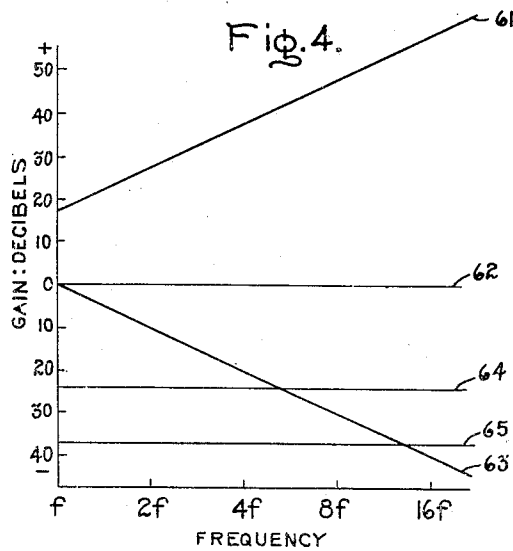
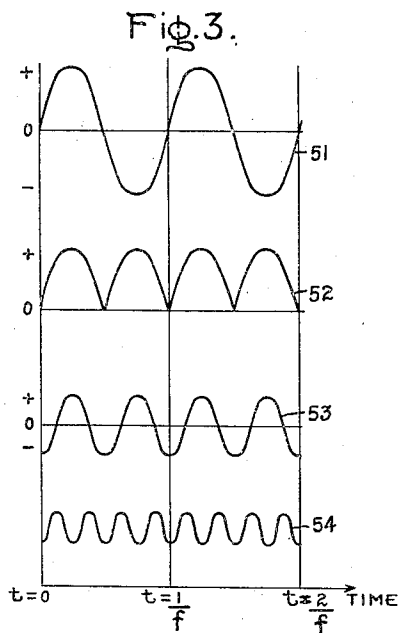
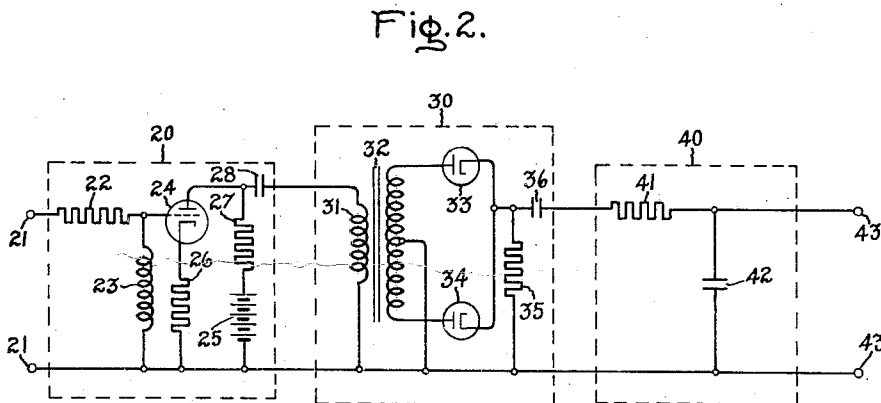
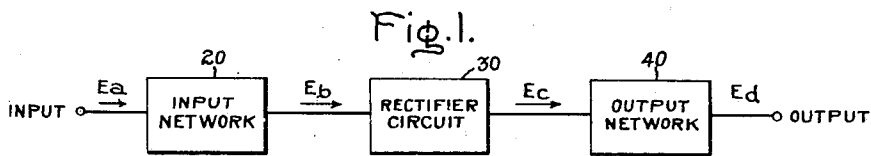


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WIDE BAND MULTIPLIER

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WIDE BAND MULTIPLIER

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5 Claims. (Cl. 250—36)

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This invention relates generally to frequency multipliers and more particularly to frequency multiplication circuits of the untuned type which are required to operate over a band of frequencies including several octaves.

Various circuits are known in the art for providing multiplication in frequency of an input signal. One class of frequency multiplication circuits is constituted by tuned amplifiers. A tuned amplifier generally has an anode load circuit resonant to a harmonic of the input frequency. While it is possible to construct such an amplifier so that the amplitude of the output is proportional to the amplitude of the input, no such circuits have been devised which operate efficiently over a wide band of frequencies. Another class of frequency multipliers is constituted by multivibrator circuits. Such a circuit may be adjusted to operate over a fairly wide band of frequencies while preserving a definite frequency ratio between the input and output signals. However, to applicant's knowledge, no multivibrator circuit has been devised which will maintain a definite and constant amplitude ratio between the input and output signals when the amplitude of the input is varied.

