

Application Notes

Marki Microwave Multipliers

By Marki Microwave, Posted Wed Jun 12 2013 14:00:00 GMT-0500 (Central Daylight Time)

There are two ways to create high frequency (low phase noise) tones: use a high frequency oscillator to directly synthesize (probably optically) or use a crystal to create a low phase noise signal at low frequency, and then use a non-linear element to multiply it up to the desired frequency range. A signal passed into any non-linear element will create all possible harmonics, and can be used as a multiplier. More sophisticated circuitry can be used to improve the three metrics that multipliers are evaluated on: **conversion loss, undesired harmonic suppression, phase noise**. For amplified multipliers there is the metric of additive thermal noise/noise figure, related to the conversion loss of the multiplier core.

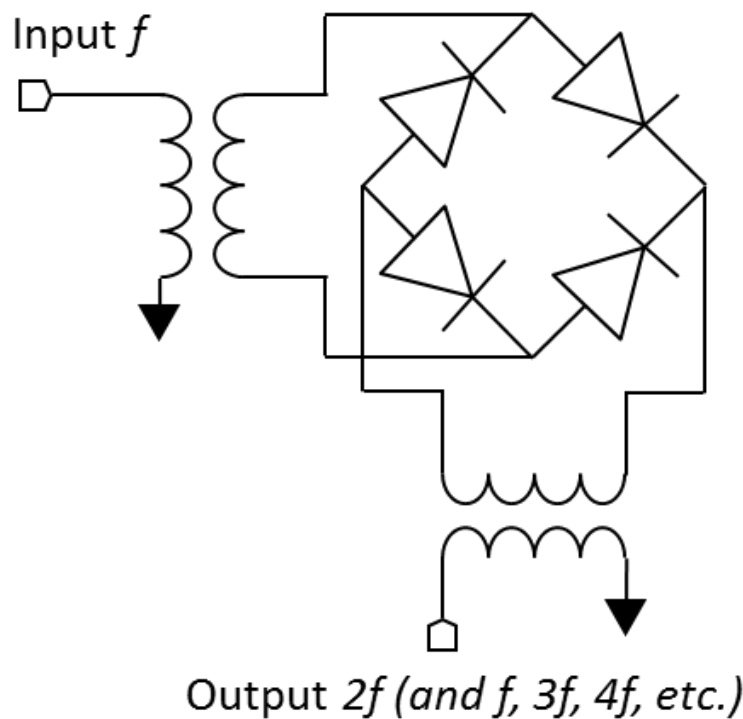
For odd order harmonic generation, Marki has found that limiting amplifiers (such as our line of LO square wave driver amplifiers) offer a superior tradeoff of conversion loss, harmonic suppression, and noise to comparable amplified multipliers. Odd harmonic generation is created by the 'clipping' effect in these saturated amplifiers. It is this same effect that causes square wave generation, and produces all odd harmonics within the bandwidth of the amplifier. For this reason Marki recommends saturated square wave amplifiers for all odd harmonic generation requirements.

An ideal square wave amplifier produces only odd harmonics, while even harmonics are suppressed as much as possible (they represent duty cycle distortion in a square wave). Even harmonic generation requires rectification. This can be accomplished using a single diode, but with poor conversion loss and harmonic suppression. The preferred technique for producing even order harmonics is to use a standard mixer diode core with passive circuitry in a special circuit configuration.

Microwave Doubler Operation

The basic microwave doubler circuit is the microwave equivalent of a low frequency full wave rectifier circuit. It is shown below.

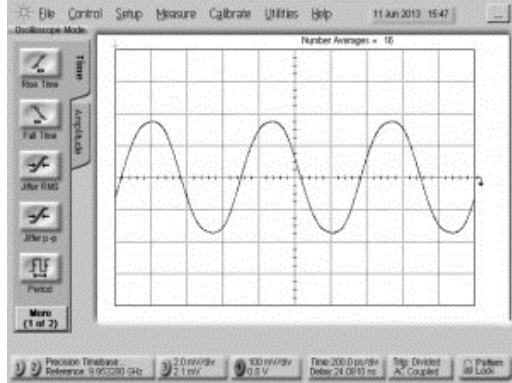




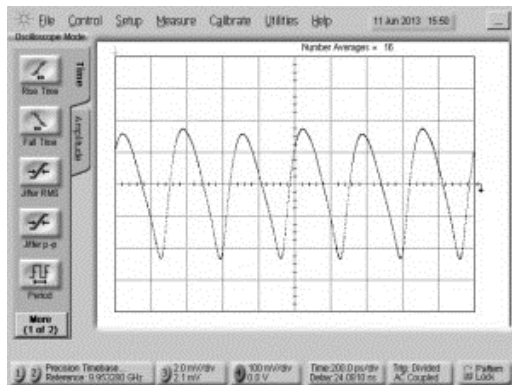
In Marki doublers the hybrid junction is typically a microwave balun, implemented in a similar fashion to our mixer baluns. The baluns perform the important function of canceling odd harmonics, such that only even order harmonics pass through. The balance of the balun determines the cancelation of the odd harmonics and thus the harmonic suppression, while the bandwidth and insertion loss largely determine the bandwidth and conversion loss of the balun.

