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Frequency Stabilized Cycloconverter

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This paper proposes a method of frequency conversion from an arbitrary frequency of input signal to a desired one. This cycloconverter may yield sinusoidal signal of stabilized frequency even when the input signal has a time-variant frequency. And high power output signal can be generated by means of switching operation.

In the first place, the principle of frequency conversion and frequency stabilizing characteristics are described. Next, the experimental results are presented.

1. Introduction

It is well known that the cycloconverter is most useful for frequency conversion of high power output signal. But the circuit construction, especially gate circuit, is very complicated.

In this paper, we present a method of frequency converter utilizing two multipliers. This frequency converter is more advantageous than the conventional cycloconverter; the circuit elements are reduced, the circuit is simple in structure, and easy control of output signal frequency. Further, this system can generate a constant frequency signal even when the input signal has a frequency fluctuation. In convenient frequency converter the frequency fluctuation of the output signal cannot be avoided (its output frequency is the sum or difference of two reference frequencies) except that two frequencies are sufficiently stable. This system, a reference signal having a correct frequency is prepared, may convert the input signal to the output one whose frequency is that of reference signal, wherein the frequency of input signal is not necessarily stable and moreover may handle the high power signals.

2 Principle

Fig.1 shows the basic construction of frequency stabilized cycloconverter utilizing two multipliers; main-multiplier operates in switched mode for high power output signal. The angular frequencies of sinusoidal input and reference signals are indicated by ω and ω_0 respectively. Applying the input signal to the sub-multiplier together with the reference signal, it generates the output sinusoidal signal having an angular frequency

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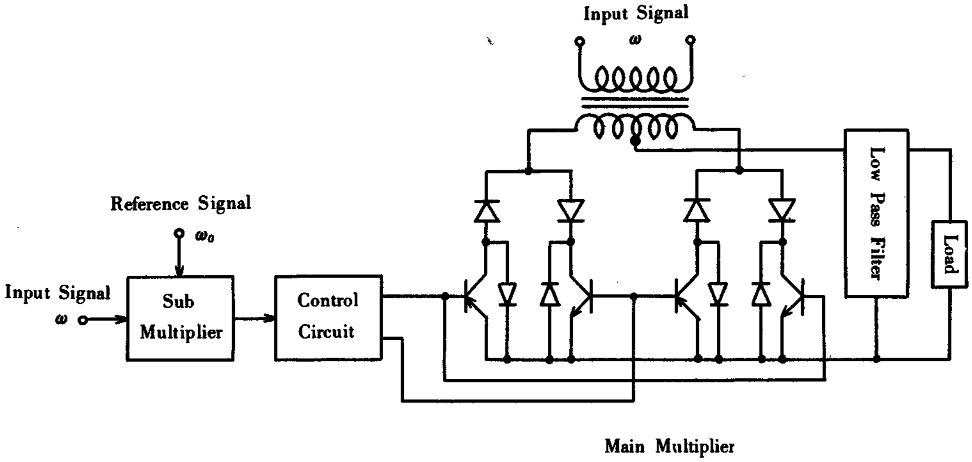


Fig. 1 Construction of frequency cycloconverter.

$\omega_0+\omega$ by eliminating the difference frequency component with a high pass filter which belongs with the sub-multiplier. And the control circuit forms it into a series of rectangular pulses to control the switching transistors of main multiplier. Applying the control pulses to the switching transistors of the main-multiplier, the output voltage the shapes of which are a series of collector-supply voltage interrupted wave forms produced by the on-off action of the switching transistors appears at the input terminals of the low pass filter. The output signal of switching transistors consists of ω_0, $\omega_0+2\omega$, $3\omega_0+2\omega$, $\cdots\cdots\cdots\cdots\cdots$ components. The frequency component of ω_0 can readily be separated from the others using a low pass filter.

This cycloconverter has another capacity to perform frequency stabilizing function. In short, if the input signal fluctuates in frequency, an output signal of required constant frequency can be obtained. Supposing that the input signal having a frequency fluctuation is a frequency modulated wave with a modulating signal which can be expressed by the following Fourier series expansion

$$S=a_0+\sum_{n=1}^{\infty}(a_n\cos npt+b_n\sin npt) \tag{1}$$

the input signal e will be written as

$$\begin{aligned} e&=E\cdot\varepsilon^{j[\omega t+\int_0^t\{a_0+\sum_{n=1}^{\infty}(a_n\cos npt+b_n\sin npt)\}dt]}\\ &=E\sum_{k=-\infty}^{+\infty}\varepsilon^{j(\omega+a_0+kp)t}\sum_{l_1=-\infty}^{+\infty}\sum_{l_2=-\infty}^{+\infty}\cdots\cdots\sum_{l_\infty=-\infty}^{+\infty}J_{l_1}(x_1)\cdot J_{l_2}(x_2)\\ &\quad\cdots\cdots\cdots\cdots J_{l_\infty}(x_\infty)\,\varepsilon^{j(l_1\theta_1+l_2\theta_2+\cdots\cdots\cdots\cdots\cdots\cdots+l_\infty\theta_\infty)} \end{aligned} \tag{2}$$

