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W. BENZ

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FREQUENCY MULTIPLIER

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Fig. 1.

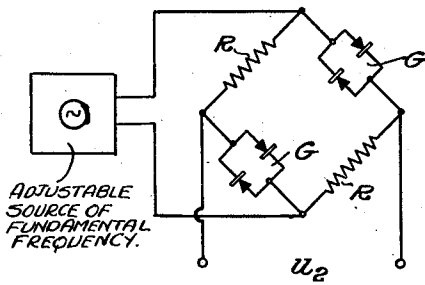


Fig. 2.

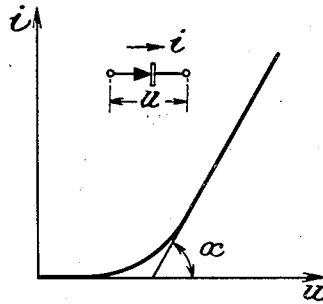


Fig. 3a.

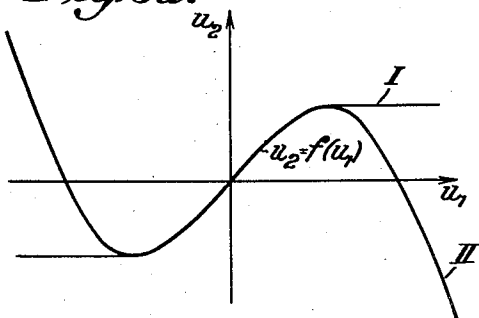


Fig. 3c.

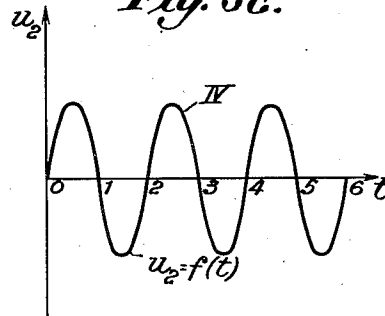
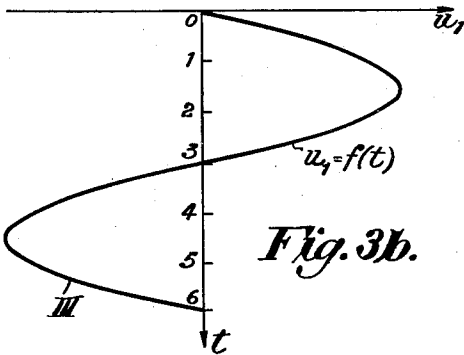


Fig. 3b.

INVENTOR
Werner Benz
BY *H.S. Brover*
ATTORNEY

UNITED STATES PATENT OFFICE

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FREQUENCY MULTIPLIER

Werner Benz, Berlin-Steglitz, Germany, assignor
to General Electric Company, a corporation of
New York

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8 Claims. (Cl. 172-281)

To obtain a definite harmonic of a higher order from a given fundamental frequency, general practice in the earlier art has been to distort the fundamental wave in a non-linear quadripole, the particular harmonic that is desired being filtered from the multiplicity or spectrum of harmonics resulting from such distortion by the aid of a suitable oscillation or tuning circuit or filter. This procedure has the disadvantage that for each such harmonic a distinct oscillation circuit or filter is required, and that, for instance, upon a change of the fundamental wave the tuning of the oscillation circuit provided for the desired harmonic must be altered or the filter be replaced.

The present invention, which overcomes these disadvantages, is concerned with a circuit adapted to secure the third harmonic of a fundamental wave by the aid of a non-linear four-terminal network designed to distort the said frequency. For this purpose there is employed a quadripole arranged in a bridge and known in the prior art as an amplitude filter, the balancing of these quadripoles being chosen so that a characteristic connecting the output potential u_2 with the input potential u_1 results, which, inside a certain drive range, fulfills roughly the function $u_2 = \frac{3}{4} k u_1 - k u_1^3$, where k is a constant.

