Design Notes for a 24 GHz Subharmonic Mixer

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INTRODUCTION

It has been said before that the heart of any transverter is a good local oscillator. If you're building your own transverter to get on one of the bands on 903 MHz or above, you know first hand that the local oscillator (LO) is a big part of the trick to getting equipment to work reliably. This seems to be especially true at the higher microwave bands. If you've ever built a transverter from scratch or perhaps in kit form, then you probably realize that the construction of a suitable LO takes the most amount of time. I may have the best noise figure LNA, or gobs of transmit power capability, but if the LO is somehow marginal, or intermittent, then all bets are off in making the QSO!

At 24 GHz, it's popular to use a 144 or 432 MHz IF frequency due to the ease and availability of portable SSB/CW equipment for these bands. Most of the transverters used by amateurs on the lower microwave bands use fundamental mode mixers – that is, the LO input signal is at the necessary frequency for the math to work. At 24 GHz this starts to become more difficult. If for instance, you use a 144 MHz IF frequency, then and LO is needed operating at 24,048 MHz (24192 MHz – 144 MHz). Most amateur schemes use a low frequency stable crystal oscillator in the 100 MHz range which is fed into successive multiplier-filter-amplifier chains to get to the final frequency. While it's relatively easy to get to X-band these days, an LO operating at roughly 24 GHz is more difficult to attain. Most of this is due to the gain of commercially available (and low cost) MMICs rapidly falling off above X-band. It seems to be "many dB harder" to generate an LO operating at 24 GHz. Another approach is to use a subharmonic mixer – a mixer that uses a lower frequency LO and then "internally multiplies" within the mixer hardware to get to the desired higher frequency LO signal. This has the advantage of making for simpler LO hardware. This is especially helpful in getting on a band like 24 GHz.

Several Local Oscillator schemes for 24 GHz are presented below:

IF	**Fundamental LO**	**LO / 2 Scheme**
144 MHz	24,048 MHz	12,024 MHz
432 MHz	23,760	11,880
1296 MHz	22,896	11,448

Figure 1 – Some 24 GHz LO Schemes



Figure 2 – A Commercial Subharmonic Mixer for Spectrum Analyzer Use

TRADEOFFS

Like anything else in life, this involves tradeoffs! Using a subharmonic mixer means a simpler LO, but somewhat more involved mixer hardware. The biggest tradeoff to using a subharmonic mixer is that the conversion loss is usually a lot higher. The HP mixer pictured above, for instance, has ~20 dB conversion loss! This is partly because of its broadband operation, but even over narrower bands for amateur use, subharmonic mixers still have more conversion loss than do standard fundamental mixers. With narrow band operation as we require for amateur work, the circuit efficiency can improve. Published narrowband x2-type subharmonic mixers for Ka Band have typical conversion loss figures of 8-10 dB. In addition to higher conversion loss, a subharmonic mixer has more undesired output frequencies due to the internal multiplication process. This can lead to higher spurious signals. For commercial applications this can be a real challenge, but for amateur applications, this is not usually a problem.

A HIGHER ORDER MIXER

I set out to design a subharmonic mixer for 24 GHz, that instead of using a x2 scheme, would use a x4 scheme. This would make a typical 24 GHz transverter system easier by requiring only a 5940 MHz LO for a 144 MHz IF scheme. I feel it's easier to generate a 6 GHz signal than it is to generate 12 GHz. Searching through the literature, the key to making this type of mixer work effectively is the proper use of idler circuits. The idler circuits essentially reflect the LO energy (and it's harmonics) back towards the mixer diodes. Here again, a x4 subharmonic mixer has several downsides: 1) the design is more complex, and 2) we expect the higher order mixer (x4) would have more conversion loss.

The mixer topology that I'm working on is based work found in the IEEE literature by Madjar[1], shown below.