My invention provides a frequency multiplier circuit which will operate over a band of frequencies including many octaves, and which will preserve a definite ratio between the amplitude of the input and output signals. Briefly in carrying out my invention, I make use of a rectifier circuit which provides an output from which the fundamental frequency of the input has been eliminated and which contains a series of harmonic frequencies in a definite ratio of amplitudes with respect to the amplitude of the input. Furthermore, I provide both an input filter and an output filter, one having inverse characteristics from the other and each having an attenuation in decibels which varies with frequency. By means of these filters, the amplitude of all harmonics except the first is reduced to an insignificant level, while the amplitude of the first harmonic remains at a fixed value with respect to the amplitude of the input signal.

Accordingly, it is an object of my invention to provide a multiplier circuit which will give an output whose amplitude is in a definite ratio to the amplitude of the input and whose frequency is an integral multiple of the frequency of the input over a range including several octaves.

A further object of my invention is to provide a frequency doubling circuit in which the magnitude of the output will be in a constant ratio

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to the magnitude of the input over a range of frequencies including several octaves, and in which the output is a wave of twice the frequency of the input and in which the level of any other undesirable harmonics can be made as low as desired.

For additional objects and advantages and for a better understanding of the invention, attention is now directed to the following description and accompanying drawings and also to the appended claims in which features of the invention believed to be novel are more particularly pointed out.

In the accompanying drawings, Fig. 1 illustrates, in simplified block form, a system for frequency-multiplying an input signal in accordance with my invention; Fig. 2 illustrates schematically the circuit details of a frequency doubling system; Fig. 3 shows a number of curves on a common time scale graphically illustrating certain voltage wave forms appearing in different parts of the circuit of Fig. 2 over a number of complete periods of the input voltage; and Fig. 4 illustrates certain characteristics of the system illustrated in Fig. 2.

My invention may best be understood by considering the characteristics of a sinusoidal wave in which the negative half cycles have been converted to positive half cycles, as occurs, for instance, in the output of a full-wave rectifier.

An example of a sinusoidal wave is illustrated by curve 51 of Fig. 3, and its wave form after full wave rectification is illustrated by curve 52. It is well known in the art that a Fourier analysis shows such a wave to consist of the following components:

$$e_o = \frac{2E}{\pi} \left[1 - \frac{2}{3} \cos 2\omega t - \frac{2}{15} \cos 4\omega t - \frac{2}{35} \cos 6\omega t - \dots \right] \quad (I)$$

Where E = the maximum amplitude of the input voltage e_a ,

$e_a = E \sin \omega t$ = input voltage

e_o = output voltage

f = frequency of operation

ω = angular frequency of operation = $2\pi f$

t = time

An inspection of Equation I reveals that the fundamental frequency of the input wave is completely eliminated from the output. The output contains a unidirectional component and even-numbered harmonics in decreasing magnitudes. Curves 53 and 54 of Fig. 3 illustrate respectively the 2nd and 4th harmonics. Assuming that the

magnitude of the input is unity, the magnitude of the 2nd harmonic is 0.424, that of the 4th harmonic is 0.0849, that of the 6th harmonic is 0.0363, etc. These correspond to levels of 7.56, 21.42 and 28.78 decibels below the level of the input wave.

Since it is desired to have only the 2nd harmonic present in appreciable magnitude in the final output, it is necessary to consider the amount of distortion caused by the higher harmonics. The percentage harmonic distortion will be given by

$$D = \sqrt{\frac{A_4^2 + A_6^2 + A_8^2 + \dots + A_n^2}{A_2^2}} \times 100 \quad (\text{II})$$

where D = % harmonic distortion in the output with respect to the 2nd harmonic.

A_2, A_4, A_6, A_8, A_n = amplitudes of the 2nd, 4th, 6th, 8th and n th harmonics respectively.

The percentage harmonic distortion after full wave rectification, considering only the 4th and 6th harmonics, with respect to the 2nd harmonic, is:

$$D = \sqrt{\frac{0.0849^2 + 0.0363^2}{0.424^2}} \times 100 = 21.7\%$$

A distortion of 21.7% is prohibitively high and must be reduced if the output is to be utilizable. In addition, the unidirectional component represented by the term i in Equation I must be eliminated.

