Comb Generator Simplifies Multiplier Design

INTRODUCTION

A comb generator uses a step recovery diode with appropriate circuitry to generate a narrow pulse of voltage from each cycle of an incident sine wave. In the frequency domain this repeated narrow pulse is seen as the harmonics of the input frequency. Power is divided approximately equally among the lower harmonics and drops off at a rate dependent on the width of the pulse. This comb of frequencies is useful for testing circuits over a range of frequencies.

Since the power output is divided among so many frequencies, the power level in each harmonic is quite low. Even at low order harmonic frequencies, the output is about 20 dB down from the input level. For example the minimum low order harmonic level of the HP 33004 comb generator is +5 dBm (Figure 1), 22 dB down from the 27 dBm input level.
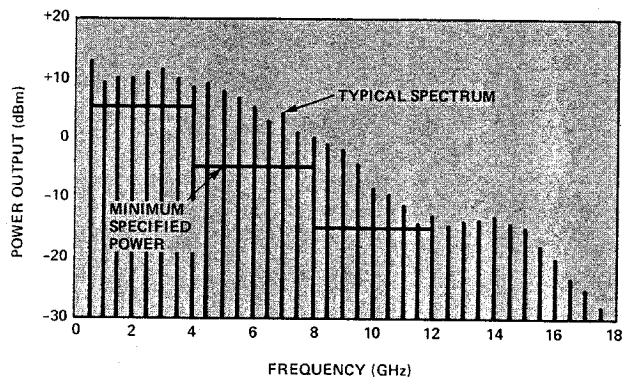

Figure 1. Spectrum Envelope of 33004A/B (500 MHz)

In applications where more power is needed at selected harmonics, an expensive microwave amplifier may be added to the comb generator. However, the required increase in power may often be obtained by adding an inexpensive bandpass filter.

The use of a passive element to amplify power in the desired frequency band may seem to violate the principle of the conservation of energy, but the increased power comes from the active element, the step recovery diode. The unwanted frequencies are reflected from the filter to the diode where they multiply and mix with each other to produce more power at the desired frequencies. When a narrow band filter passing the nth harmonic is placed at the comb generator output, the percent efficiency for the single frequency output can exceed 100/n.

FILTER ADDED TO COMB GENERATOR

To illustrate this effect a bandpass filter was added to a comb generator similar to the Hewlett-Packard model 33005D as shown in Figure 2. Since the power output results from a combination of harmonics of the 1 GHz input from the comb generator with harmonics and mixing products due to reflected signals from the filter, the phase separation between diode and filter will affect the power level at each frequency. To measure this effect a phase shifter is included in the test system.
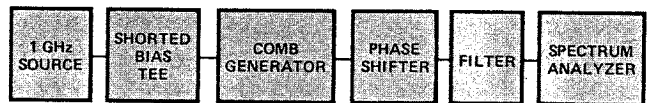

Figure 2. Block Diagram

Figure 3 shows how the filter increases the harmonic power when proper spacing between diode and filter is used. When the phase shifter in Figure 2 is set at 76° the eighth harmonic power level is 10.8 dBm with 27 dBm input. Without the filter, the power at this frequency from the comb generator is 4 dBm, less than one fourth the power from the filter.

This filter passes six harmonics, from the eighth to the thirteenth. With a narrow band filter passing only the eighth harmonic, the efficiency would be approximately $\frac{1}{n} = \frac{1}{8}$ or -9 dB. The power would be (27-9) dBm = 18 dBm, an increase of 14 dB from the comb generator power at the eighth harmonic and 7 dB from the broader band filter case.
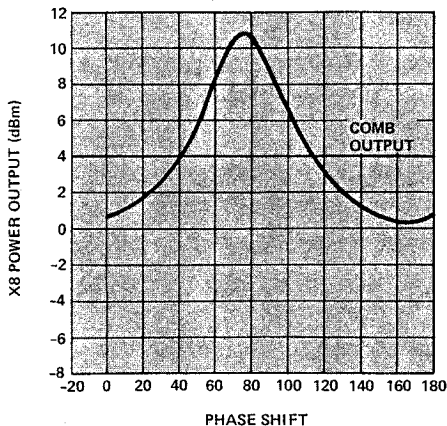
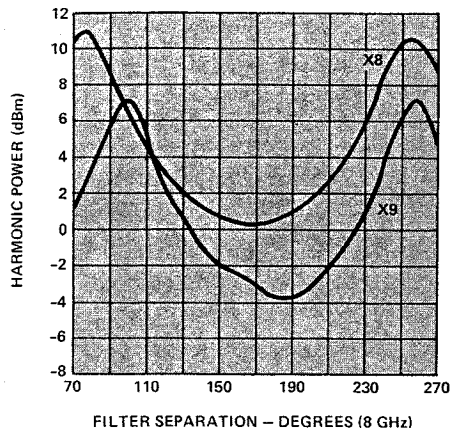Figure 3. Effect of Filter Location on Power Output at the Eighth Harmonic

