

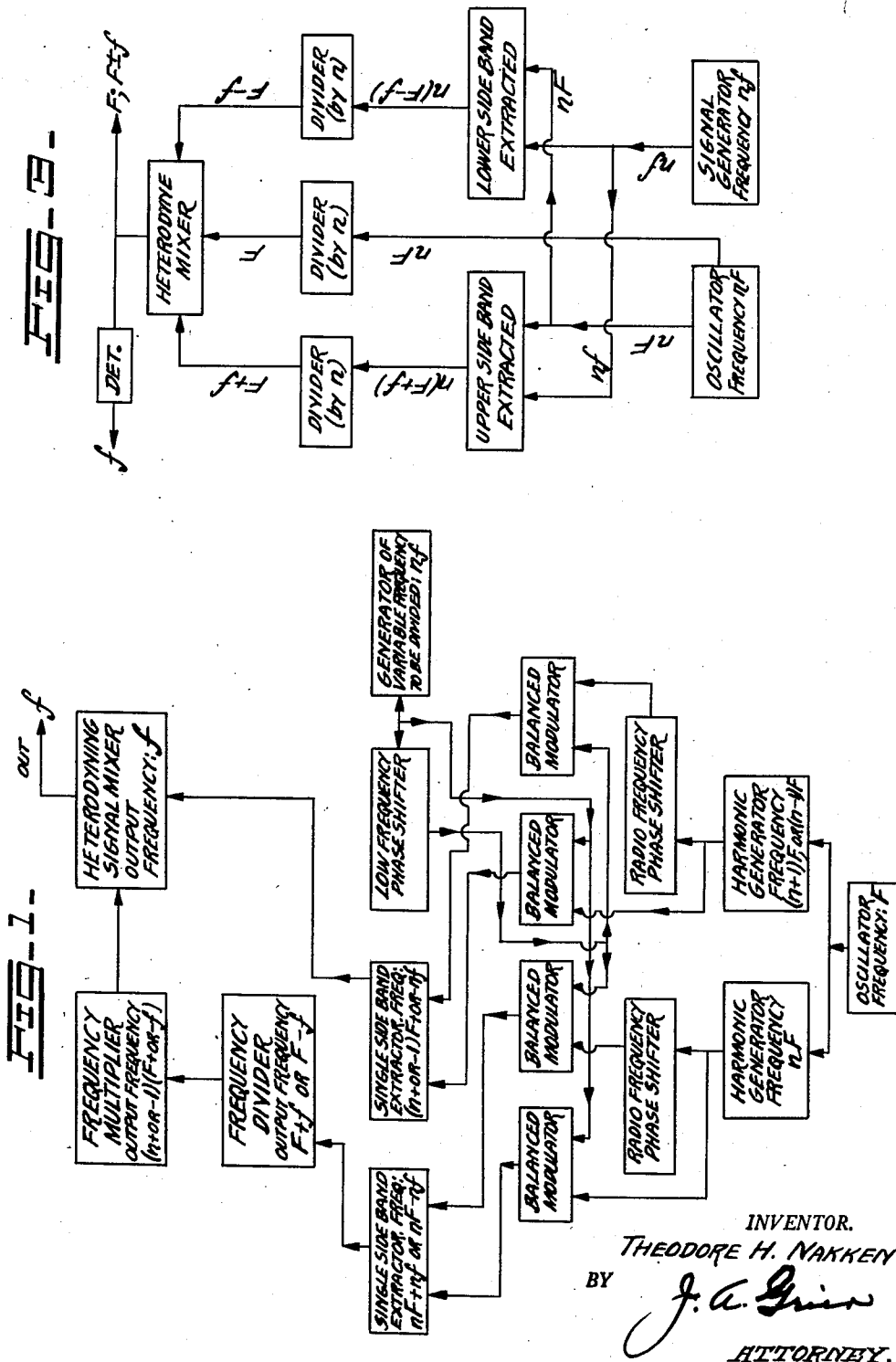
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FREQUENCY DIVISION

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FREQUENCY DIVISION

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The present invention relates to the recording and/or transmission of complex signals containing a plurality of mixed and/or intermixed frequencies, such as, for instance, signals generated by speech or musical programs, and has as an object the aliquot division of the frequencies of such signals.

