PRACTICAL DESIGN OF MICROWAVE DIODE FREQUENCY MULTIPLIERS

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Abstract

Phase noise is a critical performance parameter of frequency synthesizers for wireless communications. In phase modulated equipment the integrated phase noise in frequency synthesizer directly impacts to bit error rate of communication system. Design of frequency synthesizers with low phase noise is related to using low noise voltage controlled oscillators. Realizing such oscillators in microwave frequencies is hampered by low quality factor of tuning elements. A method to generate high frequency signal with low phase noise is to generate high quality lower frequency signal and perform frequency multiplication to deliver desired frequency. The purpose of this sheet is to give some theoretical insight for frequency multiplication and some practical guidelines for microwave diode multipliers design.

1. INTRODUCTION

The key element in designing microwave equipment is availability of clean local oscillator. Clean means a signal free from any sort of spurious frequencies or parasitic modulation effects. In most cases spurious frequencies can be filtered by using appropriate filter. The parasitic modulation with low frequency noises of active element, known as phase noise can not be filtered. Unfortunately frequency multiplication process degrades this parameter. The reason about this unfortunate characteristic is that the frequency multiplier in fact is phase multiplier. So it multiplies phase deviations as well as the frequency of input signal. The minimum carrier to noise degeneration, ΔCNR in decibels, caused by frequency multiplier is:

$$\Delta CNR = 20\log N \ ,$$

where N is multiplication factor

In spite of this fact, multiplying a very sable low-frequency reference signal can still produce signals with better phase noise then producing them directly in microwave frequencies range.

Frequency multiplication is obtained by applying nonlinear distortion to sinusoidal signal. The spectrum of distorted input signal contains a number of harmonics and suitable harmonic number can be filtered and amplified to obtain output signal with desired frequency and amplitude. Frequency multipliers can be realized either with transistors or diodes. Transistors provide better efficiency but in microwave frequencies may occurs problem with upconverting low frequency noise. The reason for this effect is that almost all transistors have high gain at low frequencies. This problem is not presented in diode frequency multipliers but they have worse efficiency. Diode multipliers are divided into two gropes – reactive multipliers and resistive multipliers. Reactive multipliers can be realized by using varactor or step recovery diodes. They have good efficiency but bandwidth in narrow. Good decision to realize microwave frequency multipliers with relatively high bandwidth is to use resistive diode approach. This type of multipliers has bad efficiency but wide bandwidth and good noise performance. That’s why they are main topic in this article.

Depending on how diodes distort sinusoidal signal, multipliers are divided into two groups – odd order and even order. The schematics and output waveforms of these multipliers are shown on fig. 1 and fig. 2. In odd order frequency multipliers the spectrum of output signal contain only odd harmonic numbers and in even order multiplier is the opposite.

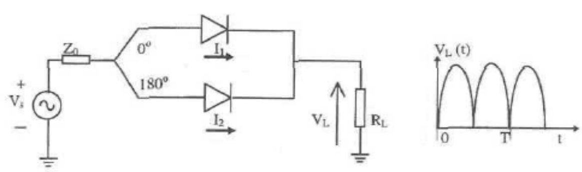

Fig. 1. Even order frequency multiplier

Unwonted harmonics must be filtered and their level has to meet requirements by standard for designed communication equipment. If unwonted harmonics are not suppressed enough, at the output of multiplier need to be placed more complicated band pass filter. Designing of such filter is difficult and sometimes impossible because it can not be manufactured within acceptable tolerances. That's why harmonic suppression is critical parameter for frequency multipliers. Since the bad efficiency can be compensated by amplifier with higher gain, the bad unwonted harmonic suppression can make design impossible. Improving this parameter is the main topic of this paper.

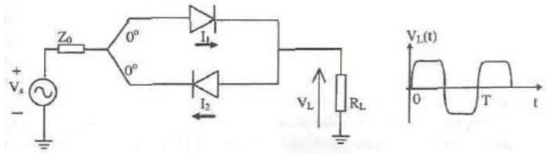

Fig. 2. Odd order frequency multiplier

2. UNWONTED HARMONIC SUPPRESSION IN MICROWAVE FREQUENCY MULTIPLIERS

As was explained above, harmonic content at the output of multiplier depends on how diodes distort the input sinusoidal signal. The generation of odd order harmonics requires paralleling the diodes as shown in fig. 2. In this case the first diode conducts during the positive semi cycle while the second conducts during the other semi-cycle. If applied voltage is high enough, the result is a symmetrical distortion in waveform, resembling square waveform. Theoretically if the duty cycle of this square waveform is 50%, its spectrum will contain only odd harmonics, and even harmonics suppression would be infinity. Unfortunately, in practice 50% duty cycle can't be obtained because ideally symmetrical structure is impossible to be manufactured. Theoretically the influence of duty cycle can be evaluated be performing Fast Fourier Transforming to a square wave signal and results of this research are presented in Table 1. In this case is performed multiplication x5 and suppression of forth and sixth harmonics is most important, because they are closest the desired harmonic. If we assume 20dB to be good even harmonic suppression, duty cycle of the output signal can be in range of 49.4 to 50.6%.

