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SINGLE SIDEBAND MODULATION SYSTEM

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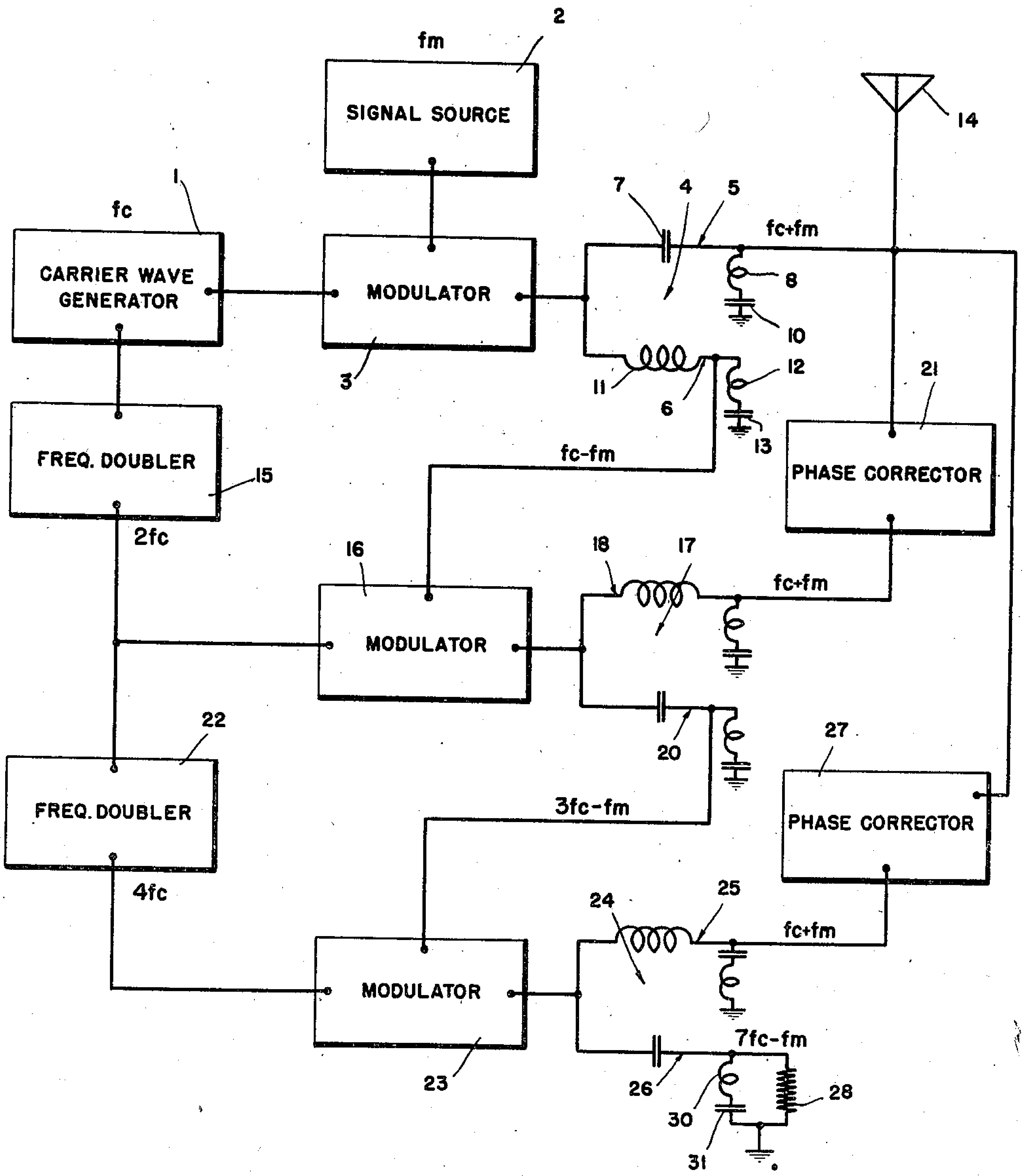

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SINGLE SIDE-BAND MODULATION SYSTEM

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This invention relates to modulation systems, and more particularly relates to a system for developing a single-sideband modulated-carrier wave.

