rf featured technology

New Topology Multiplier Generates Odd Harmonics

Contest Winner is a Classic Example of Engineering Problem-Solving.

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The winning design in this year's RF Design Awards contest is not a physically or mathematically complex circuit. Like nearly all "everyday" engineering tasks, the author has taken a small, well-defined problem (efficient odd-order multiplication) and developed an acceptable solution. That solution may not be especially difficult or even completely unique. What makes it a winner, however, is the combination of an innovative "twist" to a known phenomena, a good theoretical analysis of its function, and a clear explanation of the design, construction and testing process.

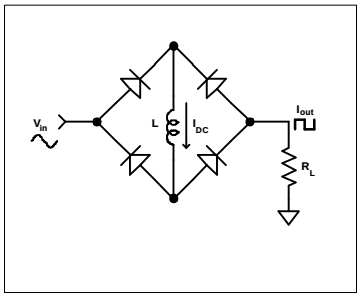

Figure 1. Sinewave to squarewave converter circuit.

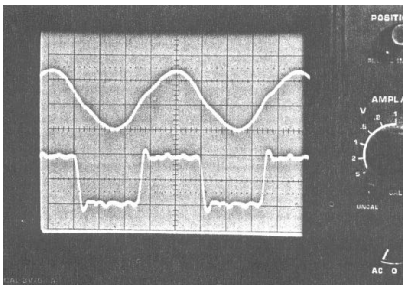

Figure 2. Top trace is signal into diode bridge (2V/div). Bottom is current in load resistor (10ma/div).

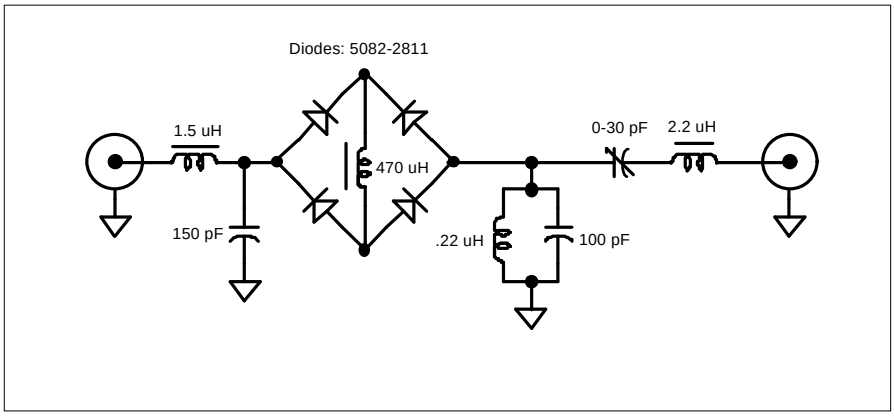

Figure 3. 10 MHz to 30 MHz multiplier circuit.

the purpose of the circuit is to take advantage of the superior noise and switching characteristics of Schottky barrier diodes to make a high performance odd-order frequency multiplier. Modern quartz oscillators have reached a level of performance where it has become difficult to multiply the fundamental frequency without degrading the phase noise by more than the unavoidable 20 dB per decade of multiplication. Thanks to the Schottky barrier diode's extremely low flicker noise, this circuit adds little excess noise to even the best sources. In addition, the upper frequency limit of this configuration should be quite high: Schottky diodes are not slowed by minority carriers in the junction region and exhibit switching speeds measured in the picoseconds. This particular application performs the difficult first stage multiplication after an ultra-low noise 10 MHz reference oscillator. Such low noise multiplication is necessary in constructing state-of-the -art synthesizers, radars and microwave communications equipment that rely on the reference oscillator for spectral purity near the carrier The multipliers are also used to make the job of measuring phase noise easier.

Topology

Figure 1 shows the voltage sinewave to current squarewave converter which forms the heart of the multiplier. This unique converter is simply a full-wave bridge with an inductor short-circuiting the DC terminals! The inductor is chosen to have a high impedance at the operating frequency so that an AC input results in DC in the inductor. This DC flows through alternate pairs of diodes due to the commutating action of the input voltage. Therefore, if one AC terminal of the bridge is driven with a low impedance sinewave, the other AC terminal will supply a squarewave to a low impedance load. The load must have a low impedance since the compliance of this current source is exactly equal to the input voltage. The photograph in Figure 2 shows the waveform obtained from the circuit in Figure 1 at 10 MHz with a 470 uH inductor. The bottom trace is the voltage across a 10 ohm resistor and represents a 10 mA p-p current squarewave. Notice that the diodes switch at the input signal's zero crossing. Consequently, this circuit produces a minimum of troublesome AM to PM conversion.

