Simple Frequency Doublers with High Performance

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Doubler: 5 MHz to 10 MHz

The recent availability of Lucent/Symmetricom GPS units with good 5 MHz oscillators has sparked a need for a frequency multiplier to provide a 10 MHz frequency standard. Mike, N1JEZ, located an article[1] by K6IQL describing a frequency multiplier for this application. However, I thought the circuit seemed a bit complex for a simple function.

The K6IQL circuit does frequency multiplication by mixing two copies of the 5 MHz signal in a mixer. Driving the mixer with two signals in quadrature eliminates a DC term and significantly reduces the fundamental frequency output and the undesired harmonics. K6IQL used a power splitter to with one leg driving a 5 MHz phase shift network to generate the quadrature signals.

I recalled seeing hybrid transformers which provide quadrature signals over a wider bandwidth. A quick search of the Minicircuits website[2] found several candidates, but they cost more than a mixer or a power splitter, which is basically a small RF transformer just like the ones in a mixer. Then it occurred to me that it should be possible to replace the transformer in a mixer with a hybrid transformer and make a frequency doubler. Has Minicircuits already done this? Another search found frequency doublers with low conversion loss and good suppression of fundamental frequency and undesired harmonics. Even better, these were priced in the same ballpark as a mixer.

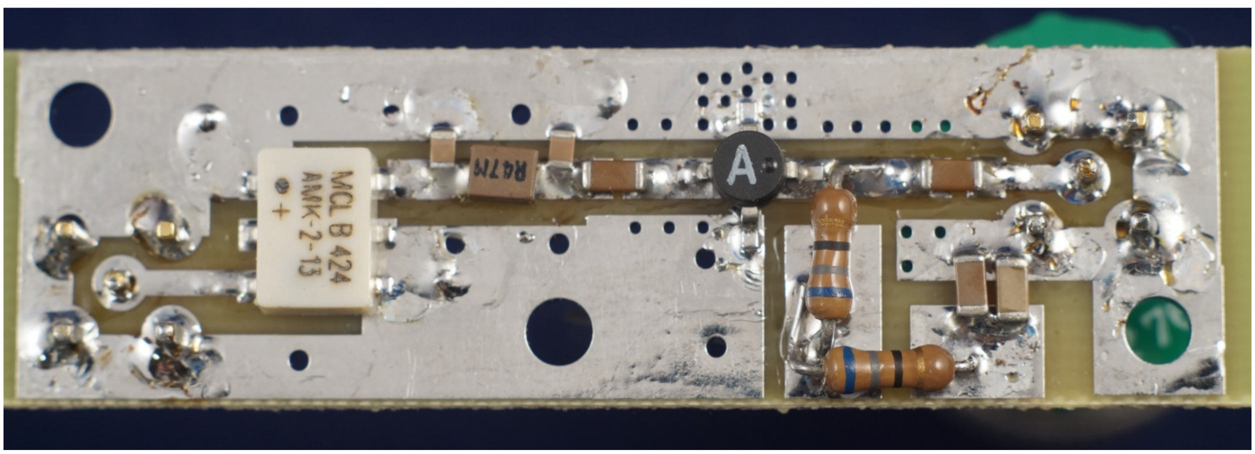

Figure 1 – Simple Frequency Doubler 5 MHz to 10 MHz

I ordered some AMK-2-13+ frequency multipliers, specified for 10 to 1000 MHz input, because I was thinking 10 MHz rather than 5 MHz. Then I did a simple PC board layout for the multiplier with an MMIC amplifier. A photo of the assembled prototype is shown in Figure 1 and the schematic diagram is shown in Figure 2.

