phonograph record;

Fig. 3 is a diagrammatic representation of a photo-electric pickup head suitable for use with the present invention; and

Fig. 4 is a schematic diagram of a passive type of differentiating network suitable for use with the present invention.

Reference is now directed to Fig. 1 in which there is shown a phonograph record **1**, a photo-electric pickup head **2**, a coupling transformer **3**, a signal differentiating and pre-amplifier circuit **4—9**, a compensated volume control network **10—14**, an audio amplifier **15**, and a loudspeaker L. S.

The photo-electric pickup **2**, shown diagrammatically in Fig. 3, may comprise a light source **16**, a vibrating mirror **17**, and a photo-electric cell **18**. Light from the source **16** may be directed onto the mirror **17** by means of a lens system **19—20**. Lenses and light source may conveniently be held in fixed alignment by an opaque cylindrical container **21**. Light from the source **16** is reflected by the mirror onto the cell **18**. The stylus **22** affixed to the mirror by means of the crank arm 23 causes the mirror to be vibrated about the central axis 24 which extends perpendicularly to the plane of the record. The light source and cell are preferably so adjusted with respect to the mirror 17 that the beam of light is normally approximately half on and half off the cell 18, so that when the pickup is placed on a record the undulations of the record grooves will cause the illuminated area of the cell to vary in accordance with the said undulations. In this type of pickup, the change in illumination of the cell is proportional to angular displacement of the mirror or stylus. At any given frequency the electrical output of the cell will be generally proportional to the change in illumination, and, therefore, also to the stylus displacement.

Although the present invention contemplates the use of any type of photo-electric pickup whose electrical output is inherently proportional to stylus displacement, it is preferred to employ a pickup similar to that disclosed in the copending application of E. O. Thompson, Serial No. 357,322, filed September 18, 1940.

The lamp or light source 16 may be connected to a source of current through the leads 25. This lamp is preferably not energized from a 60 cycle source of alternating current since the resulting cyclical variation of light intensity may cause the generation of an undesired and annoying 120 cycle hum in the photo-electric cell output. This hum would, of course, be passed on through the audio amplifier and output system. The lamp is, therefore, preferably connected to a source of direct current, or alternatively to a source of alternating current having a frequency above audibility. The latter and other expedients are fully described in U. S. Patent No. 2,242,983, issued May 20, 1941, to M. L. Thompson. In Fig. 1 a high frequency oscillator 26 is connected to the leads 25 for providing the necessary electrical energy to heat the filament of the lamp to incandescence.

The output leads 27 from the photo-electric cell 18 may be connected to an amplifier 8 through any suitable voltage step-up transformer or impedance matching device, such as the auto-transformer 3. The amplifier 8 may have associated therewith suitable signal differentiating circuits, as explained hereinafter, and an output circuit comprising the load resistor 9 and the volume control potentiometer 11. If desired, the volume control may have associated therewith suitable tone compensating networks, such for example as the high frequency compensating element 12 and the bass compensating circuit 13—14. The audio frequency amplifier 15 may comprise any conventional apparatus having sufficient gain and output power to drive the loudspeaker L. S. to a desired volume level.

Returning now to the mechanical-optical elements of the system, the phonograph record 1 may be of the conventional type bearing the usual constant velocity recording, such recordings in practice being cut at substantially constant stylus amplitude over the range up to about 300 cycles, and at constant stylus velocity above 300 cycles. The ideal amplitude-vs.-frequency characteristic of such a recording is illustrated by full line curve of Fig. 2. For constant sound energy over the audible range from 30 to 10,000 cycles, the characteristic will be seen to be flat from 30 to 300 cycles, falling rapidly above 300 cycles, and approaching the zero axis asymptotically at the higher audible frequencies. In practice, the illustrated abrupt changeover from constant amplitude to constant velocity is, of course, not obtained, and the characteristic approximates the broken line in the region of 300 cycles rather than the full line. The frequency at which the recording changes over from constant amplitude to constant velocity is sometimes referred to as the "turnover frequency." It may be noted that over the constant velocity portion of the characteristic the amplitude falls off by a ratio of 2 to 1 for every octave. Thus, at 1000 cycles the amplitude is only half that at 500 cycles. This is equivalent to an amplitude loss of 6 decibels per octave.

If now a recording having the amplitude characteristic shown in Fig. 2 be reproduced through the medium of an amplitude-responsive device, such as a pickup of the photo-electric type, it will be apparent that the fidelity of reproduction will be good only up to the turnover frequency, 300 cycles. Beyond 300 cycles the output will fall off at the rate of about 6 decibels per octave, being down by a ratio of 32 to 1, i. e., about 30 decibels, at 9600 cycles.