Another object of the invention is the provision of such divided signals for recording and reproducing purposes.

Another object of the invention is the provision of such divided frequencies of the purpose of modulating radio frequency waves for transmitting purposes.

Again another object of the invention is the generation of modulated radio frequency signals, which, upon demodulation, by means of an ordinary radio receiver, will create a signal representing such an aliquot fraction of the original signal frequencies.

Still another object of the invention is the generation of radio signals of the single sideband suppressed carrier type, which after heterodyning with the appropriate carrier will generate a signal which represents such an aliquot fraction of the original signal frequencies.

These and other objects of the invention can be readily understood by those versed in the art upon perusal of the following specification and a study of the drawings attached thereto, comprising Figures 1 to 3, inclusive. These drawings give an outline of the processes leading to the objects of this invention in the form of block diagrams.

Frequency dividers (and, for that matter, multipliers) are in daily use in radio practice, and are well known in the art, so that a detailed description of such devices seems superfluous for the purpose of understanding my invention. Such dividers are, in general, highly reliable instruments which function perfectly, provided the frequencies to be divided do not deviate more than from 4 to 6% from the frequency for which the divider is intended.

The present invention, however, envisages the division of the type of signals specified hereabove, and is supposed, therefore, to divide frequencies which may vary by almost 100%, as in musical programs, and, moreover, of any complexity which may occur in such signals.

Such dividers would be of tremendous economic importance, for instance, when applied in carrier telephony. Here aliquot division of the speech frequencies would enable a line, now used, say for 100 single sideband conversation channels,

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to be used for two, three, four, or even more times that number of speech channels without widening the frequency spectrum for which the line is constructed.

Obviously, such a multiplication of the number of channels within a given frequency spectrum would result in great savings in cost of the line, as this cost increases inordinately with widening of the spectrum to be accommodated.

It is no wonder then that frequency division, the subject of the present invention, has been the subject of protracted research by those interested in the art. The results of such research, however, were largely negative, and it seems to be the consensus of opinion amongst those who engaged in such research that the possibility of a solution of this problem is highly to be doubted, or is unattainable.

The result of this assumption was that attempts were made to achieve results similar to the objects of this invention by totally different methods. One instance of these efforts is the generation of synthetic speech, as exemplified by the "Vocoder" of the Bell Telephone Laboratories. Another is a mecano-photo-electric device as demonstrated by the British Thompson-Houston Co., while many other attempts have been made towards similar goals by others in similar lines of endeavor.

True frequency division in the sense of this invention will find a great many other fields of application. One instance is, for instance, the possibility of creating phonographic devices, using divided frequency recordings, where recording and reproduction can be accomplished at reduced speed, resulting in longer recording and playing time. In this instance reproduction should be undertaken in combination with multiplication of the recorded, divided frequencies, in order to regain the original frequencies. This field of application includes, of course, not only the usual phonograph, but likewise wire or tape recorders, sound on film devices and the like. In the latter case, for instance, frequency division would make high fidelity reproduction from 16 mm. film a reality, a fact of the greatest importance in view of the increasing use of such film in television programming.

It is quite obvious that frequency division in the sense of my invention would open the possibility of multiplying the number of available channels in those parts of the radio frequency spectrum now overloaded. It will be apparent from the following that several different methods for this purpose are available, all falling within

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the scope of my invention. Other fields of application of my invention will readily occur to those skilled in the art, such as video transmission and the like.

As stated before, there are at present no dividers known which will function over a range of frequencies such as contemplated in the invention. It is, therefore, obvious that aliquot division of complex signals appears to be feasible only if such signals are superimposed as modulators on high frequency carrier waves, the frequency of which should be, by preference, at least a hundred times as high as that of the highest frequency occurring in the signal to be divided, so as to make frequency variations but a small percentage of the total frequency. Of course it is necessary to consider which method of modulation shall be used. There are known, at present, three different modulation systems: resp., amplitude, phase and frequency modulation.