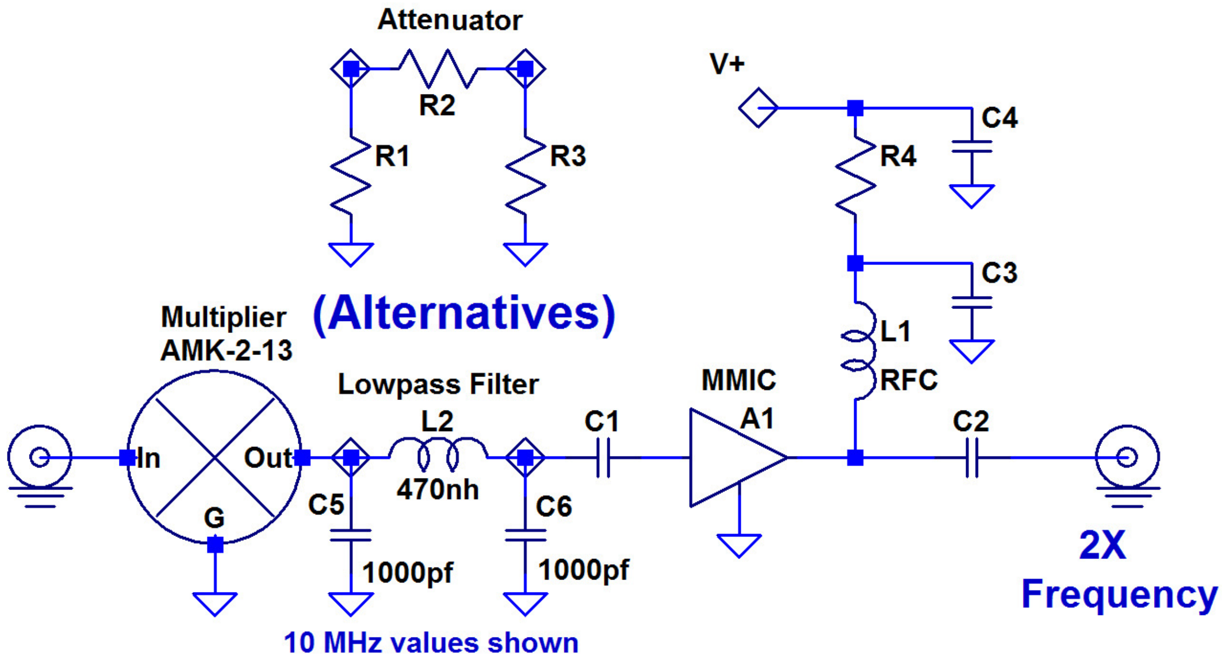

Figure 2 – Simple Frequency Doubler Schematic

I first tested the prototype unit with the frequency multiplier alone, then added an MAV-11 MMIC for the amplifier connected directly to the mixer through a blocking capacitor, without the optional attenuator or filter. It works just fine at 5 MHz – test results are shown in Figure 3. Conversion loss is about 12 dB, and both the 5 MHz fundamental and the 15 MHz third harmonic are down more than 40 dB. The 20 MHz fourth harmonic is only about 20 dB down, but is far enough away to be easily filtered out if necessary.

Frequency Doubler -- 5 to 10 MHz

5 MHz	AMK-2-13+ Alone			with MAV-11 Amplifier			
Power in ->	5	10	13	5	10	13	dBm
Output							
5 MHz	-52	-48	-44	44	-38	-35	dBm
10 MHz	-6	-2	0	4	8	10	dBm
15 MHz	-60	-48	-44	-48	-37	-30	dBm
20 MHz	-20	-20	-24	-12	-12	-21	dBm
25 MHz		noise					

Figure 3 – Frequency Doubler 5 to 10 MHz Test Data without Low-Pass Filter

I then added the simple low-pass filter shown in Figure 2, with the results shown in Figure 4. The 20 MHz fourth harmonic is significantly reduced, so that all undesired frequencies are now at least 40 dB down. The low-pass filter is also shown in the Figure 1 photo.

5 MHz with Low-Pass Filter between AMK2-13+ and MAV-11
Filter = 1000pf capacitor, 470nh inductor, 1000 pf capacitor

Power in ->	5	10	13	5	10	13	dBm
5 MHz				-44	-39	-34	dBm
10 MHz				2	7	8	dBm
15 MHz				noise	-52	-46	dBm
20 MHz				-37	-33	-36	dBm

Figure 4 - Frequency Doubler 5 to 10 MHz Test Data with Low-Pass Filter

Since these are wideband parts, I tried the prototype at a higher frequency, with an 80 MHz input frequency. Performance was similar, but with about 10 dB less suppression of fundamental and third harmonic. This is still an excellent multiplier and I can see some other uses.

Higher Frequency Doubler

Since these Minicircuits multipliers are wideband parts, rated up to 1000 MHz, I tried the prototype at a higher frequency, with an 80 MHz input frequency. Performance was similar, but with about 10 dB less suppression of fundamental and third harmonic, as shown in Figure 4. This is still an excellent multiplier and I can see some other uses.

80 MHz	AMK-2-13+ Alone			with MAV-11 Amplifier			
Power in ->	5	10	13	5	10	13	dBm
80 MHz	-42	-35	-32	-33	-27	-23	dBm
160 MHz	-6	-2	0	4	8	10	dBm
240 MHz	-42	-34	-26	-32	-24	-17	dBm
320 MHz	-22	-23	-33	-11	-16	-16	dBm

Figure 5 - Frequency Doubler 80 to 160 MHz Test Data without Low-Pass Filter

One immediate application is to multiply the output of my 200 MHz locked VCXO[3] to 400 MHz for the LO of a 432 MHz transverter – with an SDR, the IF doesn't have to be in a ham band. I assembled another PC board, this time with a GVA-84 MMIC amplifier to get a bit more power to drive a high-level mixer. The board is shown in Figure 6, with a jumper wire in place of the low-pass filter. The RF choke, L1, is 150 nH, good for 400 MHz but not 10 MHz. My initial test was with 80 MHz input so I could see the output on a spectrum analyzer with a 350 MHz maximum frequency. Performance in Figure 7 shows higher power output than the unit in Figure 5, but with similar suppression of unwanted frequencies.

