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A NOVEL METHOD FOR FREQUENCY MULTIPLICATION

by

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A Novel Method for

THE process of frequency multiplication can be separated into two operations—harmonic generation and harmonic selection. The commonly employed Class C frequency multiplier shown in Fig. 1 illustrates this process.[1] The voltage applied to the grid of the tube is large enough to bias the tube well below cutoff so that the plate current flows in brief pulses. These current pulses flow into an impedance (the plate tank circuit) designed to emphasize the desired harmonic component and attenuate all others.

Using the methods of frequency-domain analysis, the plate current can be approximated by a train of fractional sine-wave, or perhaps cosine squared, pulses. A Fourier series[2] can be determined for the plate current, and from the impedance of the tank circuit, the various harmonics in the plate voltage can be calculated.

A better physical picture of the circuit performance is obtained from a time-domain description. Using this method, the plate tank circuit is considered to be excited by each pulse of current. In the interval between pulses, the tank circuit "rings" at its own natural frequency. The plate voltage takes the form of an amplitude-modulated wave with an envelope composed of a series of decaying exponential waves. The amount of decay or decrement of the envelope depends on the interval between current pulses and the Q of the tank circuit, or in frequency-domain terms, on the discrimination of the tank circuit to adjacent harmonics.

In the generation of medium (5-10) and high (> 10) order harmonics with the Class C multiplier, efficiency considerations dictate the use of a brief current pulse. For the usual case, the spectrum of the pulse train has a decreasing envelope in the region of interest. That is, the desired harmonic component of the current is smaller in amplitude than the next

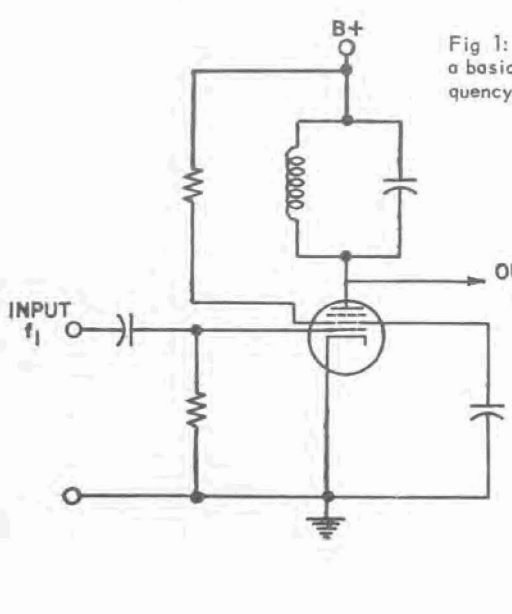


Fig 1: Diagram of a basic class C frequency multiplier.

lower harmonic and greater in amplitude than the next higher harmonic. This condition makes filtering difficult. In many applications, however, efficiency and power handling capability are of secondary importance, the primary goal being the generation of a harmonic voltage with high spectral purity, i.e., a "clean" voltage with low adjacent harmonic content. In this case the usual method is not always the best.

Advantages of a Rectangular Waveform

A study of the spectra of commonly encountered waveforms[2] indicates that, for the generation of medium- and high-order harmonics, the rectangular waveform offers many advantages. In the frequency range up to about 1 MC, several methods exist for the generation of essentially rectangular waves. The spectrum of a rectangular wave extends far into the high-harmonic region with relatively low roll-off compared to the spectra of other common waveforms. The rectangular wave spectrum also exhibits periodic nulls. These nulls represent a disadvantage if a wide smooth spectrum is desired, but for the generation and selection of a single harmonic, the nulls can often be used to advantage.

As illustrative examples of the use of rectangular waveforms, let us take the cases of frequency multiplication by factors of 5 and 10. For multiplication by a factor of 5, or indeed by any odd factor, the spectrum of a square wave displays the desirable property of containing only odd harmonics. That is, the nulls of the spectrum are positioned on the even harmonics. This property simplifies the task of filtering, allowing a relatively clean output. This behavior becomes clearer when the time-domain performance is described. Assume that a square wave of current is passed through the tank circuit of Fig. 1. One transition of the square wave excites the tank circuit which is tuned to the fifth harmonic of the input frequency. The circuit rings for 2½ cycles. At this point, just as the plate voltage is reversing polarity, the next transition of the square wave occurs, exciting the tank circuit in opposite phase and intensifying the natural amplitude of the plate voltage. In the steady state the envelope ripple of the plate voltage displays twice the rate and about half the decrement that would occur if the tank circuit were excited only once a cycle of the fundamental frequency, as by a brief pulse.

Use can again be made of the peaks and nulls of the rectangular-wave spectrum for multiplication by a factor of 10. It can be shown that a rectangular waveform with a duty ratio of 0.45 displays the unique property of maximizing the tenth harmonic and minimizing the ninth and eleventh. By decreasing the pulse duration from 0.5 to 0.45 periods, the spectrum is "stretched" so that a peak occurs close to the tenth