The invention offers the following advantages:

(1) If the requirements respecting the purity of the third harmonic are not unduly severe (in other words, if a non-linear harmonic distortion of 20% is admissible), the oscillation circuit or filter to separate the said harmonic is dispensable. (2) But, if the duty requirements respecting the purity of the third harmonic are very severe, the requisite filter means are far less elaborate than is true of the arrangements heretofore known, since the third harmonic appears in far stronger form than the fundamental wave and the undesired harmonics. (3) If demands regarding purity of the third harmonic are not excessively high, this harmonic is obtainable inside a very wide frequency band which is practically a function only of the natural or self-capacitance of the non-linear elements forming a part of the distorting means, regardless of changes of the fundamental frequency.

In the drawing:

Fig. 1 shows a circuit embodying the invention;

Fig. 2 shows the current-voltage characteristic of the individual rectifiers used in Fig. 1; and

Figs. 3a, 3b and 3c show curves illustrating the relation of input to output voltage of the circuit

of Fig. 1. Fig. 3a shows the relation between input and output voltage for the circuit of Fig. 1, curve I being for the case where resistor R of Fig. 1 is chosen substantially equal to the asymptotic value of effective rectifier resistance, and curve II is for the case where resistor R of Fig. 1 is chosen substantially greater than said limiting value. Fig. 3b shows a cycle of alternating voltage input to Fig. 1 of amplitude so related to curve II of Fig. 3a that the output voltage of Fig. 1 is given by curve IV of Fig. 3c. In Figs. 3b and 3c the corresponding points in time are indicated by the same numerals.

Fig. 1 shows a bridge arrangement known in the prior art for use as an amplitude limiter, though the same is here used as a distorting quadripole. The bridge contains in opposite arms two like ohmic resistances R or two resistances G non-linear in nature and of the same resistance behavior, the said non-linear resistances consisting of the parallel connection of two similar rectifiers, say, selenium rectifiers, of opposite forward or low resistance direction. One of the diagonals of this bridge scheme is fed with the fundamental frequency potential u_1 and the other one delivers the consumer or load potential u_2 ; that is, the third harmonic of the fundamental wave.

To further explain the mode of action of this circuit organization, reference shall in what follows be made to Figs. 2 and 3 of the drawing.

Fig. 2 shows the current i -voltage u characteristic of a selenium rectifier of the kind to be used, for instance, for the non-linear resistances G . Extending the straight portion of this characteristic to the point of intersection with the abscissa axis, then the cotangent to the angle of inclination of this straight line in reference to the abscissa axis represents an effective resistance $R_g = \cot \alpha$. If, then, one chooses the resistance $R = R_g$, the arrangement shown in Fig. 1, as known from the art, acts like an amplitude limiter or filter, the dependence of the instantaneous values of the output potential u_2 upon those of the input potential u_1 being illustrated by graph I, Fig. 3a.

Making R greater than R_g , then the previously horizontal portions of graph I will droop so that, for a definite value of R , there results, for instance curve II, Fig. 3a. Now, by judicious choice of the non-linear resistances G and the linear resistances R , it is always possible to find a graph II so that, for a definite amplitude of a purely sinusoidal input potential u_1 (see curve III, Fig. 3b) an output potential u_2 results which

(see curve IV, Fig. 3c) with very close proximation has three times the frequency of the input potential u_1 as illustrated in the curves of Figs. 3b and 3c in which, for graphs III and IV, the same time scale has been chosen.

The process may be followed qualitatively throughout a cycle for the purpose of giving a physical picture of the operation.

Suppose, for the sake of definiteness, that an input voltage U_1 is applied to the bridge of Fig. 1 with such polarity as to make the upper input terminal positive. As the input voltage slowly grows from zero, there will be a slowly growing output voltage U_2 , such that the left hand output terminal is positive. This is because rectifiers G have very high resistances to small applied voltages compared with resistors R. When the input voltage reaches a certain strength, however, the ratio of voltage drop across each of the conducting rectifiers to the current there-through becomes equal to resistance R, so that the bridge is in balance. Thus, the output voltage has started from zero, risen to a maximum, and returned to zero, all while the input voltage is still increasing. Upon a further increase of input voltage, the rectifier resistance becomes less than R, so that the output voltage starts becoming negative and continues to become more and more negative up to the point where the input voltage reaches its maximum value. The output voltage is thus represented by the first three-quarters of a cycle of the curve IV, which occurs during the first quarter cycle of curve III which represents the input voltage. As the input voltage decreases from its maximum, the output voltage retraces the series of values it had previously taken on, so as to complete the next three-quarters of a cycle of curve IV coincidentally with the input voltage completing its first half cycle by falling to zero, shown at point 3 of curve III.