It has now been found that an amplitude-responsive pickup can be satisfactorily used with constant velocity recordings if the electrical output of the pickup is applied to a network which is so constructed and arranged as to produce an output signal which is substantially proportional to the time derivative of the electrical output of the pickup. A network or circuit capable of performing this function may be broadly termed a "signal differentiating circuit," referring to the fact that such a circuit operates upon the signal effectively to differentiate it with respect to time. The effect of employing a signal differentiating circuit in connection with a constant velocity recording and an amplitude-responsive pickup is to restore the proper amplitude relations between the various recorded frequencies. This follows from the fact that in any phonograph record the stylus velocity is equal to the time derivative of the stylus amplitude, i. e.

$$v=\frac{da}{dt}$$

Therefore, a phonograph pickup, comprising an amplitude-responsive photo-electric pickup head and a signal differentiating circuit, will provide an output signal whose amplitude is proportional to the time derivative of the groove or stylus amplitude. A phonograph pickup of this type may consequently be employed in the high fidelity reproduction of modern constant velocity recordings, since it supplies an output signal whose amplitude is proportional to stylus velocity.

The schematic wiring diagram of Fig. 1 illustrates one convenient circuit for providing an electrical output whose amplitude is proportional to the time derivative of the electrical input. The circuit in this example comprises the triode amplifier 8 together with the shunt connected condenser 6 and resistor 7, the condenser and resistor being common to both the input and output circuits of the triode. By a suitable choice of values for the elements 6 and 7, the gain of the amplifier 8 may be made to vary with frequency in such a manner that the output voltage of the triode 8, as derived for example from the resistor 9, is substantially proportional to the time derivative of the voltage derived from the photo-electric pickup device 2. By correct design, the resistor 7 may be made to serve simultaneously as the self-bias resistor for the triode 8, thus eliminating the necessity of a separate bias source for that tube.

In general, where records are cut at constant amplitude below a predetermined turnover frequency (e. g. 300 cycles) and at constant velocity above this frequency, it will be desirable to design the amplifier in such a way that its gain is substantially independent of frequency below the turnover frequency, but varies with frequency above this frequency in the manner hereinbefore explained. This can be done by assigning to the condenser 6 a value such that its reactance is large compared to the resistance of the resistor 7 below the turnover frequency. Under these conditions, the amplifier operates as a conventional degenerative amplifier below the turnover frequency, the by-passing effect of the condenser 6 being negligible. Above the turnover frequency the effective impedance in the cathode circuit decreases with increasing frequency, and the gain of the amplifier is correspondingly varied. In one satisfactory embodiment of the invention, the values assigned to the resistor 7 and condenser 6 were 3300 ohms and 0.05 microfarad respectively. The 3300 ohm resistor constituted the sole source of grid bias for the triode 8. In any specific design the values of these elements will, of course, depend upon the characteristics of the amplifier 8 and the turnover frequency of the records with which the equipment is to be used.

In some instances it may be possible to secure an amplifier output which is more nearly the ideal (i. e. proportional to the time derivative of the amplifier input for frequencies above the turnover frequency) by employing an additional frequency response modifying circuit. This may conveniently comprise the condenser 4 and the resistor 5, the relative values being proportioned, preferably by trial, to give a desired frequency response characteristic to the amplifier. In the embodiment of the invention referred to above, several satisfactory sets of values assigned to the resistor 5 and condenser 4 were 330,000 ohms and 0.006 microfarad in one case, and 220,000 ohms and 0.001 microfarad in another case. For purposes of needle scratch reduction and tone control, it is, of course, possible to add any of the circuits commonly used in such service.

It is, of course, obvious that any satisfactory differentiating circuit may be substituted for the one shown in Fig. 1. Similarly, the differentiating circuit may reside in a passive network and need not be directly associated with a vacuum tube amplifier as it is in the circuit illustrated in Fig. 1. A passive signal differentiating network, i. e., one not depending upon the action of an associated vacuum tube for its operation, can be designed employing simply a series condenser 28 and a shunt resistor 29 as shown in Fig. 4. In such a circuit the elements 28 and 29 are preferably selected so that the reactance of the condenser is equal to the resistance of the resistor at some predetermined frequency near the upper end of the desired frequency range, for example 5000 or 7500 cycles. Such a simple network is practically ideal for strictly constant velocity recordings. But where the lower range is recorded under constant amplitude conditions below some turnover frequency, as is at present the practice, it is desirable to modify the network in such a way that its gain (or loss) is substantially constant below the turnover frequency. In Fig. 4 this can be satisfactorily effected by shunting the condenser 28 with a resistor 30 whose resistance is small compared to the reactance of the condenser at frequencies well below the turnover frequency, but high compared to the reactance of the condenser at frequencies well above the turnover frequency.