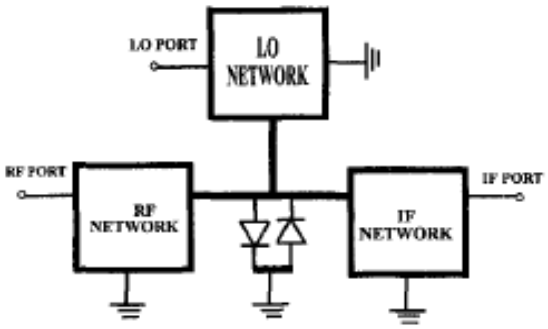


Figure 3 – Subharmonic Mixer Scheme

There are several keys to making the mixer work as a subharmonic mixer. The first is that two diodes are used, placed back-to-back to ground: the so-called “anti-parallel” diode. Best performance is obtained by keeping all the parasitic inductance and capacitances as low as possible. This implies a *very* small component. It’s also beneficial to use diodes that are well matched in their DC characteristics. Fortunately, some of the commercial semiconductor manufacturers have recognized the above nand have made low cost, high frequency schottky didoes available to the industry. One such anti-parallel diode is the M/A Com MA4E1318, shown below.

MA4E1317, MA4E1318, MA4E1319-1, MA4E1319-2, MA4E2160

Tyco Electronics

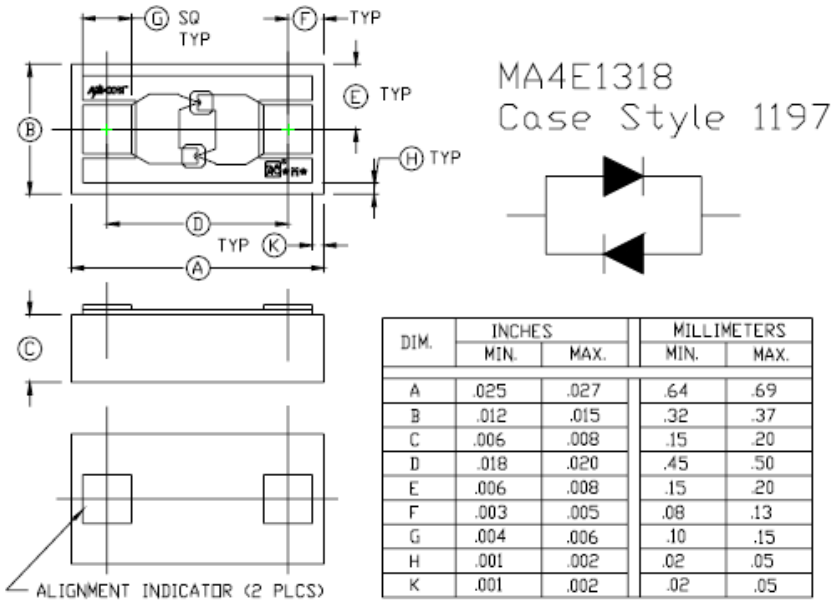
GaAs Flip Chip Schottky Barrier Diodes

M/A-COM Products
Rev. V3

Electrical Specifications @ + 25 °C

Parameters and Test Conditions	Symbol	Units	MA4E1317			MA4E1318		
			Min.	Typ.	Max.	Min.	Typ.	Max.
Junction Capacitance at 0V at 1 MHz	Cj	pF		.020			.020[3]	
Total Capacitance at 0V at 1 MHz[1]	Ct	pF	.030	.045	.060	.030[3]	.045[3]	.060[3]
Junction Capacitance Difference	DCj	pF					.005	.010
Series Resistance at +10mA[2]	Rs	Ohms		4	7		4	7
Forward Voltage at +1mA	Vf1	Volts	.60	.70	.80	.60	.70	.80
Forward Voltage Difference at 1mA	DVf	Volts					.005	.010
Reverse Breakdown Voltage at -10uA	Vbr	Volts	4.5	7				
SSB Noise Figure	NF	dB		6.5[4]			6.5[4]	

Figure 4-A – MA/COM Single and Anti-Parallel Mixer Diode Specifications.