where,

$$k=l_1+2\,l_2+\cdots\cdots\cdots\cdots\cdots+\infty\,l_\infty \tag{3}$$

$$x_n=\sqrt{a_n^2+b_n^2}\,/\,np \tag{4}$$

$$\tan\,\theta_n=-b_n/a_n\,. \tag{5}$$

In order to simplify Eq. (2), let

$$\Sigma=\sum_{l_1=-\infty}^{+\infty}\ \sum_{l_2=-\infty}^{+\infty}\ \cdots\cdots\cdots\cdots\sum_{l_\infty=-\infty}^{+\infty} \tag{6}$$

$$\boldsymbol{J}=J_{l_1}(x_1)\cdot J_{l_2}(x_2)\cdots\cdots\cdots\cdots\cdots\cdots J_{l_\infty}(x_\infty) \tag{7}$$

$$\boldsymbol{\theta}=l_1\,\theta_1+l_2\,\theta_2+\cdots\cdots\cdots\cdots\cdots\cdots+l_\infty\,\theta_\infty\,. \tag{8}$$

On referring to Eqs. (3), (6), (7) and (8), we rewrite the equation as follows.

$$e=E\,\varepsilon^{j(\omega+a_0+np)t}\quad\Sigma\boldsymbol{J}^*\,\varepsilon^{j\theta*} \tag{9}$$

$$\boldsymbol{J}^*:\ \text{the value of}\ \ \boldsymbol{J}\ \text{for}\ \sum_{q=1}^{\infty}ql_q=k.$$

$$\boldsymbol{\theta}^*:\ \text{the value of}\ \ \boldsymbol{\theta}\ \text{for}\ \sum_{q=1}^{\infty}ql_q=k\ .$$

Since the output signal through the sub-multiplier is given by

$$e_m=\varepsilon^{j(\omega+\omega_0+a_0+np)t}\quad\Sigma\boldsymbol{J}^*\,\varepsilon^{j\theta*} \tag{10}$$

Among the frequency components of the output voltage, each amplitude of frequency components distributed around ω_0, which can be obtained as the product of Eqs. (9) and (10), is given by

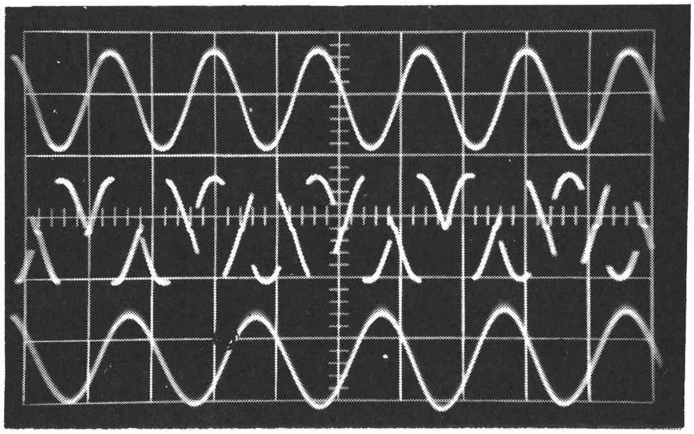
$$\begin{aligned}E_{(\omega_0+Kp)}&=E\sum_{k=-\infty}^{+\infty}\left\{\Sigma\boldsymbol{J}^*\,\varepsilon^{-j\theta*}\ \Sigma\boldsymbol{J}^{**}\,\varepsilon^{j\theta**}\right\}\\&=\begin{cases}E/2 & \text{for}\quad K=0\\ 0 & \text{for}\quad K\neq 0\end{cases}\end{aligned} \tag{11}$$

$$\boldsymbol{J}^{**}:\ \text{the value of}\ \ \boldsymbol{J}\ \text{for}\ \sum_{q=1}^{\infty}ql_q=k+K.$$