When the amplitude of a carrier wave is modulated in accordance with a signal of variable frequency, a modulated carrier wave is developed which comprises an upper and a lower sideband. It is well known that all the information contained in the signal is present if the carrier frequency and only one of the sidebands is transmitted. Accordingly, one of the sidebands of a modulated carrier wave represents surplusage, and for this reason single sideband transmission where only the carrier frequency and one of the sidebands is transmitted has been proposed in the past. Present television standards, for example, demand transmission of the video signal by vestigial sideband transmission thereby to reduce the width of the channel required for the transmission of an image with given detail.

Modulation of a carrier wave in accordance with a video signal, which may include frequencies from zero to approximately 5 megacycles, presents considerable difficulties. For this reason, modulation of the carrier wave at low levels is preferred because it is practically impossible to amplify the video signal to a high power level. On the other hand, amplification of a carrier wave modulated in accordance with a video signal also presents appreciable difficulties in view of the extremely wide sidebands of the carrier. Thus, for example, amplification of a modulated carrier wave by means of a class C amplifier, which is the most efficient amplification method, is not possible. Therefore, it has been proposed to remove one of the sidebands of the modulated carrier wave before further amplification takes place. The undesired sideband of a modulated carrier wave is conventionally suppressed by means of a filter network. However, unless the power amplifier stages used for amplifying the single-sideband modulated-carrier wave have exactly linear amplification, the undesired sideband is reinserted. Modulation systems have also been suggested where a modulated carrier wave is developed having a single sideband only. This is effected by destroying the undesired sideband through interference, that is, by introducing a phase shift of 180 degrees between two components of the undesired sideband.

It is an object of the present invention, therefore, to provide a modulation method and system for developing a single-sideband modulated-carrier wave of appreciable power without requiring a high modulation level of the signal to be transmitted.

A further object of the invention is to utilize one of the two sidebands developed by modulating a carrier wave for feeding a utilization device, such as an antenna, while the other normally undesired sideband is utilized for developing a further sideband or further sidebands identical in frequency with the desired sideband, thereby to increase the amplitude or power of the desired sideband.

In accordance with the present invention, there is provided a single sideband modulation system comprising means for developing a signal and for developing a carrier wave of frequency f. Means are provided for modulating the carrier wave in accordance with the signal to develop a modulated carrier wave of frequency f, having an upper and lower sideband. One of the two sidebands is the desired sideband and the other one, the undesired sideband. Means are further provided for doubling the frequency of the carrier wave to develop a carrier wave of frequency $2f$. There is also provided a means for modulating the carrier wave of frequency $2f$ in accordance with the undesired sideband. Thus there is developed a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of which is substantially identical in frequency with the desired sideband. Accordingly, a further sideband is developed which has substantially the same frequency as the desired sideband. Finally means are provided for adding these identical sidebands. In accordance with a preferred embodiment of the invention the upper sideband is the desired sideband.

For a better understanding of the invention, to gether with other and further objects thereof, reference is made to the following description, taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

In the accompanying drawing, the single figure is a circuit diagram, partly in block form, of a single sideband modulation system embodying the invention.

Referring now to the drawing, there is illustrated a single sideband modulation system comprising carrier wave generator 1. Generator 1 is arranged to develop a carrier wave at the frequency f_c. A signal of variable frequency f_m is developed by signal source 2. The signal developed by source 2 may, for example, be a video signal or an audio signal. In modulator 3, connected to the outputs of generator 1 and signal source 2, the amplitude of the carrier wave of frequency f_c is modulated in accordance with the signal developed by source 2. Modulator 3 thus develops a modulated carrier wave having an upper sideband and a lower sideband. The frequencies of the modulated carrier wave are given as follows: f_c+f_m and f_c-f_m, where the first expression represents the upper sideband and the second expression the lower sideband.

The two sidebands are segregated by filter network 4, having a high pass section 5 and a low pass section 6. High pass filter section 5 comprises series condenser 7 and further comprises inductance element 8 and condenser 10 arranged in series and shunted between series condenser 7 and ground. High pass filter section 5 is arranged to pass the upper sideband of the modulated carrier wave developed by modulator 3, that is, frequencies within the range f_c+f_m.