It is relatively easy to eliminate the direct current component of the output by means of a blocking condenser. By providing a low-pass filter, it is possible to increasingly attenuate all harmonics as a function of their frequency with respect to the second harmonic. For instance, this can be done by a filter whose attenuation in decibels increases linearly with every octave of frequency. By providing an attenuator whose attenuation increases at a high rate per octave, the ratio of the magnitude of the fourth harmonic to that of the second can be made as small as desired. Unfortunately, this will also produce a reduction in the same ratio in the amplitude of the second harmonic with respect to that of the fundamental. Moreover, the magnitude of the output with respect to that of the input will decrease as the frequency of the input rises. To remedy this condition, an input network is inserted before the rectifier circuit and is provided with an attenuation characteristic which is the inverse of that of the output network. In other words, the input network provides a gain which increases with frequency by the same amount per octave as the attenuation of the output network. When this is done, the level of the input voltage to the rectifier circuit increases as a function of frequency so that although the level of the second harmonic in the output decreases as a function of frequency with respect to the input, it actually remains constant with respect to the signal into the input network.

A system capable of performing the functions previously described is illustrated in block form in Fig. 1. The system comprises an input network 20 to the input of which a signal voltage E_a is supplied. This network supplies a voltage E_b to a rectifier circuit 30 which in turn supplies a voltage E_c to an output network 40. The voltage E_d available at the output terminal is doubled in frequency from that supplied to the input terminal and is at a constant level with respect to it.

Moreover, the fundamental frequency of the input signal is completely eliminated from the output signal and higher harmonics than the second are reduced to a level which can be made as low as desired by proper design of the input and output networks.

Fig. 2 illustrates an actual circuit which meets the requirements of the block diagram of Fig. 1 and in which the circuit elements are arranged in groups performing the same functions within dashed rectangles, and bearing the same reference numerals as the corresponding blocks in Fig. 1. The input network comprises an electronic valve 24 whose cathode is grounded through a resistor 26 and which is supplied with operating potential by a battery 25 through an anode resistor 27. The input circuit to the valve from terminals 21 comprises a series grid resistor 22 and a shunt inductance 23. Resistor 22 is selected so that its resistance is appreciably larger than the reactance of inductance 23 throughout the range of frequencies over which the system is to operate. The result of this choice is to cause the amplification of the valve to vary with frequency, since the reactance of inductance 23 and, therefore, the voltage developed across it, is directly proportional to frequency. Referring to Fig. 4, curve 61 illustrates a typical frequency-gain performance for such a circuit. The ratio of output to input voltage increases linearly with frequency, and the circuit constants have been selected to provide a gain of 17.56 decibels at the lowest frequency of operation f and an increase in gain of 10 decibels for every octave above f . For instance, at a frequency of $16f$, which is the initial frequency of the fifth octave and which is four octaves higher than f , the gain is 57.56 decibels. The gain in decibels at any octave is given by $7.56 + M \times (\text{octave number})$, M being a positive integer which has a value 10 in this embodiment. The purpose of the constant term 7.56 is to compensate for an attenuation of 7.56 decibels in the second harmonic caused by the operation of the rectifier circuit.

The rectifier circuit 30 comprises a transformer having a primary winding 31 connected to the output of the input network and a secondary winding 32. The secondary winding has a center tap, which is grounded, and has its free terminals connected to the anodes of a pair of diode valves 33 and 34. The cathodes of these valves are connected together and have a connection to ground through a resistor 35, and the output is available through a capacitor 36 connected to the cathodes.

The output circuit comprises simply a series resistor 41 connected between capacitance 36 of the rectifier circuit and one of the output terminals 43. A capacitor 42 is connected across the output terminals. Resistor 41 is selected so that its resistance is considerably larger than the reactance of capacitor 42 over the range of operating frequencies. Since the reactance of capacitor 42 and, accordingly, the voltage developed across it are inversely proportional to frequency, the ratio of the voltage available at the output terminals 43 to the voltage supplied from the rectifier circuit will also be inversely proportional to frequency. Curve 63 of Fig. 4 illustrates a typical frequency-gain characteristic for such a filter. The attenuation is 0 for a frequency f and increases by 10 decibels for every octave of frequency. For instance, at a frequency of $16f$, that is, a frequency four octaves higher than f , the attenuation is 40 decibels.