The negative half of the wave of input voltage will be symmetry of the bridge produce the negative of the first three half cycles of curve IV, thus carrying this curve up to point 6. It will be seen that the application of one full alternating cycle of suitable amplitude to the input terminals of Fig. 1 will result in three full cycles of alternating output voltage and the important thing about this is that no resonant circuit is relied upon to produce or select out this triple frequency output.

In what follows, the operation of the circuit organization of the invention shall be mathematically investigated by calculation by reference to these curves.

Suppose the characteristic II of Fig. 3, for a definite range, satisfies the equation

$$u_2 = K' u_1 - K u_1^3 \quad (1)$$

Suppose further that

$$u_1 = U \sin \alpha \quad (2)$$

where

$$\alpha = \omega t + \phi \text{ and } \omega = 2\pi f \quad (3)$$

from (1) and (2) there results:

$$u_2 = K' U \sin \alpha - K U^3 \sin^3 \alpha \quad (4)$$

or

$$u_2 = K' U \sin \alpha - K U^3 \left(\frac{3}{4} \sin \alpha - \frac{1}{4} \sin 3\alpha \right) \quad (5)$$

and

$$u_2 = U \left(K' \frac{3}{4} K U^2 \right) \sin \alpha + \frac{1}{4} K U^3 \sin 3\alpha \quad (6)$$

for the special case

$$K' = \frac{3}{4} K U^2 \quad (7)$$

there becomes

$$u_2 = \frac{1}{4} K U^3 \sin 3\alpha \quad (8)$$

In other words, what is obtained in this case is nothing but the third harmonic of the fundamental wave. Making the amplitude of the latter $U=1$, then

$$k' = \frac{3}{4} k$$

and thus for characteristic II, Fig. 3, there results this equation:

$$u_2 = \frac{3}{4} K u_1 - K u_1^3 \quad (9)$$

Now, under practical conditions the graph represented by the preceding equation cannot be strictly realized. However, by suitable choice of the linear and the non-linear resistances of the distortion means, at least inside a definite range, such a close proximation to this curve may be obtained that the desired result will be obtainable to an adequate extent.

It will be understood that the invention is by no means confined to the bridge arrangement in the form of a quadripole as here illustrated and described; on the contrary, in lieu of this arrangement any other bridge schemes known in the art of amplitude filters could be used. Inside the bridge, it is, of course, not necessary that the resistance ratio of opposite arms of the bridge should be as 1:1. In certain circumstances it may also prove to be of advantage to impress the non-linear resistances with a negative biasing potential. Moreover, there is a chance to use a plurality of such distorter arrangements each adapted to obtain the third harmonic and connected in series with the result that the 9th, the 27th and higher harmonics are obtained.

The invention is adapted to be used with particularly great advantage in connection with heterodyne buzzers or beat frequency oscillators. To the end of avoiding the troublesome pull-in-step effect arising in these devices, it is known from the earliest art to cause the second and third harmonic of the fundamental waves of the two transmitters to enter in beat relations. In such schemes previous practice has been to vary the transmitter furnishing the second harmonic, while that of the other transmitter was unvaried. As a consequence, upon making such change in the frequency, it has always been necessary to change also the tuning of the oscillatory circuit tuned to the second harmonic. Where the invention is used for oscillators or buzzers of the said kind, the transmitters whose second harmonic is employed, is left unchanged, while the other transmitter is made variable, the third harmonic of this transmitter being produced by adopting a circuit arrangement as here disclosed. In this case, variation of tuning of the oscillatory circuit that has heretofore been necessary is dispensable since in practicing the invention no filter or oscillation circuits are required to obtain the third harmonic.