Low pass filter section 6 comprises series inductance element 11 and further comprises inductance element 12 and condenser 13 arranged in series and shunted between inductance element 11 and ground. Low pass filter section 6 is designed to pass the lower sideband of the modulated carrier wave developed by modulator 3, that is frequencies within the range f_c-f_m.

Filter network 4 has been illustrated with lumped elements but it is to be understood that filter network 4 may also consist of suitable sections of transmission lines having distributed capacitance and inductance, as is well known in the art. Other types of filters including multi-section structures may also be used.

The upper sideband including the carrier frequency, that is, frequencies in the range f_c+f_m are passed by high pass filter section 5 which may be connected to antenna 14 for the purpose of radiating the single-sideband modulated-carrier wave into space.

For single sideband transmission it is conventional practice to dissipate the undesired sideband, which is usually the lower sideband, by means of a load resistor connected in parallel across inductance element 12 and condenser 13 of low pass filter section 6. In accordance with the present invention, the undesired sideband, that is the lower sideband, is utilized for developing a further sideband of the frequency f_c+f_m. To this end the frequency of the carrier wave developed by generator 1 is doubled by frequency doubler 15. The output of frequency doubler 15, therefore, is a carrier wave having the frequency of $2f_c$. The amplitude of the carrier wave of frequency $2f_c$ is modulated in modulator 16 in accordance with the lower sideband f_c-f_m obtained from low pass filter section 6.

The output of modulator 16 accordingly is a modulated carrier wave having an upper sideband of frequency $3f_c-f_m$ and a lower sideband of frequency f_c+f_m. Thus it will be seen that the lower sideband of the modulated carrier wave developed by modulator 16 is identical in frequency with the upper sideband of the modulated carrier wave developed by modulator 3.

For the purpose of segregating the two sidebands developed by modulator 16, there is provided filter network 17 having a low pass filter section 18 and a high pass filter section 20. Low pass filter section 18 is similar to low pass filter section 6, while high pass filter section 20 is similar to high pass filter section 5. However, low pass filter section 18 is designed to transmit

frequencies in the range of f_c+f_m, that is, the lower sideband of the modulated carrier wave developed by modulator 16. High pass filter section 20, on the other hand, is arranged to transmit frequencies within the range $3f_c-f_m$, that is, the upper sideband of the modulated carrier wave developed by modulator 16.

The sideband of the frequency f_c+f_m which is developed by modulator 16 and passed by low pass filter section 18 is added to the sideband passed by high pass filter section 5. However, it is necessary to add the two identical sidebands of frequency f_c+f_m in phase. If the two sidebands are out of phase, a phase corrector indicated at 21 may be arranged, for example, in the lead connecting low pass filter section 18 to antenna 14.

The upper sideband developed by modulator 16 and passed by high pass filter section 20 may be utilized again to develop a further sideband of the frequency f_c+f_m. To this end the frequency of the carrier wave developed by frequency doubler 15 is doubled again by frequency doubler 22. The carrier wave developed by frequency doubler 22 has the frequency $4f_c$. The amplitude of this carrier wave may be modulated in modulator 23 in accordance with the upper sideband developed by modulator 16 and having the frequency $3f_c-f_m$. The two sidebands of the modulated carrier wave developed by modulator 23 have the frequencies $7f_c-f_m$ and f_c+f_m, respectively. Thus a further sideband of the desired frequency is developed.

For the purpose of segregating the lower sideband from the upper sideband of the modulated carrier wave developed by modulator 23, there is provided filter network 24 comprising low pass filter section 25 and high pass filter section 26. Low pass filter section 25 is arranged to pass frequencies within the range f_c+f_m, while high pass filter section 26 is arranged to pass frequencies within the range $7f_c-f_m$.

The desired sideband of frequency f_c+f_m which is passed by low pass filter section 25 may also be fed to antenna 14 through phase corrector 27 to insure that the sideband is added to the other sidebands in phase.

The upper sideband of frequency $7f_c-f_m$ which is passed by high pass filter section 26 may be dissipated by load resistor 28 shunted across inductance element 30 and condenser 31 of filter section 26. Alternatively, it is feasible to utilize the upper sideband of frequency $7f_c-f_m$ for developing another desired sideband by modulating therewith a carrier wave of frequency $8f_c$. This procedure may be repeated again to develop as many desired sidebands as required.