The following table will facilitate the understanding of the operation of the circuit:

TABLE I
Input

E _a		E _b		
Freq.	Level, Decibels	Freq.	Gain, Decibels	Level, Decibels
f	0	f	17.56	+17.56
2f	0	2f	27.56	+27.56
4f	0	4f	37.56	+37.56

E _c (2nd harmonic)			E _{c'} (4th harmonic)			E _{c''} (6th harmonic)		
Freq.	Loss	Level	Freq.	Loss	Level	Freq.	Loss	Level
2f	Db.	Db.	4f	Db.	Db.	6f	Db.	Db.
2f	7.56	+10	4f	21.42	-3.86	6f	28.78	-11.22
4f	7.56	+20	8f	21.42	+6.14	12f	28.78	-1.22
6f	7.56	+30	16f	21.42	+16.14	24f	28.78	+8.78

Output

E _d (2nd harmonic)			E _{d'} (4th harmonic)			E _{d''} (6th harmonic)		
Freq.	Att.	Level	Freq.	Att.	Level	Freq.	Att.	Level
2f	Db.	Db.	4f	Db.	Db.	6f	Db.	Db.
2f	10	0	4f	20	-23.86	6f	26	-37.22
4f	20	0	8f	30	-23.86	12f	36	-37.22
6f	30	0	16f	40	-23.86	24f	46	-37.22

The meaning of the symbols above is as follows:

E_a=voltage supplied to the input terminals.

E_b=voltage supplied from the input network to the rectifier circuit.

E_c, E_{c'}, E_{c''}=second, fourth and sixth harmonic voltages supplied from the rectifier circuit to the output network.

E_d, E_{d'}, E_{d''}=second, fourth and sixth harmonic voltages at the output terminals.

To illustrate the operation of the circuit, let it be assumed that voltages at frequencies f , $2f$, and $4f$, and at a level of zero decibels, be supplied to the input terminals 21 of the system. Each of these voltages considered individually is a pure sine wave, such as illustrated by curve 51 of Fig. 3. In accordance with the gain characteristic of the input network, as illustrated by curve 61 of Fig. 4, the output voltage E_b of the input network will contain voltages at the same frequencies f , $2f$, and $4f$. However, since there is a gain of 17.56, 27.56 and 37.56 decibels respectively for each of these frequencies, the respective levels will change to +17.56, +27.56 and +37.56 decibels, as shown in Table I. The voltage existing across resistor 35 of the rectifier circuit has a wave form in accordance with curve 52 of Fig. 3. The unidirectional component contained in this wave form is blocked by the capacitor 36 and does not appear in the output of the rectifier circuit E_c. The output will contain all even-numbered harmonics of the input voltage and these will exist at levels corresponding to those at the input to the rectifier circuit, taking into account the magnitudes as expressed by the Fourier series in Equation I. The levels of the second, fourth and sixth harmonics will suffer a loss of 7.56, 21.42 and 28.78 decibels respectively. The output network 40 has a frequency attenuation characteristic represented by curve 63 of Fig. 4. Accordingly, the attenuation acting on the second harmonics of the input voltages will be 10, 20, and 30 decibels for the frequencies $2f$, $4f$, and $8f$ respectively. Since these attenuations are exactly equal to the gains in the voltages from which these frequencies were derived, the re-

sulting level for the second harmonic in each case is zero. With respect to the fourth harmonic voltages constituting E_{d'}, whose frequencies are $4f$, $8f$, and $16f$ respectively, the attenuation acting upon them will be 20, 30, and 40 decibels respectively. Accordingly, the level of the fourth harmonics at the output are uniformly reduced 10 decibels more than the second harmonic and are 23.86 decibels below the zero level. This reduction of 23.86 decibels is caused to the extent of 13.86 decibels by the normal action of the full wave rectifier, and to the extent of 10 decibels by the action of the input and output networks. Considering now the sixth harmonic constituting E_{d''}, whose frequencies are $6f$, $12f$, and $24f$ respectively, the attenuation, in each case, is 26, 36, and 46 decibels. Accordingly, the resultant level, in each case, is 37.22 decibels below the level of the second harmonic. The horizontal lines 62, 64, and 65 of Fig. 4 illustrate respectively the output levels of the second, fourth, and sixth harmonics at the output of the system. The second harmonic comes out at the same level as the input voltage was supplied at the system, namely at the zero level, while higher harmonics come out at lower levels. Thus it will be apparent to those skilled in the art that harmonics higher than the second can be reduced to as low a level as desired by increasing the gain per octave of the input network, and the attenuation of the output network to higher values, in equal proportions. For an input and output filter combination in which each filter has a slope of 6 decibels per octave, the total harmonic distortion in the output, with respect to the second harmonic, will be less than 6.6%, while with a slope of 14 decibels per octave, it will be less than 4.6%. However, it is not necessary that the input filter have this particular value of increase in gain per octave. It may have any convenient value, provided that the output filter is given an inversely sloping characteristic.