Figure 4. Effect of Filter Location on Harmonic Power

OPTIMUM FILTER SPACING

Figure 4 shows the power variation for the eighth and ninth harmonics when the phase is varied. In order to simulate a change in physical distance of the filter location, the phase shift at the eighth harmonic is plotted for both harmonic outputs. The ninth harmonic power at optimum phase is 7 dBm compared to 0 dBm for the comb power. If equal power were needed from these two harmonics, the phase shift would be set at 97° where the curves cross. If, however, equal degradation from the peak is the criterion, a phase shift of 88° will reduce both harmonics 1.5 dB from their peaks.

Because phase changes more quickly at higher frequencies as the separation increases, the X9 peak will move closer to the X8 peak when a half wavelength is added. At 257° the power levels reach a peak for both harmonics.

It is only coincidence that the addition of a half wavelength spacer brought the two peaks together. Figure 5 shows how randomly spaced are the peaks for the six harmonics passed by this filter. The peaks for any adjacent pair of harmonics may be brought together within 10° by adding multiple half wavelengths. Four multiples would be needed for X9 and X10. If more than two harmonics are needed, a spread of power levels must be accepted.
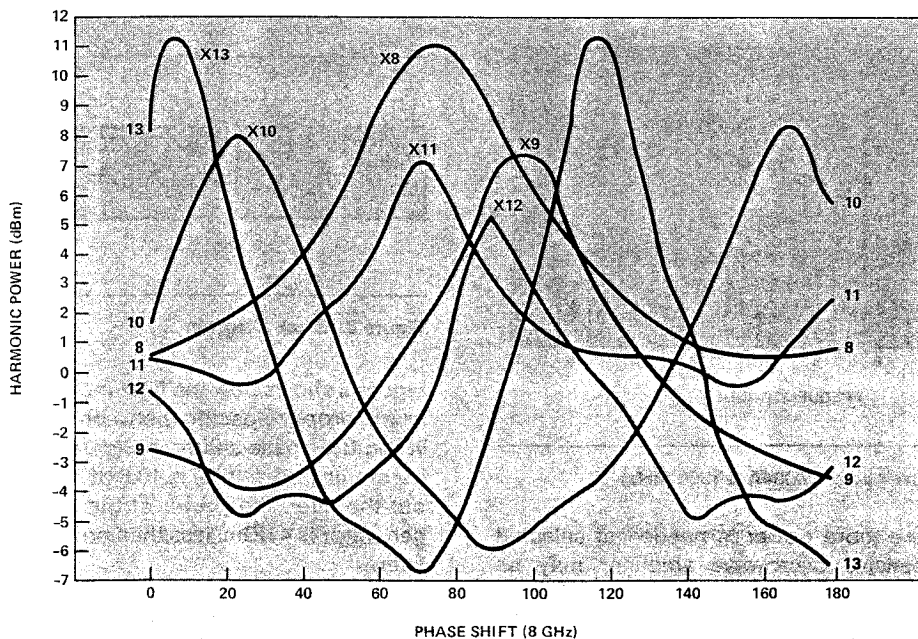

Figure 5. Effect of Phase Shift

FILTER "GAIN"

Figure 6 compares the peak of each harmonic output with the filter to the harmonic output of the comb generator without the filter. Input power at approximately 1 GHz is 0.5 watt. Power levels have been corrected for filter loss. The increase in power varies from 7 to 27 dB. More "gain" would be expected from filters with narrower bandwidth.

