Double Balanced Diode Ring Mixers

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Introduction

Mixers are frequency conversion devices, used to convert signals to/from a high frequency (the RF frequency) from/to a lower Intermediate Frequency (IF) or baseband. In communications systems the RF is the transmission frequency, which is converted to an IF to allow improved selectivity (filtering) and an easier implementation of low noise and high gain amplification.

Diode based mixers are passive mixing devices (requiring no DC supply) that can offer low insertion loss and high linearity. Most modern diode mixer designs use Schottky diodes as they are majority carrier devices with a higher switching speed than p-n junction diodes [1]. This publication discusses double balanced diode ring mixers; it explains their operation and presents an example of a practical design.

The Operation of Double-balanced Diode Ring Mixers

Double balanced mixers operate with balanced RF and LO signals, which provides inherent isolation between all mixer ports and suppression of many spurious products (all even order products of the LO and/or the RF are suppressed). The most common form of double-balanced diode mixer is the diode ring, depicted in Figure 1. Matched diode rings (fabricated in close proximity on the same substrate material) are readily available as both bare die and packaged components. Completely integrated double balanced diode mixer MMICs, including RF and LO baluns and IF filtering are also widely available.

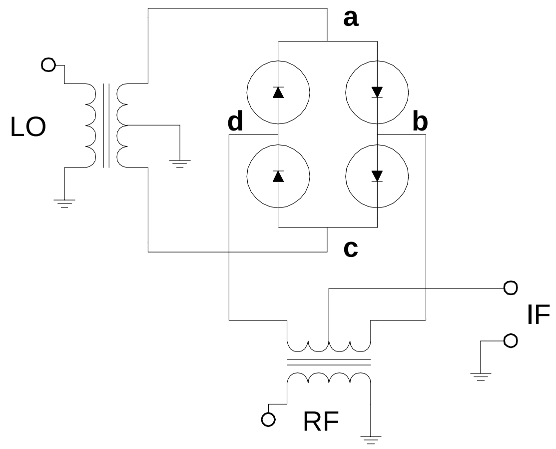

Figure 1: Block diagram of a double-balanced diode ring mixer

The operation of a double balanced mixer is best understood by considering the diodes as switches [2]. The LO signal alternately turns the left hand pair and right hand pair of diodes on and off in anti-phase. Points ‘a’ and ‘c’ are virtual earths to the RF signal and can be considered as connected to ground. Thus points ‘b’ and ‘d’ (where the balanced RF signal is connected) are alternately connected to ground (at points ‘a’ and ‘c’) by on-state diodes. This means an in-phase RF signal and an anti-phase RF signal are alternately routed to the IF port under control of the LO. Thus the signal at the IF port is effectively the RF signal multiplied by an LO square wave of peak magnitude ±1.

This action is easily demonstrated using simple mathematical processing software. Figure 2 shows a sinusoidal voltage waveform at a frequency of 1GHz; consider this to be the RF waveform. The LO switching waveform is depicted in Figure 11, it is a square wave at a frequency of 870MHz. Multiplication of the two will produce a waveform with a strong component at the difference frequency (IF) of 130MHz.

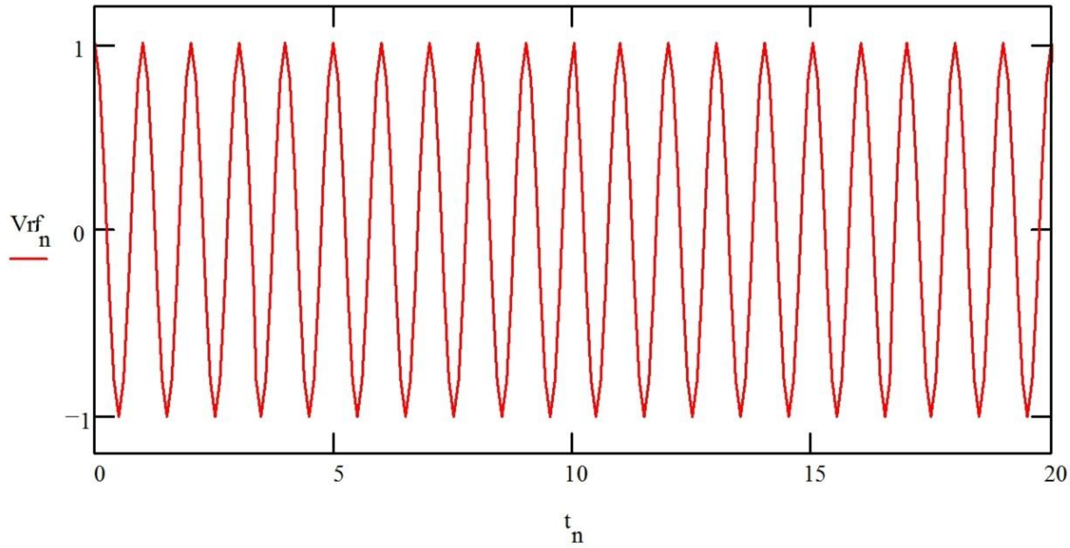

Figure 2: RF waveform (sinusoid at 1GHz)

