Experiments with Singly Balanced Mixers Wes Hayward, w7zoi, 29Jan08

Recently Bob Kopski, K3NHI, built some balanced diode mixers. Bob used a variety of diodes with both singly and doubly balanced circuitry. The doubly balanced mixers worked as expected, and the diode type didn't really matter a lot at low frequency. However, Bob was frustrated with the singly balanced mixers. (Ref: EMRFD Yahoo Group, 23Jan08, Posting #1361)

Bob used a LO at 12.5 MHz in his experiments, usually with a LO power of +7 dBm. His RF input was 5 MHz while the outputs at both 7.5 and 17.5 were observed. The circuit he used was that of EMRFD Fig 5.19 B. Bob was most frustrated to find that the both converted sidebands at 7.5 and 17.5 MHz had a poor conversion gain of -10 dB or worse. Bob's RF power was -10 dBm. Much of the literature talks of a conversion loss of 6 to 7 dB.

Bob expressed concern. First, he asked if he was doing something wrong in his experiments. (He of course was not.) He then ask if the literature was wrong; was it possible that a diode mixer with just two diodes can really produce a low conversion loss. Many of us have built two diode mixers where we had measured very low conversion loss, so we were equally puzzled.

The experiments that I did are outlined in Fig 1 below.

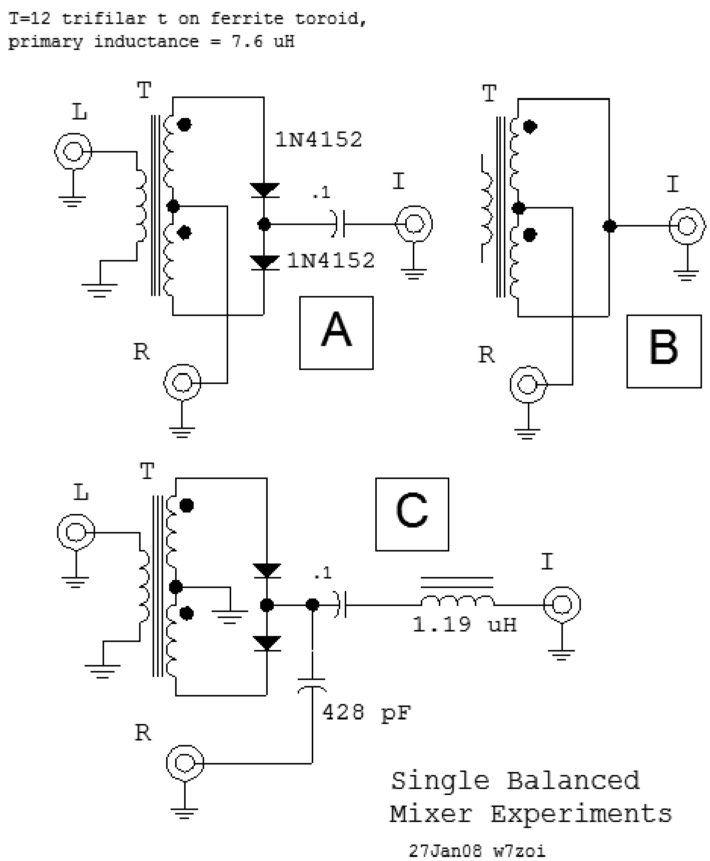

Fig 1. Schematics for experiments.

My first experiment is the mixer of Fig 1A. My transformer used relatively low inductance in the transformer. However, the primary L was still well above the characteristic impedance driving the primary (5X or more) so the low inductance was not a concern. (I had merely grabbed an already wound multiple winding toroid from the junk box.) My mixer also had a blocking capacitor at the IF port. I set up my gear for about the same conditions that Bob had. I used a slightly higher LO power of +9 dBm, but F_{LO} was 12.5 MHz, F_R=5, and P_R=-10 dBm. The R and I termination impedances were all a solid 50 Ohms. That at L was not quite as good, but still reasonable. My first measurement is shown in Fig 2.

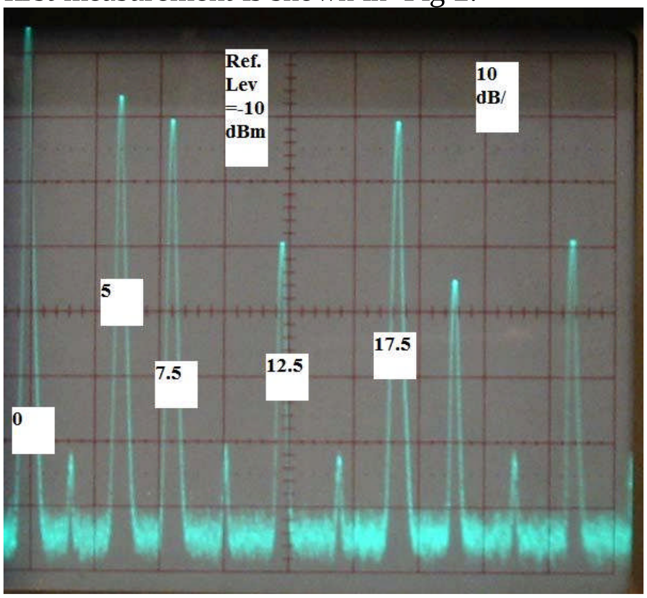

Fig 2. The Spectrum Analyzer was set up for 10 dB per division with a reference level of -10 dBm at the top of the screen. The 0 spur was moved one major division in from the left edge just to produce reasonable graticule lighting from the ambient light. The highest output is the 5 MHz RF feedthrough, just 7 dB down from the available input of -10 dBm. The converted sidebands at 7.5 and 17.5 indicate a conversion loss of 11 dB or more.