The modulation system of the invention has certain advantages over those of the prior art. The modulation level of signal source 2 need not be very high for modulating the carrier wave developed by generator 1. The upper as well as the lower sideband of the modulated carrier wave developed by modulator 3 will have a higher power level than that of the signal developed by source 2. The lower sideband of frequency f_c-f_m is utilized for modulating a carrier wave of frequency $2f$. Thus the desired lower sideband developed by modulator 16 will again have a higher power level than that of the desired sideband developed by modulator 3.

The difficulties presented by raising the power level of a carrier wave are, of course, considerably less than those of amplifying a modulated carrier wave in view of the large frequency range of a modulated carrier wave. Since the method of obtaining a further desired sideband may be repeated several times, the power level of the single-sideband modulated-carrier wave may be raised to an appreciable extent without requiring a high modulation level of the signal source.

Instead of developing a modulated carrier wave having an upper sideband only, it is also feasible in accordance with the invention to develop a modulated carrier wave having a lower sideband only. To this end the output of low pass filter section **6** should be connected to antenna **14**, while the output of high pass filter section **5** should be connected to modulator **16**. Thus the lower sideband of a frequency f_c-f_m is fed to antenna **14**, while the upper sideband of a frequency f_c+f_m is passed to modulator **16**. The modulated carrier wave developed by modulator **16** has two sidebands of the frequencies $3f_c+f_m$ and f_c-f_m, the latter being the desired lower sideband. Filter sections **18** and **20** should, in this case, be arranged to pass the lower and the upper sideband developed by modulator **16** having, respectively, the frequencies f_c-f_m and $3f_c+f_m$.

With the connections shown in the drawing, modulator **23** will then develop a modulated carrier wave having a lower sideband of the desired frequency f_c-f_m and an upper sideband of a frequency $7f_c-f_m$. Filter sections **25** and **26** should, in this case, be arranged to pass the lower and the upper sideband of the modulated carrier wave developed by modulator **23**.

It will be observed that regardless of whether the upper or the lower sideband is the desired sideband, the lower sideband of the modulated carrier waves developed by modulators **16** and **23**, respectively, is always the desired sideband.

In case the lower sideband is the desired sideband, the upper sideband developed by modulator **23**, which has the frequency $7f_c+f_m$, may be utilized again for developing a further desired sideband. To this end the output of high pass filter section **26** may be connected to a further modulator where a carrier wave of frequency $8f_c$ is modulated therewith. In that case load resistor **28** may be omitted.

The modulation system of the invention will also operate when the amplitude of the desired or transmitted sideband is not uniform throughout the frequency range. In some vestigial sideband transmission systems, the amplitude of the transmitted sideband decreases in the neighborhood of the carrier frequency and reaches zero amplitude at a point in the frequency spectrum located in the frequency range of the undesired sideband. As long as the points where the desired sideband reaches zero amplitude and where the desired sideband reached maximum amplitude are symmetrically disposed with respect to the carrier frequency, the undesired sideband is a mirror image of the desired sideband and will, after its transformation to a further desired sideband, be identical in frequency with the desired sideband. The term single sideband modulation system as used in the claims is meant to include such a vestigial sideband transmission system.

While there has been described what is, at present, considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband the other one the undesired sideband, means for developing a carrier wave of frequency $2f$, means for modulating said carrier wave of frequency $2f$ in accordance with said undesired sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, and means for adding said identical sidebands.

2. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating the amplitude of said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband and the other one the undesired sideband, means for doubling the frequency of said carrier wave to develop a carrier wave of frequency $2f$, means for modulating the amplitude of said carrier wave of frequency $2f$ in accordance with said undesired sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, and means including a phase correcting device for adding said identical sidebands in phase.

3. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband and the other one the undesired sideband, means for segregating said upper and said lower sidebands developed by modulating said wave of frequency f, means for developing a carrier wave of frequency $2f$, means for modulating said carrier wave of frequency $2f$ in accordance with said undesired sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, means for segregating said two sidebands developed by modulating said wave of frequency $2f$, and means for adding said identical sidebands in phase.

4. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, said upper sideband being the desired sideband, means for developing a carrier wave of frequency $2f$, means for modulating said carrier wave of frequency $2f$ in accordance with said lower sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with

said upper desired sideband, and means for adding said identical sidebands in phase.

5. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating the amplitude of said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, means for doubling the frequency of said carrier wave to develop a carrier wave of frequency $2f$, means for modulating the amplitude of said carrier wave of frequency $2f$ in accordance with said lower sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said upper sideband, and means including a phase corrector for adding said identical sidebands in phase.

6. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, means for segregating said upper and said lower sideband developed by modulating said wave of frequency f, means for doubling the frequency of said carrier wave to develop a carrier wave of frequency $2f$, means for modulating said carrier wave of frequency $2f$ in accordance with said lower sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said upper sideband, means for segregating said two sidebands developed by modulating said wave of frequency $2f$, and means for adding said identical sidebands in phase.

7. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the wanted sideband and the other one the unwanted sideband, means for successively doubling the frequency of said carrier wave to derive carrier waves each having a frequency being a multiple of f, means for modulating each of said carrier waves having a frequency which is a multiple of f in accordance with the unwanted sideband developed by the modulation of the carrier wave of half the frequency thereof, thereby to develop modulated carrier waves each having two sidebands, the lower one of said sidebands being substantially identical in frequency with said wanted sideband, and means for adding said identical sidebands in phase.

8. A single sideband modulation system comprising means for developing a signal, means for developing a carrier wave of frequency f, means for modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the wanted sideband and the other one the unwanted sideband, means for segregating said two sidebands developed by modulating said wave of frequency f, means for successively doubling the frequency of said carrier wave to derive carrier waves each having a frequency being a multiple of f, means for modulating each of said carrier waves having a frequency which is a multiple of f in accordance with the unwanted sideband developed by the modulation of the carrier wave of half the frequency thereof, thereby to develop modulated carrier waves each having two sidebands, the lower one of said sidebands being substantially identical in frequency with said wanted sideband, means for segregating said two sidebands developed by modulating one of said waves having a frequency which is a multiple of f, and means for adding said identical sidebands in phase.

9. The method of developing a modulated carrier wave having a single sideband which comprises developing a signal, developing a carrier wave of frequency f, modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband and the other one the undesired sideband, developing a carrier wave of frequency $2f$, modulating said carrier wave of frequency $2f$ in accordance with said undesired sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, and adding said identical sidebands in phase.

10. The method of developing a modulated carrier wave having a single sideband which comprises developing a signal, developing a carrier wave of frequency f, modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband and the other one the undesired sideband, segregating said upper and said lower sideband developed by modulating said wave of frequency f, doubling the frequency of said carrier wave to develop a carrier wave of frequency $2f$, modulating said carrier wave of frequency $2f$ in accordance with said undesired sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, segregating said two sidebands developed by modulating said wave of frequency $2f$, and adding said identical sidebands in phase.

11. The method of developing a modulated carrier wave having a single sideband which comprises developing a signal, developing a carrier wave of frequency f, modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, doubling the frequency of said carrier wave to develop a carrier wave of frequency $2f$, modulating said carrier wave of frequency $2f$ in accordance with said lower sideband, thereby to develop a modulated carrier wave of frequency $2f$ having two sidebands, the lower one of said sidebands being substantially identical in frequency with said upper sideband developed by modulating said wave of frequency f, and adding said identical sidebands in phase.

12. The method of developing a modulated carrier wave having a single sideband which comprises developing a signal, developing a carrier wave of frequency f, modulating said carrier wave of frequency f in accordance with said signal to develop a modulated carrier wave of frequency f having an upper and a lower sideband, one of said sidebands being the desired sideband and the other one the undesired sideband, successively

doubling the frequency of said carrier wave to develop carrier waves each having a frequency being a multiple of f, modulating each of said carrier waves having a frequency which is a multiple of f in accordance with the undesired sideband developed by the modulation of the carrier wave of half the frequency thereof, thereby to develop modulated carrier waves each having two sidebands, the lower one of said sidebands being substantially identical in frequency with said desired sideband, and adding said identical sidebands in phase.

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