DIM.	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
A	.025	.027	.64	.69
B	.012	.015	.32	.37
C	.006	.008	.15	.20
D	.018	.020	.45	.50
E	.006	.008	.15	.20
F	.003	.005	.08	.13
G	.004	.006	.10	.15
H	.001	.002	.02	.05
K	.001	.002	.02	.05

Figure 4-B – MA/COM Anti-Parallel Mixer Diode Package

The good news here is that these diodes are at least offered in tiny surface-mount type packages, so no wire-bonding is required. The bad news is that they're only 26 mils in length… really small! You need a microscope or high powered magnifier to work with these components. A conductive epoxy is used to attach the diodes to a small printed circuit board.

Each portion of the mixer circuitry will be discussed below (see Figure 3 above).

The purpose of the RF Network shown above is several-fold. In general, it looks like a fairly wide band pass filter at 24 GHz. It provides some degree of out-of-band rejection, but more importantly it also keeps the various LO signals from radiating out the RF input of the mixer. It looks reflective to the LO energy and reflects this back towards the diodes. The RF network also includes a small section of microstrip transmission line to provide an impedance match to the diodes. The LO network is a narrowband filter centered at roughly 6 GHz. It filters the incoming LO energy, but perhaps more importantly, it looks very reflective at all other frequencies. It reflects the 12 GHz and 18 GHz LO harmonic energy back towards the mixer diodes to improve the efficiency. The LO network also has a matching section to match from 50 ohms into the low impedance offered by the diodes. The IF section of the mixer passes the mixer's desired IF output energy but, as just as in the other portions of the mixer, reflects the LO energy back toward the mixer diodes. Each of the circuit sections reflect energy back towards the diodes with the correct *phase* signal for optimal performance.

RF FILTER SECTION

The schematic of the RF band pass filter is shown below. The BPF consists of two quarter wavelength, short circuited stubs separated by a series transmission line. At each end of the filter traps are included to reflect back the 5940 MHz and 11880 MHz LO energy back toward the mixer diodes. This is simple, but fairly wide band filter. The filter section was designed using rough hand calculations and then optimized using the student version of the Ansoft Designer circuit design software[2].

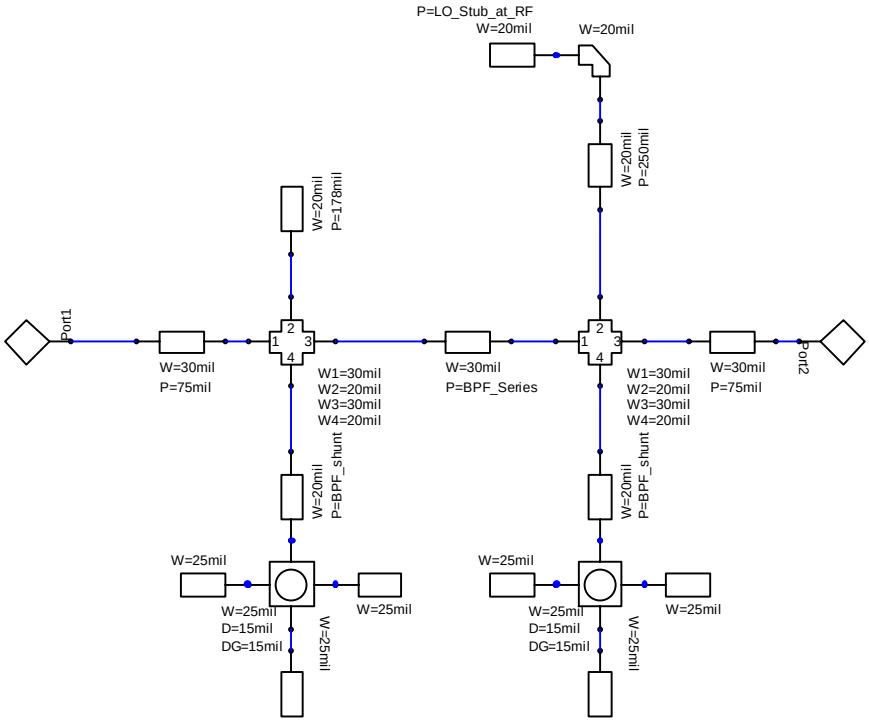


Figure 5 – RF BPF and Traps for 5940 and 11880 MHz

The predicted circuit response for the RF Filter section is shown in the figure below. A very low insertion loss is shown at 24 GHz, with >40 dB theoretical attenuation at 5940 MHz and 11880 MHz.