The results are virtually identical with those that Bob obtained. This was not a surprise. But now we looked at the circuit with greater care with an analytical eye. An explanation emerged immediately and is shown in a quick experiment that we performed, shown in Fig 1B. We removed the diodes, disconnected the LO, and measured the loss between the R and I ports. There was none. Essentially, the two ports are connected directly together. This makes sense when we examine the circuit. Assume some load at I and current injected at R. The current will split with some of it flowing into the transformer winding with a dot, the “beginning.” The other portion enters the other winding, but into the “end” without a dot. The two magnetic fields that build in the core tend to cancel, so there is virtually no self inductance. If the current split between the two halves is not equal, the larger current will produce a net field. This constitutes an inductance with a reactance that tends to reduce that current. The effect is that the transformer forces an equal current split with a net field of zero.

The overall circuit result is that the R and I ports are connected directly to each other in the circuit of Fig 1A. The output voltage that results is developed across 25 Ohms and not 50 Ohms. Yet it is only the part that reaches the 50 Ohm spectrum analyzer half that we observe as output. We only see half of the output power. The other part appears in the source impedance at the R port.

While I did not observe it, I'm sure that insertion of a directional coupler or splitter at the R port would let us see an identical power delivered there at 7.5 and 17.5 MHz.

Mixers with a diplexer.

My interest was now to investigate mixers with a diplexer at the IF port. This will generate some mild filtering action, which will tend to isolate the energy at the two parts of the IF termination. To more effectively realize this, I moved F_R from 5 to 10 MHz, which forces the IF to 2.5 and 22.5 MHz. I measured this configuration with the original circuit, now shown in Fig 3.

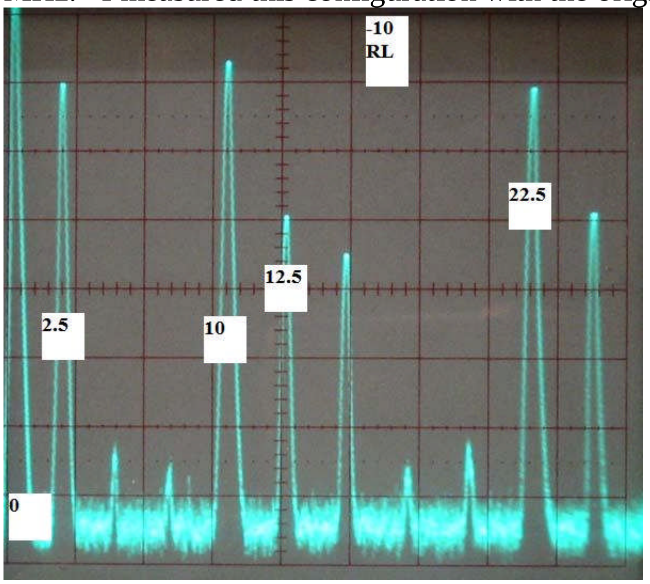

Fig 3. A mixer using the circuit of Fig 1A with RF at 10 MHz, LO at 12.5, resulting in IF at 2.5 and 22.5 MHz. Although frequencies have changed, the levels are essentially the same as we saw in Fig. 2.

The next experiment inserts a diplexer. R energy is no longer inserted at the transformer center tap. Rather, the center tap is grounded. The R and I ports are almost in parallel. However, an inductor is inserted in series with the I port while a capacitor is in series with R. We pick components with equal reactance at the geometric mean of 2.5 and 22.5 MHz, which produces a perfect 50 Ohm load being seen by the junction of the two diodes at ALL frequencies. This differs from the 25 Ohm load produced by the earlier topology.

The data produced with the diplexer circuit is shown in Fig 4 below where the conversion loss at 2.5 MHz has dropped to 7 dB. Conversion loss to 22.5 MHz has, however, increased to 18 dB.