In true amplitude modulation there is no change in the frequency of the wave transmitted, but the amplitude of this wave varies in accordance with the amplitude of the modulating signal, so that an envelope is created which is a substantially faithful picture of the modulating signal.

A divider, in general, is a regenerative device, quiescent in the absence of a signal, but which starts operating when a signal is present. It will faithfully divide the frequency of an amplitude modulated signal, i. e., it will produce a lower frequency wave. However, as it is actuated by this signal, the amplitude of its output is a function of the amplitude of the input signal. Hence, the envelope of the output signal is a duplicate of the envelope of the input signal. The divider cannot, per se, create a new envelope, and therefore does not change anything in the nature of the signal obtained after demodulation, and hence does not operate so as to attain the objects of this invention.

In either phase or frequency modulation there occur phase respectively frequency deviations, the magnitudes of which are determined by the momentary amplitude of the modulator. These deviations occur at a frequency which is determined by the frequencies present in the modulator. Obviously a divider will not change the frequency with which these deviations occur, and so simple division of these kinds of signals will not result in frequency division in the sense of my invention.

These facts then show that division of a modulator cannot be attained by the division of a normally modulated high frequency wave. To attain my objects other means must be employed.

The above remarks are, however, a good indication of what kind of a signal would be most desirable for the purposes of the invention. Such a signal should be modulated in such a manner that the frequency deviates from that of the carrier by the frequency of the modulator. If such a high frequency signal existed, division of such a signal would result in a new signal, in which the deviation after division would be a fraction of the original deviation. If then such a signal were demodulated after division, there would result a divided modulator signal.

The only case in which such frequency deviation exists is found in the so-called single sideband, as extracted from an amplitude modulated signal. Apparently then this single sideband signal is the one to be used, and could be used in

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the form of a pure side band or in the form of such a side band mixed with the carrier.

Demodulation of a pure single sideband is attained by heterodyning such side band with its proper carrier. The modulator is obtained by the extraction of the differential beatnote, which, by definition, possesses the frequency of the modulator.

If a single sideband is mixed with its proper carrier, the possibility exists of obtaining the addition heterodyne signal. This signal, however, again takes the form of a single sideband, and in order to be demodulated recourse must be had once again to heterodyning, this time with a carrier having a frequency twice that of the original carrier, and extracting the differential beatnote. As, therefore, both methods are similar in this respect, description of the events occurring when a pure single sideband is extracted will also suffice for the case of sideband and carrier admixed.

If, then, a single sideband be divided, a new signal will be obtained, which shows frequency deviations that are a fraction of those in the original sideband. If, then, this divided sideband is heterodyned with a carrier, which is the same fraction of the original carrier as the divided sideband, there will exist, between the new signal and the divided carrier, frequency differences equal to a fraction of the original modulator frequencies. The differential beatnotes created in this process will, therefore, have a frequency which is the same fraction of the original modulator frequency.

Apparently, then, division of the modulator can be accomplished in this comparatively simple way. However, when this process is attempted, it is found that, although division of the modulator has been accomplished, this divided modulator is admixed with a great many spurious frequencies.

These spurious frequencies are the result of the fact that the single sideband, in addition to possessing a frequency which differs from that of the carrier by the frequency of the modulator, is also amplitude modulated whenever the modulator contains two or more component frequencies. As in the case of division of an amplitude modulated signal, this envelope is not changed in the slightest by the divider.

Thus, when demodulating the divided sideband by heterodyning it against the divided carrier, the divided signal generated by the heterodyne process will be admixed and intermodulated with the signal generated by the action of the amplitude modulations as represented by the original envelope of the sideband. Apparently all attempts at elimination of these spurious admixtures have failed up to the present time, and this failure apparently convinced those skilled in the art that frequency division in the sense of the present invention is impracticable, if not impossible.

My invention consists, therefore, essentially in having discovered the fact that these spurious frequencies are eliminated automatically if one heterodynes, against one another, two radio frequency signals in the form of single sidebands, which, first of all, differ in frequency by that of the divided modulator, but which, moreover, possess identical envelopes, i. e., the envelope of the undivided single sideband.