While my invention finds its most convenient application in a frequency doubling circuit, it can be applied to circuits providing any factor of frequency multiplication. However, to operate as a multiplier by a factor greater than two, it is necessary to convert the input voltage into poly-phase voltages. For example, if it is desired to multiply the output frequency by a factor N, an N-phase amplifier or oscillator is used to provide the input voltage. The input network will include means to operate on each phase in accordance with a characteristic such as represented by curve 61 of Fig. 4. The rectifier circuit will comprise N rectifying elements or diode valves so that the output of the rectifier circuit will comprise the Nth harmonic of the input frequency. The characteristic of the output network will then be similar to that already described with reference to Fig. 2, and the output voltage will contain the Nth harmonic of the input at the same level and with all higher harmonics proportionally reduced in amplitude.

While a specific embodiment has been shown and described, it will, of course, be understood that various modifications may be made without departing from the invention. The appended claims are, therefore, intended to cover any modifications within the true spirit and scope of the invention.

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

1. A frequency multiplier circuit comprising an input network, a rectifier circuit, and an out-

put network, said input network being adapted to be supplied with a voltage of variable frequency and amplitude, means in said input network to amplify said input voltage and to supply the amplified voltage to said rectifier circuit, said means having an amplification increasing with frequency, said rectifier circuit comprising a plurality of rectifying elements whereby said amplified voltage is converted into an intermediate voltage comprising a series of harmonics, said series of harmonics being supplied to the output network, and means in said output network to attenuate said harmonics, said last means having an attenuation increasing with frequency at the same rate as said amplification, whereby the output contains the first order harmonic of the input at one level and higher order harmonics at increasingly lower levels.

2. A frequency multiplier circuit comprising an input network, a rectifier circuit, and an output network, said input network being adapted to be supplied with a voltage of variable frequency and amplitude, means in said input network to amplify said input voltage and to supply the amplified voltage to said rectifier circuit, said means having an amplification increasing linearly with frequency, said rectifier circuit comprising a plurality of rectifying elements whereby said amplified voltage is converted into an intermediate voltage comprising a series of harmonics, said series of harmonics being supplied to the output network, and means in said output network to attenuate said harmonics, said last means having an attenuation increasing linearly with frequency, whereby the output contains the first order harmonic of the input at one level and higher order harmonics at increasingly lower levels.

3. A frequency doubler circuit comprising an input network, a rectifier circuit, and an output network, said input network being adapted to be supplied with a voltage of variable frequency and amplitude, means in said input network to amplify said input voltage and to supply said input voltage to said rectifier circuit, said means having an amplification increasing linearly with frequency, said rectifier circuit comprising a full wave rectifier whereby said amplified voltage is converted into an output voltage comprising a series of even harmonics, said series of harmonics being supplied to the output network, and means in said output network to attenuate said

harmonics, said last means having an attenuation increasing linearly with frequency, whereby the output contains the first order harmonic of the input at one level and higher order harmonics at increasingly lower levels.

4. A frequency doubler circuit comprising an input network, a rectifier circuit and an output network, said input network being adapted to be supplied with a voltage of variable frequency and amplitude, said input network providing an attenuation in decibels which varies as the inverse logarithm of frequency, said rectifier circuit comprising a full wave rectifier whereby said attenuated input voltage is converted into an output voltage comprising a series of even harmonics, said series of harmonics being supplied to said output network, said output network providing an attenuation which varies as the logarithm of frequency, whereby the output contains the first order harmonic of the input at one level and higher order even harmonics at increasingly lower levels.

5. A frequency doubler circuit comprising an input network, a rectifier circuit, and an output network, said input network being supplied with a voltage at a certain reference level of amplitude whose frequency varies over a number of octaves, and an amplifier in said input network to amplify said input voltage and to supply the amplified voltage to said rectifier circuit, said amplification being of $M+7.56$ decibels at the initial frequency of the first octave and increasing by M decibels for every octave of frequency, where M is any positive number, said rectifier circuit comprising a full wave rectifier, whereby said amplified voltage is converted into an output voltage comprising a series of even harmonics, said series of harmonics being supplied to said output network, said output network comprising an attenuator which provides an attenuation of zero decibels at the initial frequency of said first octave and which increases by M decibels with every octave in frequency, whereby the output contains the second order harmonic of the input at said reference level, the fourth order harmonic of the input at a level $M+13.86$ decibels lower than said reference level, and higher order harmonics at increasingly lower levels.

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No references cited.