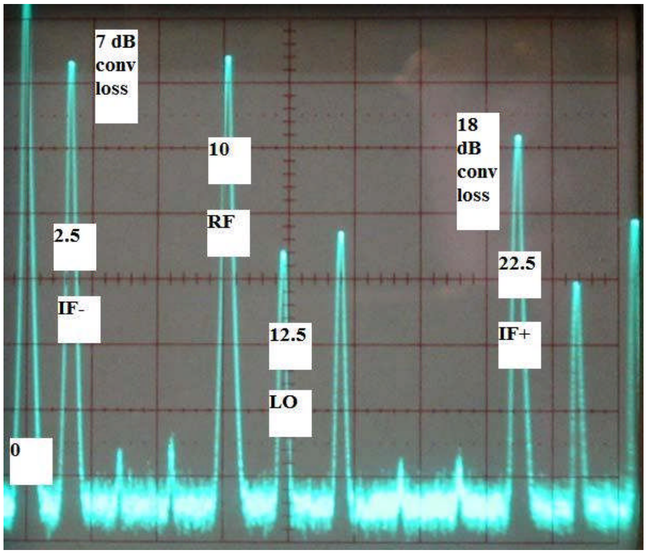

Fig 4. A diplexer singly balanced mixer with the inductor in the I leg. This produces improved conversion gain for the LSB.

The next experiment, Fig 5, places the series capacitor in the IF leg while the inductor is in the R path. (I just switched the coax connections.) We observed slightly contorted results, for F_R is in the middle of the band. I moved F_R down to 1.25 MHz to see the result shown in Fig 5.

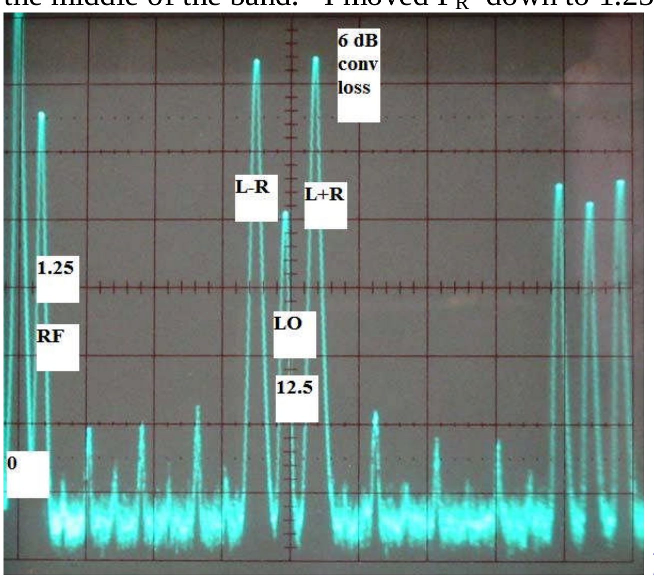

Fig 5. A diplexer singly balanced mixer with the capacitor in the I leg. Now both the USB and LSB show low conversion loss of around 6 dB, for the net impedances presented to the junction of the diodes is 50 Ohms.

The mixer that we built to evaluate the topologies is shown in Fig 6. No special circuit schemes are used, and the diodes are just the familiar junction diodes.

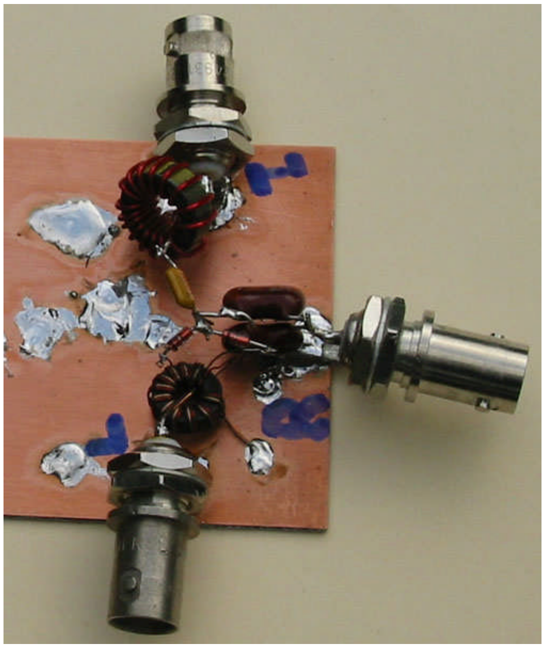
Fig 6. The experimental mixer.

Some other details.

Notice the LO component in Fig 5. The 12.5 MHz energy appearing in the output load is -39 dBm for an available LO power of +9 dBm.   Hence, the L to I isolation is the difference of 48 dB. This is really quite good for a casual mixer with only one toroid and sloppy wiring.   This is the topology we would have if we were using this mixer as a balanced modulator to generate double sideband.   But in that case, we might inject baseband sidebands at -10 dBm per tone.   Each would be converted to the output with a 6 dB conversion loss to result in -16 dBm for each output tone.   Comparing this with the -39 dBm output carrier yields a carrier suppression of only 23 dB, which is poor.   It would still be fine for most applications where we consider DSB today, but it also explains why most simple balanced modulators for DSB include a balance control.

While I'll not bother to present any details, I did quite a bit of playing with SPICE to simulate these mixers.   Most of the measured details presented were qualitatively observed in the simulations.   However, we found it difficult to obtain the exact conversion gain results.   This serves to illustrate a characteristic of simulations that Rick Campbell (KK7B) and I observed time and time again when using SPICE and some other sophisticated tools in the design of integrated circuits: ***The simulation is the greater experiment.***