It will at once be apparent to those versed in the art that two such signals will be in phase respectively 180° out of phase at a rate determined by the difference in frequency between the

two signals, i. e., by the frequency of the divided modulator. This phase relationship will create addition respectively difference amplitudes at the frequency of the divided modulator. Thus, an entirely new envelope will be created, and this envelope is the same as would characterize the single sideband if it were created by the divided modulator, had the latter a priori been available.

Referring now to Figure 1, I show one way in which the above purpose may be accomplished. An oscillator, generating a frequency F , actuates two harmonic generators, one of which generates a frequency nF , the other one, for instance, a frequency $(n-1)F$.

This procedure is followed for the purpose of at all times maintaining the exact numerical ratio of $n:(n-1)$ between the output frequencies of the two harmonic generators, as any deviation from this ratio would result in faulty operation of the aggregate, and would give rise to frequency distortions, as will be understood by those versed in the art.

The signal to be divided, which may be of the most complex nature, is created by a generator, the frequency of which may be designated, at any moment, by the term nf .

This variable frequency is used to modulate the waves generated by the two harmonic generators, with the purpose of extracting, in each case, a single sideband. I have used a diagram denoting the so-called phase rotation method for this purpose, although it is clear that the single sidebands may be extracted by means of any process which may lead to this end.

While the single sidebands extracted may be either the upper or lower ones, I will assume, for an example, that the sidebands extracted have frequencies of respectively $nF-nf$ and

$$(n-1)F-nf$$

The first one of these two sidebands is passed through a divider which, after division by n , generates a signal with a frequency of $F-f$. This signal is then passed through a multiplier, which generates a signal with a frequency $n-1$ times higher, so that the final result is a wave of frequency $(n-1)F-(n-1)f$.

I now have available two signals with identical envelopes, which differ, in frequency, by the number f , which, of course, equals the frequency of the original modulator (nf) divided by n . In other words, if I should beat these signals against one another, the demodulation product will be the original modulator, divided by n , which is one of the objects of my invention.

In the drawing I have indicated other numerical relations which will lead to the same result, but it is quite evident that such relations are normal ones and may be derived by any one familiar with the art, after a study of this specification.

Referring now to Figure 2, I have outlined a process which may be used for two different objects: either for the extraction of the dividend modulator, or for obtaining a radio signal modulated by the divided modulator. Here again I have indicated sideband extraction by means of phase rotation, arranged in such manner that simultaneously both the upper and lower sidebands are obtained separately. After extraction of the two sidebands they are each separately divided by a factor of $2n$, if overall division by n is desired. Following the diagram it will be seen that the divided sidebands show a numerical frequency difference equal to f , while the modulator

frequency equals nf , so that the final differential beatnote will be the original modulator, divided by n . It is quite obvious, that the requirement that both beating signals shall have the same envelope is fully satisfied in this procedure.

However, this circuit may likewise be utilized for the purpose of generating a radio signal by using the addition heterodyne product. As will be seen, this signal will possess a frequency F , if the oscillator has a frequency nF as indicated. This signal will be amplitude modulated for following reasons.

Each one of the sidebands is amplitude modulated, after division, and retains in that process the original envelope of the undivided sidebands. As the two divided sidebands show a frequency difference equal to f , the waves will be in phase respectively out of phase, f times per second, so that addition amplitudes and subtraction amplitudes will occur at that frequency in the heterodyne signal of frequency F . Thus, again, a new envelope is created, which is characteristic of modulation by a modulator of frequency f .

This signal, being amplitude modulated, can be received on an ordinary radio receiver designed for amplitude modulated reception. The signal, of course, contains no carrier, so there will be no wave transmitted when no modulation is present.

Figure 2, therefore, represents a procedure by means of which two separate objects of the invention may be attained, and in one of its possible forms represents a highly useful and novel way of radio communication.

It is obvious that when such a radio signal is received by means of an ordinary A. M. receiver, the demodulated signal shows a frequency equal to f , which is, as desired, the equivalent of the divided modulator. There exists, in this case, the possibility of holding n equal to 1, which means, of course, that the two sidebands would be divided by 2. The two divided sidebands then show a frequency difference equal to that of the original modulator, and thus, upon demodulation, reproduce the original modulator. The radio signal created in this manner, however, occupies a bandwidth equal to f , as is clear from the diagram Figure 2. I have, therefore, attained a new way of radio communication, in which the channel needed to accommodate a modulated signal comprises no more cycles than the number of cycles of the modulator, as against twice this channel width used for normal amplitude modulated signals. Yet, this radio signal will be received with its original frequency by ordinary A. M. radio receivers.