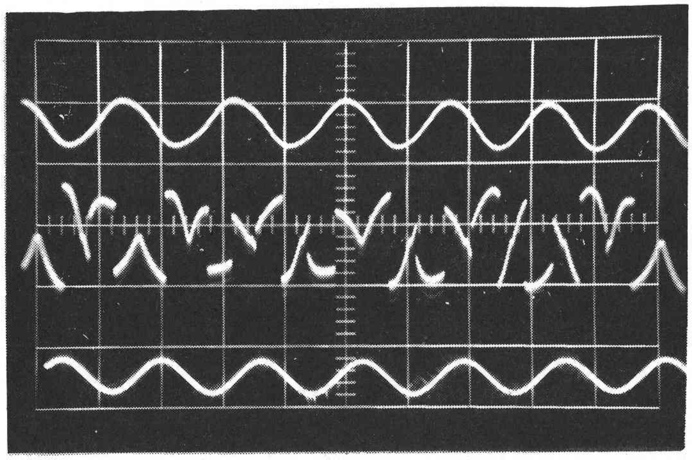
$$\boldsymbol{\theta}^{**}:\ \text{the value of}\ \ \boldsymbol{\theta}\ \text{for}\ \sum_{q=1}^{\infty}ql_q=k+K.$$

As seen in Eq.(11), the frequency components which cause the frequency fluctuation of the input signal do not appear and only the desired reference frequency component can be obtained.

Fig.2 shows the experimental results. In this figure, (a) shows the oscillograms for converting 60Hz signal into 50Hz, the top, middle and bottom are the input signal of 60Hz, the wave form of output voltage and the output signal of 50Hz respectively. And Fig.2(b) verifies the behavior of stabilizing the frequency of output signal even if the input signal fluctuates in frequency, the top is the input signal the frequency of



(a) Top : Input signal 60Hz 5V/div.
Middle : Wave form of output voltage 5V/div.
Bottom : Output signal 50Hz 2.5V/div.



(b) Top : Input signal having a fluctuating frequency 10V/div.
Middle : Wave form of output voltage 10V/div.
Bottom : Output signal 60Hz 5V/div.

Fig. 2 Experimental results.

which is time-variant, the middle is wave form of output voltage and the bottom is the sinusoidal output signal having a constant frequency of 60Hz.

In actual circuit, the output signal is composed of the two groups of frequency components, one is destributed in around the sum of ω_0 and ω, and another is around the difference of the two. It may be designed such that only the group of frequency components around $\omega + \omega_0$ should be separated through the high pass filter in the sub-multiplier.

In general, the expression for a frequency modulated wave shows the infinitely wide band is required. Practically, however, it is well known that the major portion of the energy is included inside the band of frequencies within a frequency deviation plus the frequency of the modulating wave. The frequency modulated waves produced by a square modulating wave as shown in Fig.3 requires the widest effective frequency band than those for any other modulating wave. Supposing that the square wave may be approximated by the frequency components up to M-th one in considerable degree, the expression for the frequency-modulated wave produced by a square modulating wave needs the frequency components inside the band of frequncies within the (M + N)th order. 1)

Where,

$$N = d + 1 . \tag{12}$$

Accordingly, the maximum frequency deviation p capable of stabilizing the output signal frequency is,given as

$$p < \frac{\omega_0 + \omega - (\omega \sim \omega_0)}{2(M+N)} \tag{13}$$

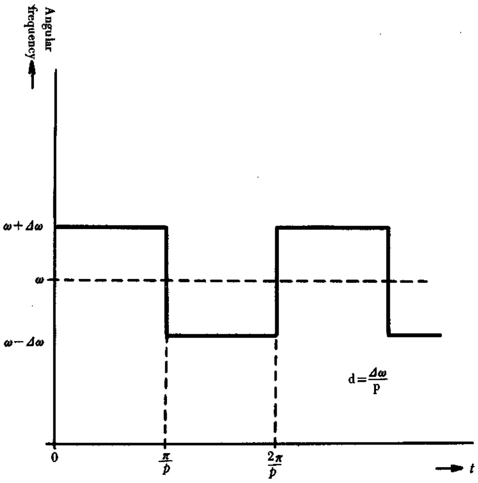


Fig. 3 Instantaneous angular frequency of FM wave modulated by square signal.

In the actual operating condition, if the relation of Eq.(13) holds, the output signal shows a sinusoidal wave without frequency deviation.

3. Conclusion

This paper discusses a principle of the frequency stabilized cycloconverter, wherein the switching transistors are used for high power switches. This method can be obtained a sinusoidal signal of stabilized frequency if the input signal has a time-variant frequency of Eq.(13). Further, high power output signal can be generated by means of switching operation and its efficiency is nearly 100%.

This paper treats of the theoretical analysis entirely from the linear circuit in spite of using switching technique in actual circuit. There is no difference of results between applying the switching analysis and linear analysis except that many harmonics around the sum or difference frequency of odd-multiple of $\omega_0 + \omega$ and ω appear in case of applying switching analysis. Since these harmonics are removed by using a low pass filter, there is no harm in applying linear analysis to investigate the circumstance of frequency sideband around ω_0 for understanding the frequency stabilizing operation of this method.

This cycloconverter can be used for the source supply of the apparatus which requires the accuracy of frequency.

References

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