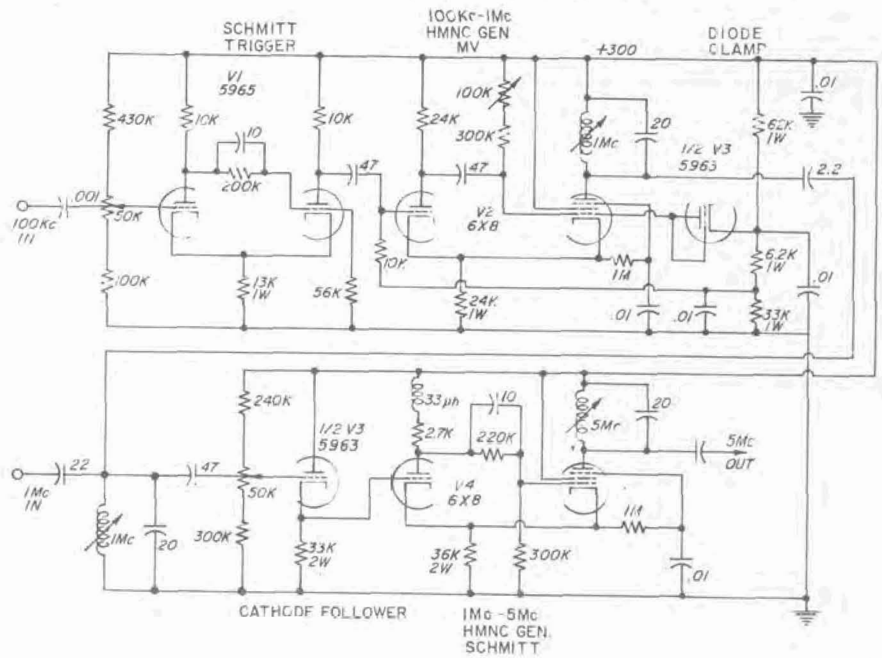
Frequency Multiplication

harmonic and nulls occur close to the ninth and eleventh harmonics. In the time domain again, this waveform results in two decay regions of the tank voltage, one of 4.5 and one of 5.5-cycle duration. This results in a smaller decrement than would occur if the tank circuit voltage were allowed to decay for the entire 10-cycle interval.

A Practical Circuit

A circuit utilizing the above principles is shown in Fig. 2. This circuit is used to multiply input frequencies of either 100 KC or 1 MC to 5 MC. If the input frequency is 100 KC, it is first multiplied by a factor of 10 to 1 MC using the 0.45 duty-ratio rectangular pulse discussed above and thence to 5 MC using a square wave.

Fig. 2: Diagram of frequency multiplier - output is 5mc with 0.1 or 1.0mc input.



Both halves of V1 are connected as a Schmitt trigger circuit[3] which generates standard trigger pulses independent of the waveform of the 100 KC input voltage. These trigger pulses synchronize the following stage involving V2 and half of V3. The triode half of V2 and the screen grid, control grid, and cathode (a simulated triode) of the pentode half are connected as a cathode-coupled monostable multivibrator[4] which produces a rectangular pulse of current 4.5 μsec. in duration when triggered. The circuit is triggered every 10 μsec. (100 KC), thereby producing the desired 0.45 duty-ratio pulse. The rectangular current pulse is coupled into the plate circuit of the pentode half of V2 which contains a parallel resonant tank circuit tuned to 1 MC. One-half of V3 is connected as a diode to stabilize the action of V2. The 1 MC signal is further filtered in a second tank circuit which also serves as the input point for an input frequency of 1 MC. The well filtered 1 MC signal is applied through the other half of V3 connected as a cathode follower to V4. V4 is connected as a Schmitt circuit which, when driven by the essentially sinusoidal 1 MC signal, produces square current pulses having, theoretically, only odd harmonic components. These current pulses are coupled to the plate circuit of the pentode half of V4 where the fifth harmonic (5 MC) is accentuated by the tank circuit.

Figure 3 shows several of the waveforms produced by the circuit. Waveform A shows the trigger pulses applied to the input grid of V2. A small pulse can be seen on this voltage which is coupled back from the monostable multivibrator when it resumes its stable state. Waveform B shows the typical multivibrator grid voltage at the grid of the pentode half of V2. When the multivibrator action is initiated by a positive trigger pulse, the grid voltage falls rapidly, cutting off the V2 pentode. The grid voltage then rises toward the B+ voltage with a time-constant determined primarily by the coupling capacitor and the pentode grid-return resistor. When the pentode grid voltage enters the grid base, the multivibrator switches back to its stable state, returning current to the pentode. Waveform C shows the 1MC plate volt-

A. Trigger pulses at input grid of V2, 100 kc

B. V2 pentode grid voltage, 100 k

C. V2 pentode plate voltage, 1 Mc

D. Filtered 1-Mc signal

E. Input signal to V4, 1 Mc

F. 5-Mc Output Voltage

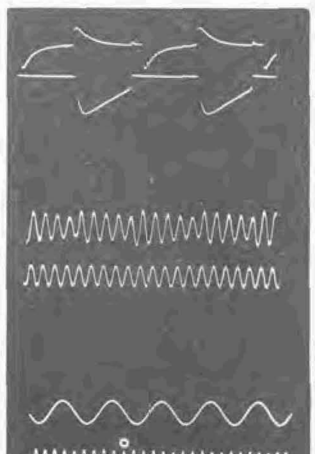


Fig. 3: Multiplier waveforms for circuit shown in Figure 2.

age of the V2 pentode. Note the 4.5 and 5.5-cycle portions of the waveform. Waveform D shows the 1 MC signal after the next stage of filtering. The decrement is almost completely absent. Waveform E is an expanded view of this voltage. Waveform F shows the 5 MC output voltage at the plate of the pentode half of V4.

Conclusion

For fundamental frequencies up to about 1 MC, the rectangular wave output of multivibrator-type circuits can often be used to great advantage for frequency multiplication by moderate factors.

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