Table 1. Evaluating influence of duty cycle to even harmonic suppression

Duty cycle [%]	Fourth harmonic suppression [dB]
50	infinity
49.5	22
49	17

In general microwave resistive diode multipliers are realized with dual in package shotky diodes. In this case the diodes have almost the same parameters and asymmetry due to their difference can be neglected. Here more substantial parameter, which influence the duty cycle is parasitic capacitances in diode package and asymmetry in layout due to manufacturing tolerances. Most critical element from PCB layout in microwave frequencies is grounding holes. In fig. 3 is shown equivalent circuit of two shotky diodes in package SOT23. This model was used for designing frequency multiplier x5. The input signal is in frequency range from 1.9 GHz to 2.3 GHz. The circuit was simulated with harmonica simulator, provided by ansoft.

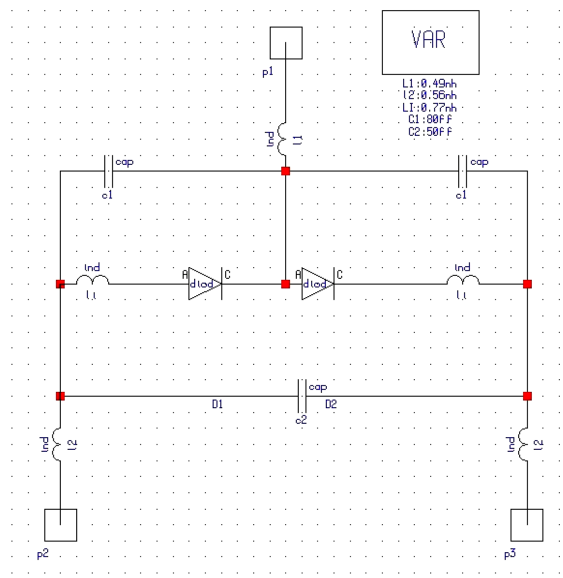

Fig. 3. Nonlinear model for dual shotky diodes in SOT23 package

It wasn't surprising, that simulator shows perfect even harmonic suppression. Here asymmetry in layout is not taken into account. To gain real insight how circuit works the simulated layout of frequency multiplier was manufactured. Material used in design is Arlon25N with deictic permeability 3.38, substrate thickness 0.51mm and loss tangent 0.0025. In fig.4 is shown measured test fixture.

Fig. 4. Test fixture for microwave diode multiplier x5

To measure even harmonic suppression was used input signal with frequency 2.1 GHz and power level of 10dBm. Measured output spectrum is shown in fig. 5.

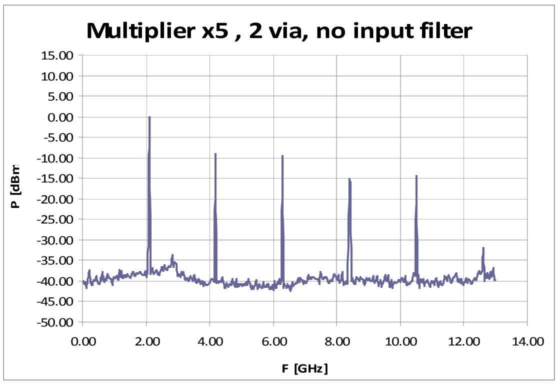

Fig. 5. Measured output spectrum of diode frequency multiplier x5

It's obvious that fourth and fifth harmonic have almost the same levels and we can't speak for any even harmonic suppression. At fist sight the design is absolutely filed. To reduce the influence of asymmetry in grounding holes, was put one big solder drop between grounded pins of diode, as shown in fig. 6.

Fig. 6. Diode frequency multiplier with added solder drop between grounded pins

The result of this experiment is shown in fig. 7. Here we notice improvement in harmonic suppression with about 8 dB.

This decision is not good from manufacturing view point. This solder drop must be putted manually and manufacturing process cannot be automated.

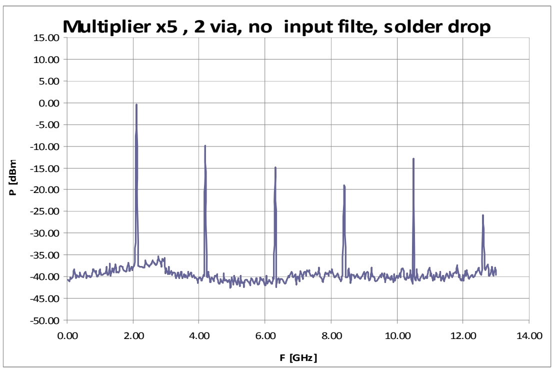

Fig. 7. Measured output spectrum of diode frequency multiplier x5 with added solder drop between grounded pins

To decide this problem was manufactured another test fixture with six grounding holes as shown in fig. 8.