Odd harmonics appear as a differential signal to the balun, and thus are canceled. This is similar to a double balanced mixer, where even order spurious products are canceled. In this case, however, the input signal acts as both the LO and the RF signals, meaning that a certain threshold level must be met in order to turn on the diodes that make up the ring quad for the doubler core. As with a mixer this threshold is determined by the turn on voltage of the diodes that make up the doubler, and are typically specified as Low, Medium, or Intermediate level diodes. Each doubler operates over a limited input power range for low conversion loss and low additive noise performance. All Marki doublers use silicon schottky diodes, which provide excellent additive phase noise and thermal noise properties.

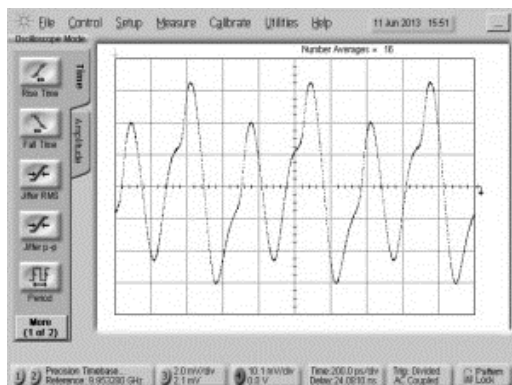
The time domain operation of a doubler is shown below. In the first scope capture a 1.5 GHz input at 16 dBm is shown.



This is input to a D-0204MA, and the output from this is shown below. Note that the scale is different (10 dB of attenuation is removed, the conversion loss of a typical doubler is 10 dB).



As you can see the frequency is doubled. Since the output is AC coupled, the baseline remains 0V, whereas in a true full wave rectifier there would be a DC component. The wave distortion from an ideal full wave rectifier is caused by imperfect cancelation of odd harmonics (causing the asymmetric nature of the output wave) and the finite bandwidth of the circuit. Note that if the doubler is underdriven, not only will the conversion loss suffer, but the suppression of the harmonics will also suffer, particularly the fundamental leakthrough. This will result in a distorted output waveform, as shown below with the doubler driven at only +9 dBm.



The asymmetric waveform is again a result of the unsuppressed odd harmonics.

Generally the output of a doubler is used as a local oscillator downstream in the system. To counteract the conversion loss of the doubler and create a

suitable local oscillator an amplifier is typically used after the doubler. Marki amplified doublers offer an application matched amplifier combined with our world class doubler core to provide high output powers suitable for driving a high frequency mixer.

Amplified Quadrupler Operation

Marki quadrupler circuits come in several flavors based on the same underlying principle. The basic principle is just to double an incoming signal twice. To provide high fundamental and undesired ($2f$, $3f$) suppression with high conversion gain across a specified bandwidth an appropriate combination of amplifiers and doubler circuits must be used. Our DAD circuits (DAD-0225, DAD-0405) use an input low level doubler, amplify the output signal at the intermediate frequency, and double the intermediate frequency with a low level, higher frequency output doubler. Our AQA circuits (AQA-1933, AQA-2032, AQA-2040, AQA-2050), however, amplify the incoming signal to a high level, double to an intermediate frequency with a high level, low frequency doubler core, double the intermediate frequency with a low level, high frequency doubler, and amplify the resulting output with a high frequency amplifier. The selection of amplifiers and doublers with appropriate power levels and frequency ranges is the art of amplified quadrupler design, and has been honed by Marki for over 40 years.

Filtering

As with mixer outputs, filtering of the multiplier output signal is critical. While the circuit can suppress the adjacent harmonics (i.e. a doubler suppresses the f and $3f$ harmonics while maximizing the $2f$ harmonic), it is usually powerless to suppress the higher order even harmonics ($4f$ for a doubler). This means that filtering is required for the application the doubler will be used in. Without the use of a tunable filter this will frequently limit the useable bandwidth of a doubler circuit to a single octave. If a doubler can provide an output of 1-4 GHz then the $4F$ harmonic will start to leak into the band when it is used below 2 GHz. This is why many of our doublers are limited to octave band. Much broader bandwidth multipliers are available, but they may require switched filter banks at the output to maintain harmonic suppression in the application circuit.

Performance Metrics

Conversion Loss

The conversion loss of a basic doubler is limited by the Fourier expansion of a full wave rectifier. The coefficients for these are given by

$$a_n = -\frac{4}{\pi} \left(\frac{1}{n^2 - 1} \right)$$

where n is all even harmonics. This results in the minimum conversion loss for a doubler of 7.4 dB, and for the fourth harmonic from a doubler of 21.4 dB. This is the minimum theoretical conversion loss for a doubler and suppression of the fourth harmonic.

Harmonic Suppression

As mentioned above the suppression of harmonics is determined mainly by the balance of the balun circuits, as well as the balance of the diodes in the ring quad.

Phase Noise

Additive phase noise is critical for most multiplier applications. Phase noise is fundamentally degraded in the frequency domain during a multiplication as a result of it being constant in the time domain. For example, a 10 GHz signal with 10 ps of jitter on it will occupy 10% of the period, while if a 20 GHz signal has the same 10 ps of jitter on it, it will occupy 20% of the period. Since frequency multiplication occurs in linear time this means that multiplication will always increase the phase noise by a factor that can be shown to be $20 \cdot \log_{10}(n)$ (thanks Chris Irwin!), where n is the number of multiplications (2 for a doubler, 4 for a quadrupler, etc.) and phase noise is expressed in dBc/Hz. Conversely, in a frequency divider the phase noise is reduced by the same factor (less whatever phase noise is added by the divider itself).

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