The implications of this novel way of transmission are of the greatest importance. It is clear that the wave channel required by it is the same as that required for single sideband transmission. In the latter method of communication, however, a local generator is needed for the production of a carrier frequency to be heterodyned with the signal received. If this locally generated carrier deviates from the correct frequency distortion results.

My novel method of communication, while occupying the same channel width, as the single sideband, does not require such a local carrier, and frequency distortion cannot normally occur. This fact causes a great simplification in all such cases where now carrier telephony by means of single sidebands is practiced, both over telephone lines and in radio communication.

Referring now to Figure 3, there is shown a diagram in even more simplified form for the

extraction of the upper and lower sidebands. As stated above, it is immaterial in what manner this extraction is accomplished, as this process per se has no bearing on the present invention.

In Figure 3 frequency division by n is applied not only to the two sidebands, but likewise to the original carrier wave, after which all three divided waves are united in a heterodyne mixing stage. The divided carrier should preferably have an amplitude at least twice as great as the greatest amplitude of the sidebands.

In this case the heterodyning produces a new signal, consisting of the divided carrier and two sidebands. As the sidebands so heterodyned fall into and out of phase with the carrier at a frequency equal to the modulator frequency divided by n , and mutually with a frequency twice as great, an entirely new envelope is created, this time with a shape which represents the modulator frequency divided by n . This signal, obviously, is of the nature of an ordinary amplitude modulated signal, modulated by a signal with $1/n$ th the frequencies of the original modulator.

This signal can be received on an ordinary A. M. receiver and the demodulation signal is an audio signal with $1/n$ th the frequency of the original modulator. The waveband required for this signal, however, will be $2/n$ th of the original modulator frequency, in contradistinction with that for the arrangement of Figure 2.

Above, I have discussed such circuits as will divide a given complex signal into an aliquot fraction, or which will produce modulated high frequency wave signals that, upon demodulation, will furnish an aliquot fraction of said complex signal. I wish to point out, however, that my invention may find other, useful applications in such cases where the generation of signals is desired, the frequency of which is a compound fraction of a given, original signal.

An example, which I would like to point out, is the application of such compound dividers to electronic musical instruments, such as organs or pianos. When such instruments are employed to accompany, for instance, vocalists, it is often necessary to transpose from one scale into the other for the adaptation of the instrument to the singer's range. However, whenever music composed for these instruments is transposed, the color or mood of the music changes in the process, due to the fact that these instruments are tuned in the tempered scale. Transposition thus introduces intervals unlike those intended by the composer. Frequency division resulting in a compounded fractional output may be applied to the audiofrequency waves generated by such an instrument, and by this process transposition is automatically effected by means of the divider instead of by the musician. The latter may continue to play the music in the way it was written, but by a simple push-button operation a compound-fractional divider which may be one of a group of such apparati, transposes the original music to any other scale desired, with complete retention, however, of the originally intended proportional intervals.

Referring now, as an example, to Figures 1 and 3, it will be clear that simple omission of the divided sideband multiplier in each of these circuits enables me to generate new signals with frequencies which have a value of $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$, $\frac{7}{8}$ etc. of the originally generated frequencies.

On the other hand, if, in this multiplier, a factor $(n-2)$, $(n-3)$ etc. be employed, rather than

$(n-1)$, such compound fractions as $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{4}{5}$, $\frac{5}{6}$, $\frac{6}{7}$ etc. may be obtained.

It is obvious that those versed in the art may attain such results by various other arrangements in the dividing apparatus, but such arrangements all fall within the scope of this invention as long as instruments are employed, in which signals with identical envelope and different frequencies are heterodyned against one another for the purpose of obtaining a new signal with a derived frequency.