If the six peak powers shown in Figure 6 could be obtained at once, the total efficiency would be 8.8%. Higher efficiency would probably be obtained in circuits more directly coupling the filter to the diode. In this experimental circuit there are coaxial to waveguide adapters as well as coaxial adapters. For example a multiplier has been reported[1] with seven harmonics from the eighteenth to the twenty-fourth. Reported efficiency is 9%, even though the order of multiplication is much higher.

SUMMARY

Step recovery diodes may be used in impulse generator circuits to produce a broad band of frequencies harmonically related to the input frequency. When a narrow band of frequencies is needed a filter may be added to the comb generator to eliminate the unwanted harmonics and increase the power output of the desired harmonics.

Note:
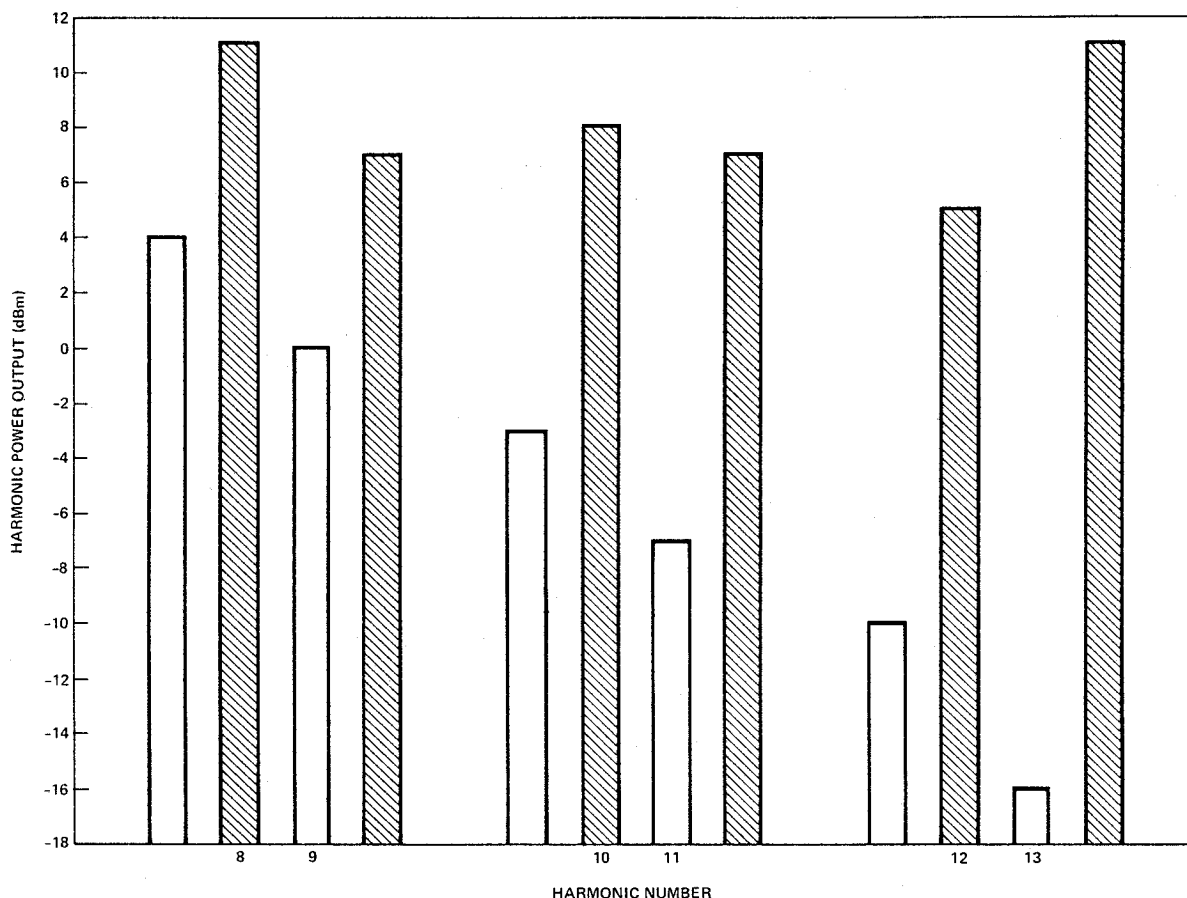1. R.E. Winkelman and E.G. Crystal, "Filter Matches to SRD Impulse", Microwaves, pp. 34-38, September 1970.

Figure 6. Effect of Filter on Harmonic Power Output