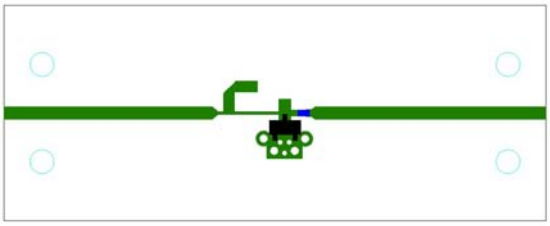

Fig. 8. Redesigned multiplier with 6 grounding holes

Measurement results show that, the redesigned test fixture has almost the same harmonic suppression as the first one with solder drop, fig.6. This decides problem with manufacturing automation but 8dB harmonic suppression is still not enough. This frequency multiplier is suitable for use in VSAT down converters and VSAT standard require unwonted harmonic suppression to be at least -60dBc. If we assume that even harmonic suppression of frequency multiplier is 8dB, to meet the standard we need filter which attenuate fourth and sixth harmonic at least 52dB. This requirement makes filter design very complicated.

To improve even harmonic suppression of frequency multiplier was researched the influence of input signal. Most of the signal sources do not generate clean sinusoidal signal. It always contains high order harmonics – second, third etc. The question is "How harmonic content of input signal affect the even harmonic suppression". To find answer of this question was made analogy with frequency up converter. The first harmonic from the spectrum of input signal acts as local oscillator frequency for up converter. Its power is high enough to change diodes nonlinear transconductance. The second harmonic has much lower power level than first harmonic. It can be represented as RF signal for the assumed upconverter. Furthermore if higher order harmonics exists, they also will be mixed with the first harmonic and products of this mixing will appear at the output of frequency multiplier. We assume that their level is low enough and they can be neglected. The second harmonic is the major factor, which contribute for harmonic content at the output of multiplier. Below are listed some products form obtained from mixing first and second harmonic of the input signal and resultant harmonic which they appear at the output.

$$H1 + H2 = H3$$
$$H1 + 2H2 = H4$$

H1 + 3H2 = H5

H1 + 4H2 = H6

It's obvious that they increase levels of all harmonics higher than third and this impact to even harmonic suppression of frequency multiplier. This statement was proved in practice by using frequency multiplier test fixture shown in fig. 4. Let's remind that harmonic suppression was improved with 8 dB by putting additional grounding holes. Now will be shown how even harmonic suppression can be improved further, by filtering the second harmonic of input signal. In fig. 8 is shown spectrum of original input signal and in fig.9 is depicted spectrum after filtering.

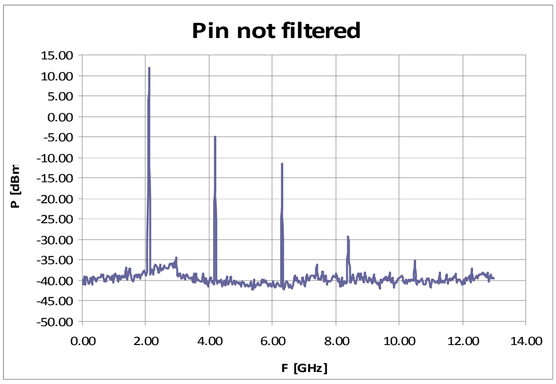

Fig. 8. Spectrum of input signal without low pass filter

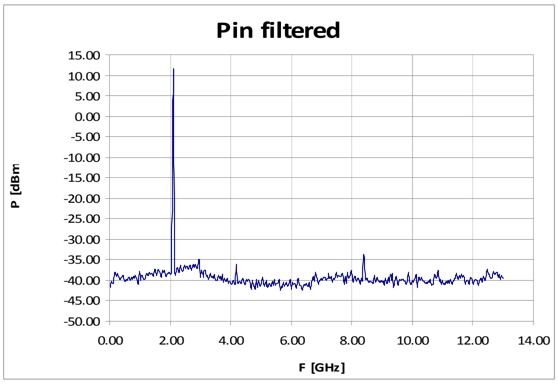

Fig. 9. Spectrum of input signal after filtering high order harmonics

Measurement results without low pass filter are shown in fig. 5 and results with filtered input signal are shown in fig. 10.

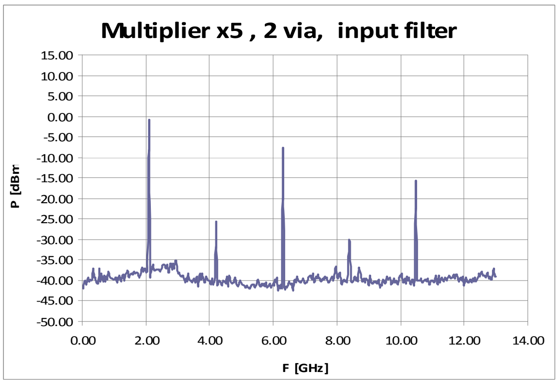

Fig. 10. Measured spectrum of frequency multiplier with filtered input signal

It can be easily seen that improvement in even harmonic suppression by filtering second harmonic is about 15dB.

3. CONCLUSION

A low coast frequency multiplier with uncomplicated design was described. As was explained the harmonic suppression is critical parameter in multiplier design. Practically were proved two methods for enhancing this parameter. The first is to ensure good grounding to diodes. This can be obtained by increasing number of grounding holes in PCB layout of frequency multiplier. And the second method is to use clan input signal. Its second and high order harmonics must be filtered.

References

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