A study of this specification will undoubtedly enable those versed in the art to provide other arrangements which will lead to the generation of either divided modulators or of radio signals modulated by a divided modulator, of the different types as here indicated. It is evident, that any such arrangements will fall within the scope of this invention, if the results obtained are dependent on the use of two separate sidebands which are characterized by the fact that they have identical envelopes and exhibit such frequency differences that the heterodyne products, either by addition or by subtraction, possess the desired characteristics of modulation by a fraction of the original modulator.

I claim:

1. The method of dividing a complex variable frequency signal to obtain a new complex variable frequency signal having frequencies which are predetermined fractions of the frequencies of said first signal, which includes the step of modulating continuous high frequency waves and extracting therefrom single side bands which consistently differ in frequency by said fractions, the step of heterodyning said side bands against one another, and the final step of extracting said new signal.

2. The method of obtaining a new signal that is an aliquot fraction of a given variable frequency signal, which comprises the step of modulating continuous high frequency waves by means of said given signal, the step of producing single side bands from the modulated signal which have identical envelopes and which differ in frequency by the desired frequency of said new signal, the step of passing said side bands through a heterodyning stage, and the final step of extracting said new signal.

3. The method of obtaining a new signal, that is, an aliquot division of a given variable frequency signal, which comprises the step of modulating continuous high frequency waves by means of said given signal, the step of producing single side bands from the modulated signal, the step of dividing at least one of said side bands, the step of passing said side bands through a heterodyning stage, and the final step of extracting the new signal.

4. The method of obtaining a new variable frequency signal which is fractional as compared to a given original variable frequency signal, which comprises the step of modulating a continuous high frequency wave by means of said original signal, the step of extracting single side bands from the modulated signal, the step of individually dividing said side bands to produce the new frequency, the further step of beating the divided side bands against each other to destroy the original envelopes and create a new one, and the final step of extracting the desired new signal.

5. The method of obtaining a new signal that is an aliquot fraction of a given variable frequency signal, which comprises the step of modu-

lating continuous high frequency waves by means of said given signal, the step of producing single side bands from the modulated signal which have identical envelopes and which differ in frequency by the desired frequency of said new signal, the step of beating said side bands against each other, and the final step of extracting said new signal.

6. The method of obtaining a new variable frequency signal which is fractional as compared to an original variable frequency signal from which it is derived, comprising the step of modulating a continuous high frequency wave by means of said original signal, the step of producing single side bands from the modulated signal which have identical envelopes and which differ in frequency by the desired frequency of said new signal, the step of heterodyning said side bands against each other, and the final step of extracting said new signal.

7. The method of dividing an original variable frequency signal to obtain a new variable frequency signal which is fractional as compared to said original signal, comprising the steps of: modulating a continuous high frequency wave by means of said original signal, deriving single side bands from the modulated signal which have identical envelopes derived from the original signal and which differ in frequency by the desired frequency of the new signal, the step of heterodyning said side bands against each other to destroy the original envelopes and to create a new envelope, and the step of extracting the desired new signal having said new envelope.

8. The method of dividing a complex variable frequency signal to obtain a new complex variable frequency signal having frequencies which are predetermined fractions of the frequencies of said first signal, which includes the step of modulating continuous high frequency waves and extracting therefrom single side bands, the step of

dividing one of said side bands to produce a new frequency, the step of heterodyning said divided side band against the other one, and the final step of extracting said new signal.

9. The method of dividing a complex variable frequency signal to obtain a new complex variable frequency signal having frequencies which are predetermined fractions of the frequencies of said first signal, which includes the step of modulating continuous high frequency waves and extracting therefrom single side bands, the step of dividing one of said side bands by a factor to produce a new frequency, leaving the other side band intact, the step of heterodyning said divided side band against the other one, and the final step of extracting said new signal.

10. The method of dividing a complex variable frequency signal to obtain a new complex variable frequency signal having frequencies which are predetermined fractions of the frequencies of said first signal, which includes the step of modulating continuous high frequency waves and extracting therefrom single side bands, the step of dividing one of said side bands to produce a new frequency, the step of multiplying said divided side band to produce a frequency different from said last new frequency, the step of heterodyning said divided side band against the other one, and the final step of extracting said new signal.

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