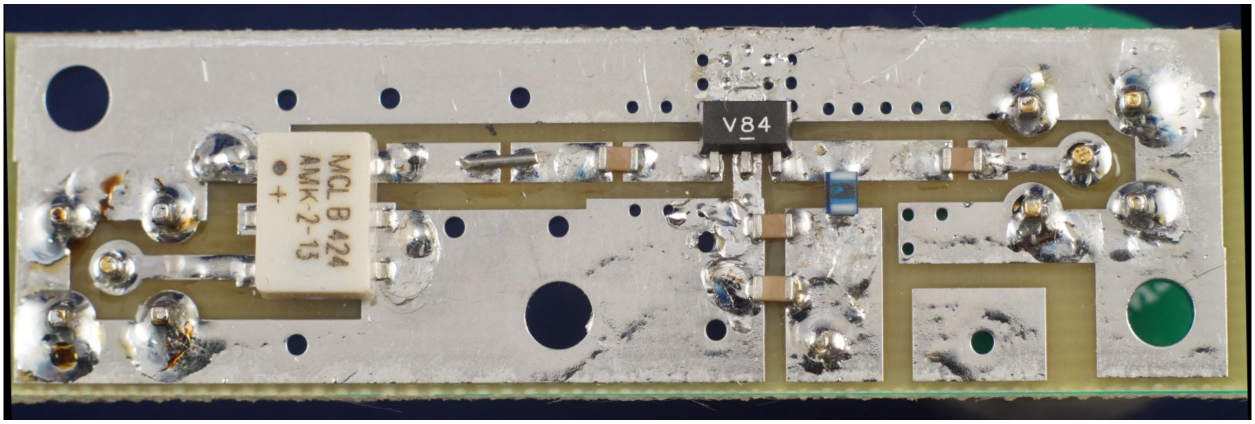

Figure 6 – Frequency Doubler for higher frequencies

Frequency Doubler - high frequency version

80 MHz	AMK-2-13+ with GVA-84 Amplifier				
Power in ->	0	5	10	13	dBm
80 MHz	-27	-19	-13		dBm
160 MHz	11	17	20	21	dBm
240 MHz	-30	-19	-13		dBm
320 MHz	-7	0	-5		dBm

Figure 7 – Performance of Frequency Doubler for higher frequencies, 80 to 160 MHz

At higher frequencies, I was only able to measure total power output, shown in Figure 8, but the power at undesired frequencies should be small. The output power at 400 MHz is excellent. I tried it at higher frequencies as well and found only a small rolloff at 1000 MHz. I pushed it up to 1296 MHz, where the output is a few dB down, but still very usable. To be certain that the output is at 1296 MHz and not just fundamental feedthrough, I put a good interdigital filter on the output – the output power was only a hair lower, so the multiplier is still working fine.

		AMK-2-13+ with GVA-84 Amplifier				
Power in ->		0	5	10	13	dBm
Freq IN	Freq OUT					
200 MHz	400 MHz	10.5	17	21.5	21.3	dBm
400 MHz	800 MHz	10.2	15.5	18.8	20	dBm
500 MHz	1000 MHz	9.2	14.3	17.5	18.8	dBm
576 MHz	1152 MHz	7.7	12.4	15	17.2	dBm
648 MHz	1296 MHz	6.8	11.5	14.6	16	dBm

Figure 8 - Performance of Frequency Doubler at higher frequencies

Higher Frequency Doubler with Filter

Eventually I got a working spectrum analyzer and was able to look at harmonic levels. I also added a simple 400 MHz low-pass filter to reduce the higher harmonics. The filter uses the same simple circuit as the one in Figure 2, with C5 and C6 = 22 pf, and L2 = 12 nh.

I measured harmonic levels with input of +5 dBm at 200 MHz. The 200 MHz fundamental was about 30 dB below the 400 MHz output without the filter and about -35 dBc with the filter. The third harmonic, 600 MHz, was -30 dBc without the filter, reduced to -50 dBc with the filter. The troublesome fourth harmonic was only -20 dBc without the filter, reduced to -30 dBc with the filter. Higher harmonics were not measured without the filter, but were -55 dBc at 1000 MHz and -40 dBc with the filter.

Summary

The performance of this simple frequency doubler is quite impressive, and adequate for many applications with no additional filtering. With a simple low-pass filter, the output is pretty clean. It is a simpler and much less expensive solution than other frequency multipliers I have used, which usually must be followed by a helical or printed filter to clean up the output. Minicircuits also offers higher-order multipliers, with some well into the microwave region – further investigation is in order.

References

1. John C. Roos, K6IQL, "Convering a Vintage 5 MHz Frequency Standard to 10 MHz with a Low Spurious Frequency Doubler," ***QEX***, March/April 2011, pp. 19-35.
2. www.minicircuits.com
3. Paul Wade, W1GHZ, "Locked VCXOs for Stable Microwave Local Oscillators with Low Phase Noise," *Proceedings of Microwave Update 2013*, ARRL, 2013, pp. 121-143.