What is claimed is:

1. A circuit for producing the third harmonic of a fundamental sinusoidal wave, comprising a non-linear quadripole in the form of a four-terminal network designed to distort the fundamental wave, said network constituting a bridge, a source of alternating current of fundamental

frequency coupled to one pair of said terminals of said network, and an output circuit coupled to the other pair of said terminals, the arms of said bridge having such values that there results a characteristic connecting the output potential and the input potential which, within a definite operating range, satisfies roughly the function

$$u_2 = \frac{3}{4}ku_1 - ku_1^3$$

where k is a constant, u_1 is the input potential and u_2 is the output potential.

2. Circuit organization as claimed in claim 1, with the characteristic feature that the distorting quadripole consists of a bridge containing in one pair of opposite arms two equal ohmic resistances and in the other pair of opposite arms two non-linear resistances having the same resistance characteristic, the ohmic and the non-linear resistances of the bridge being so chosen that between the sinusoidal fundamental frequency potential fed to one diagonal and the output potential derived across the other diagonal, at least inside a certain working range, there results a dependence required for the production of the third harmonic of the fundamental wave.

3. Circuit organization as claimed in claim 1, with the characteristic feature that the non-linear elements of said network consist of the parallel connection of two selenium rectifiers of contrary forward directions.

4. In combination, a device having output voltage which changes sign a number of times as an instantaneous magnitude of input voltage increases from zero to a predetermined amount and whose output voltage varies approximately sinusoidally with respect to said input voltage, means to impress alternating input voltage on said device, means for adjusting the amplitude of the alternating input voltage to cause the output of the device to change sign a desired number of times per cycle of input voltage, whereby the output voltage frequency is equal to the input voltage frequency multiplied by one-half said desired number and the output voltage is substantially sinusoidal.

5. A frequency multiplier for producing a third harmonic of a fundamental wave comprising a Wheatstone bridge arrangement having a pair of input terminals and a pair of output terminals connected to conjugate points, a pair of ohmic resistors in opposite arms of the bridge, the other arms of the bridge being each composed of a pair of oppositely poled rectifiers connected in parallel, the ohmic resistors having such values that there results a characteristic connecting the output potential and the input potential which within a definite operating range satisfies roughly the equation

$$u_2 = \frac{3}{4}ku_1 - ku_1^3$$

where k is a constant, u_1 is the input potential, and u_2 is the output potential, means for impressing a voltage wave of fundamental frequency on said input terminals, and means for utilizing the third harmonic wave produced between said output terminals.

6. A system for obtaining an odd harmonic of a fundamental wave comprising a first third harmonic frequency producer in the form of a non-linear four-terminal network designed to distort the fundamental wave, said network constituting a bridge, a source of alternating current of fundamental frequency coupled to one pair of said terminals of said network, and an output circuit coupled to the other pair of said terminals, the arms of said bridge having such values that there results a characteristic connecting the output potential and the input potential which, within a definite operating range, satisfies roughly the function

$$u_2 = \frac{3}{4}ku_1 - ku_1^3$$

where k is a constant, u_1 is the input potential, and u_2 is the output potential, and a second similarly arranged third harmonic frequency producer four-terminal network, and means for connecting said two four-terminal networks in series, whereby there is obtained a harmonic which is an odd multiple of said third harmonic.

7. In a frequency tripler system for producing an output voltage whose frequency is three times the input frequency, a device for producing an output voltage which changes sign at least once as the instantaneous input voltage increases from zero to a predetermined value, means for applying an alternating input voltage to said device, and means for adjusting the amplitude of said input voltage to cause the output voltage of said device to change sign six times per cycle of input voltage.

8. In combination, a device having an output voltage which is zero for zero input voltage, and which for increasing input voltage of one sense said output voltage increases at first, passes through a maximum, decreases to zero, reverses in sign and increases in magnitude, while for an input voltage of the other sense the output voltage varies similarly but with its sign opposite to the output voltage first described at corresponding magnitudes of input voltage, means to impress alternating input voltage on said device, means for adjusting the amplitude of the alternating input voltage to cause the output of the device to change sign a desired number of times per cycle of input voltage, whereby the output voltage frequency is equal to the input voltage frequency multiplied by one-half said desired number and the output voltage is substantially sinusoidal.

WERNER BENZ.