The Fourier expansion of a squarewave is:

$$f(x) = A \times \frac{4}{\pi} \sum \frac{\sin(n\omega x)}{n}$$

$$n = 1,3,5...$$

Notice that only odd harmonics are present with an amplitude inversely proportional to the harmonic number. All that is necessary to make a frequency multiplier is to design input and output circuits to select and enhance the desired

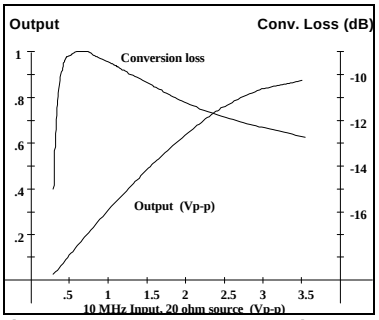

Figure 4. Prototype test results

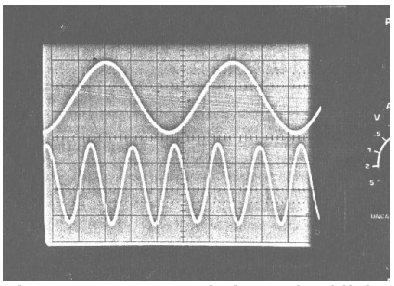

Figure 5. Top trace is input (1V/div) and bottom trace is output (.5V/div)

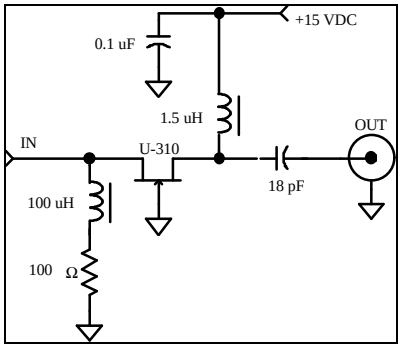

Figure 6. 30 MHz amplifier added to multipliers.

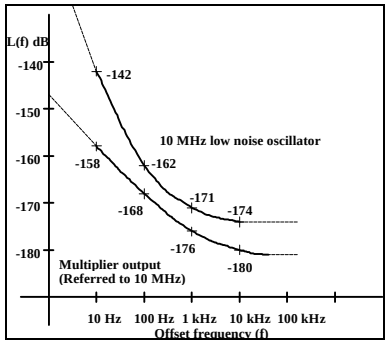

Figure 7. Phase noise measurement.

harmonic without disturbing the sine to square conversion.

Circuit Description

The circuit of Figure 3 meets these requirements, providing multiplication from 10 MHz to 30 MHz. The input matching network consisting of the 1.5 uH choke and the 150 pF capacitor does three jobs: it steps up the input voltage to welcome the diodes' barrier potential with series resonance; it provides a low impedance to ground for the switching current; and it isolates the input from the switching current. It is interesting to note that the input impedance of this series tank would be quite low except that the diodes' conduction spoils the Q with a resulting input impedance near 50 ohms for a 2 V, input. For smaller input signals the input impedance drops, which explains the conversion efficiency peak near 0.5 V for the 25 ohm source (Fig. 4). This variable Q provides a degree of feedback to help ensure that the multiplier has a usable output over a wide range of input voltage.

The output network presents the required low impedance to the bridge while directing the desired harmonic to the output. The 0.22 uH choke and the 100 pF capacitor provide the low impedance away from 30 MHz and the series tank formed by the 2.2 uH choke and the 30 pF trimmer provide a low impedance path to the load at 30 MHz. Either higher Q or additional filtering may be used here if harmonic rejection better than about 30 dB is required.Schottky diodes are mandatory for best performance. Passivated diodes without the p-n guard ring like the H-P 5082-2835 are good for higher frequencies but reverse voltage breakdown must be avoided. Hybrid diodes which include a guard ring are desirable due to the higher break down voltage, but they do exhibit more capacitance (about 1 pF at 0 V). The 5082-2811 has a reverse breakdown of 15 V and exhibits 1.2 pF at 0 V. The 5082-2813 is a matched quad version. The load inductor should exhibit a high impedance at the input and output frequencies. At low frequencies almost any large choke will suffice, but at higher frequencies a slight improvement is obtained by selecting an inductor to resonate with the diode capacitance at the input frequency.

Test Results

Figure 5 shows the input and output waveforms and Figure 4 shows the performance over a range of input voltage. The conversion gain is good over a wide range considering that no active gain stages are employed. The conversion efficiency is as high as diode frequency doublers even though the multiplication factor is higher.

In order to check the phase noise, a second multiplier was constructed and grounded-gate amplifiers were added to boost the output level (Figure 6). Figure 7 shows the measured phase noise of the multipliers and of the oscillator used to make the measurement. The Appendix describes the phase noise measurement technique. The multipliers' noise is significantly better than the oscillator so this test relies on noise cancellation in the mixer which should occur since both multipliers receive the same noise. Substituting a noisier oscillator increased the measured noise, suggesting that the measured noise may be in part due to dispersion in the signal paths Such a measurement error would make the multipliers appear noisier than they actually are, but the indicated noise is already below most "ultra-low noise" oscillators.

The cost of this multiplier is quite low since the component count is low and no exotic parts are used. The trimmer capacitor should be high quality since the rivetlike connection to the rotor of cheap trimmers can become noisy. The prototype used molded chokes and NPO dielectric capacitors.

Applications

A half-wave version is easily constructed by eliminating the bottom two diodes and connecting the inductor to ground. This configuration is convenient for high frequency layout and has been used to multiply 100 MHz to 500 MHz with about 20 dB of loss. Add a $0.98 MMIC amplifier for a cost effective high performance multiplier. Stripline techniques would prove interesting above 500 MHz.

For high order multiplication the constant current inductor can be reduced so the output becomes a short pulse instead of a square wave, reducing the power in the lower harmonics. This change also makes a nice bipolar pulse generator.

Conclusion

A high performance, low cost frequency multiplier of uncomplicated design has been described. The phase noise performance is sufficiently low to avoid serious degradation of the best commercially available oscillators and the conversion loss is good even for low level inputs. The new topology will provide state-of-the-art odd-order frequency multiplication over a wide range of frequencies. rf