If desired, the network of Fig. 4 may be substituted for the elements 4—5 of Fig. 1, but in that event the cathode of tube 8 is preferably connected directly to ground, or alternatively, the condenser 6 should be selected to have a reactance which is small compared to the resistance of the element 7 at all frequencies in the desired audio frequency band, as is the practice in the design of cathode biased amplifiers.

In order to eliminate the complication and expense incident to use of a photo-electric tube of the vacuum or gas filled types, it is preferred to employ, in the pickup head, a light sensitive electric circuit element of the barrier photocell type. These generally employ a photosensitive material, such as selenium or cuprous oxide, and are particularly desirable in that they require no battery or other external voltage source as do the high vacuum or gas-filled cells of the photoemissive type. The barrier cell 18 of Fig. 3 may be coupled to the amplifier 8 of Fig. 1 by way of the leads 27 and the transformer 3. Since the signal output level of the barrier cell is relatively low, it is desirable to shield the transformer 3 from stray alternating current fields by means of an enclosing shield structure 31.

If a photo-electric pickup head of the type illustrated in Fig. 3 is used, it will be seen that a substantial direct current voltage is generated by the barrier cell, since the cell is illuminated, on the average, by one-half the cross sectional area of the reflected light beam. In order to isolate the input circuit of the triode 8 from this direct current component of voltage, it is preferred to couple the barrier cell to the amplifier either by means of a double-winding transformer, or by means of a single-winding transformer (auto-transformer) and a blocking condenser. In Fig. 1 the latter connection is shown, the barrier cell being isolated from the amplifier (for direct current) by means of the auto-transformers 3 and the blocking condenser 4. By this connection the proper bias conditions for the triode 8 are not disturbed by variations in intensity of the light source 16.

In order to improve the frequency characteristics of the barrier cell circuit and to provide a step-up in voltage, it has been found desirable to employ a coupling transformer having a relatively high step-up ratio. In this connection it was found desirable to utilize the barrier cell as a current generator rather than as a voltage source by operating the cell into an impedance approximately equal to, or preferably less than, the impedance of the cell itself. The cell impedance in one embodiment was about 800 ohms. In this embodiment a transformer having a voltage step-up ratio of approximately 1 to 20 in combination with a secondary load of 220,000 or 330,000 ohms was found to give satisfactory results.

Although the invention has been described with particular reference to a preferred embodiment, it is not limited thereto but is capable of various modifications within the scope of the appended claims.

We claim:

1. In a phonograph record reproducing system for use with a phonograph record recorded at constant amplitude over the low frequency portion of its range and at constant velocity over the remainder of its range, a photo-electric phonograph pickup device employing a stylus, a light source, and a low-impedance light-sensitive electric circuit element, said element being respon-

sive, through the medium of a directed light beam, to the movement of said stylus in accordance with undulations cut in said record, the output signal of said light-sensitive element being substantially directly proportional to the amplitude of the motion of said stylus, a coupling transformer having a relatively high step-up ratio, the low-impedance winding of said transformer being connected to the output of said light-sensitive element, and an electrical network connected to the high impedance winding of said transformer and adapted to be substantially inoperative over said low frequency portion and to differentiate the output signal from said element over the remainder of said range, thereby to provide a modified output signal substantially proportional to the velocity of said stylus.

2. In a phonograph record reproducing system for use with a phonograph record recorded at constant amplitude over the low frequency portion of its range and at constant velocity over the remainder of its range, a photo-electric pickup device employing a stylus, a light source, and a low-impedance light-sensitive electric circuit element, said element being responsive, through the medium of a directed light beam, to the movement of said stylus in accordance with the undulations in said record, the electrical output of said light-sensitive element being substantially directly proportional to the amplitude of the motion of said stylus, a coupling transformer having a relatively high step-up ratio, the low-impedance winding of said transformer being connected to the output of said light-sensitive element, and an electrical network connected to the high impedance winding of said transformer, the output of said network being substantially directly proportional to the stylus amplitude over said low frequency range, but substantially directly proportional to stylus velocity over the remainder of the frequency range.

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