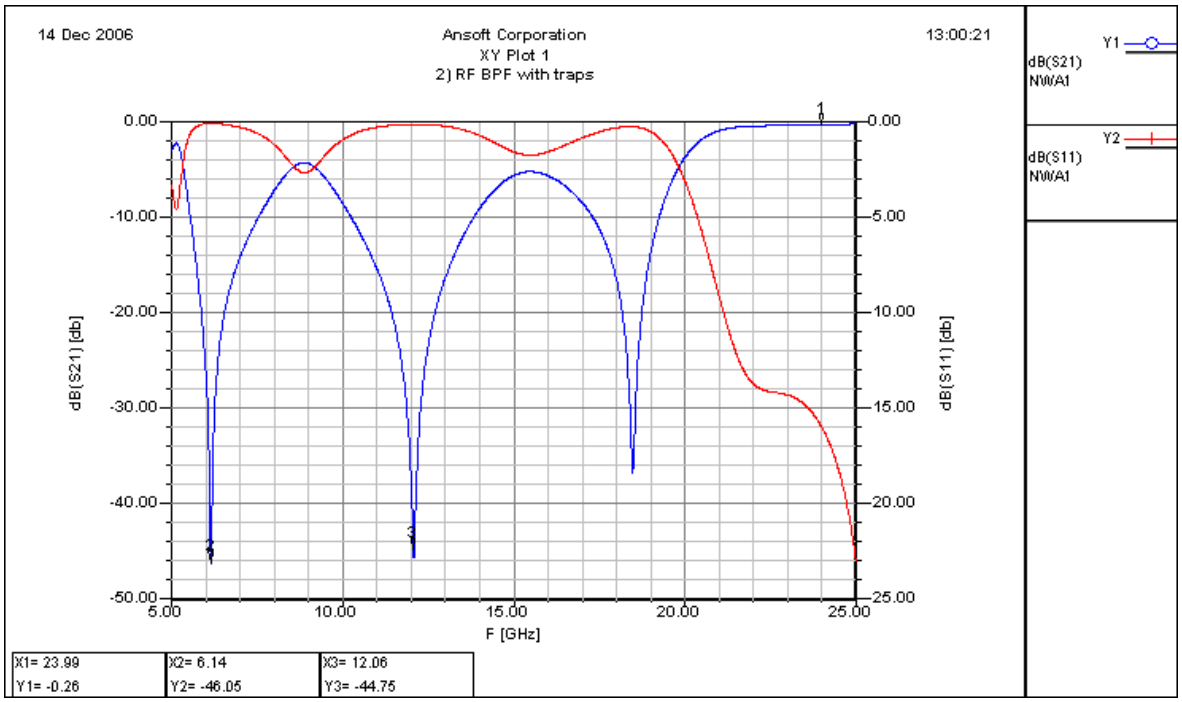


Figure 6– Predicted Response for RF Filter Section

So, with an easily obtainable component available to the general public and very predictable results through simulation, this project is now being pursued. Time constraints prohibited any actual results from being recorded for the close of this paper and for the 2008 SVHFS proceedings. My presentation at this years conference will cover the further development of this design hopefully with favorable results detailing the construction and recorded data.

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[1] A. Madjar, "A Novel General Approach for the Optimal Design of Microwave Subharmonic Mixers," IEEE MTT Transactions, Nov 1996.

[2] Ansoft Designer Student version may be downloaded from: www.ansoft.com