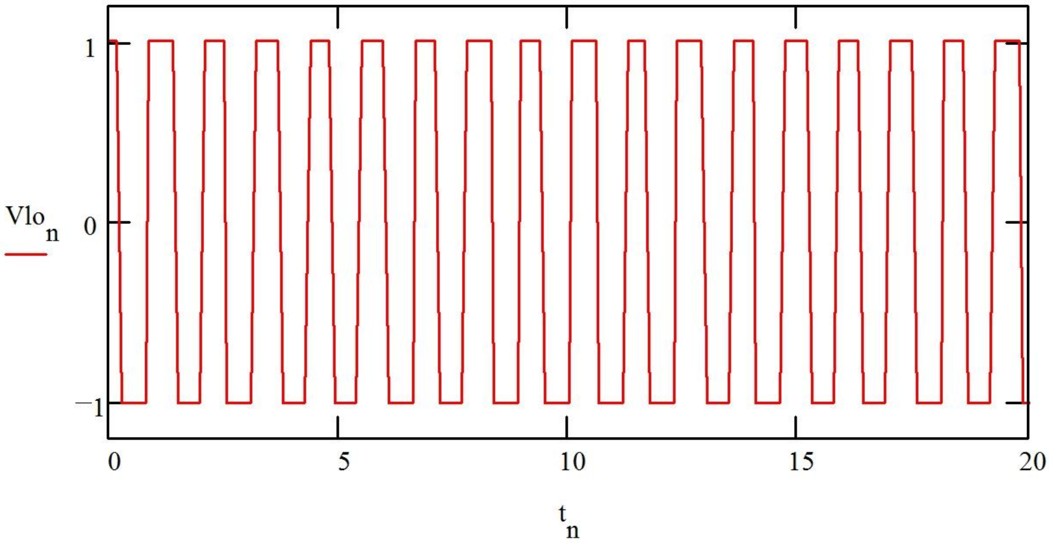

Figure 3: LO waveform (square wave at 870MHz)

Figure 4 shows the result of multiplying the LO and RF waveforms. A low frequency sinusoid is clearly visible. This is a replica of the RF signal (i.e. a sinusoid) translated to the IF frequency of 130MHz. Although this method of mixer analysis provides a qualitative understanding of how the mixer functions, it is not adequate to predict the RF functionality. Ideal square wave multiplication, such as this, results in a conversion loss of 3.9dB. In practice diode-ring mixers have additional losses (in the baluns and diodes) and imperfections that increase the conversion loss actually achieved. A loss of between 6 and 8dB is typical for a well-designed diode ring mixer. In order to predict accurately the mixer’s performance, large signal circuit simulation must be performed. This is shown for the practical example given below.

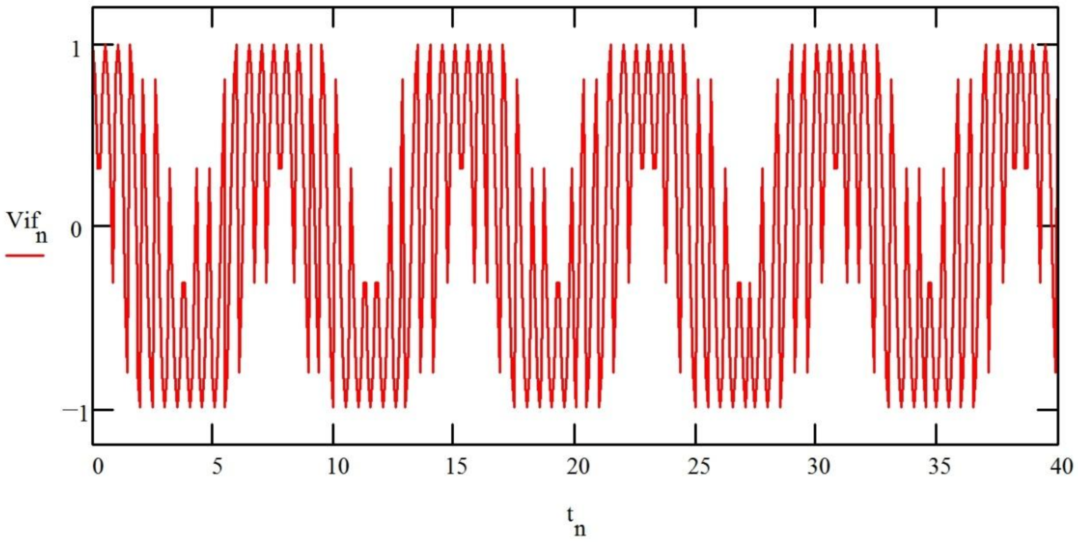

Figure 4: RF waveform multiplied by LO waveform

Some Practical Considerations

The block diagram in Figure 1 shows the differential RF and LO signals provided using wire-wound ferrite transformers. Wire-wound transformers can be used at frequencies up to around 2 to 3GHz but practical mixers often use other balun implementations, particularly at higher frequencies. Many types of printed balun are available [2] and these can offer good performance at a low cost; they are therefore a common choice, particularly for fully integrated mixers such as that described in the practical example section below. It is important to be aware of how the performance of the baluns being used differs from the wound transformers shown above. The centre-tapped point for connection of the IF port is often not available and suitable IF filtering must be designed and implemented. This must provide a low loss through path at IF frequenices and a high impedance input at RF to avoid loading the mixer and degrading its performance. The IF port should usually be connected to the RF side of the mixer, as in normal operation the LO signal is much larger than the RF and any leakage to the IF port would be at a much higher level.

Double-balanced diode mixers using a star configuration are also possible, details can be found in [1].

Practical Example

Low cost double-balanced diode mixers are now commercially available as MMICs. All required circuitry is integrated on to a single die, Figure 5 is a layout plot of a 6 to 23GHz part designed by Plextek RFI. The baluns are spiral structures to allow a compact layout and adopt a Marchand configuration [3]. The LO input is to the left and the RF output to the right with the quad diode ring at the centre. Care should be taken in ensuring symmetry of the layout in order to obtain optimum balance.

The IF input/output is tapped from the RF balun. As mentioned previously the RF signal is normally at a significantly lower level than the LO and it is the preferred point to connect the IF. A simple IF filter structure is included comprising a shunt MIM capacitor and a high impedance (inductive) series transmission line.

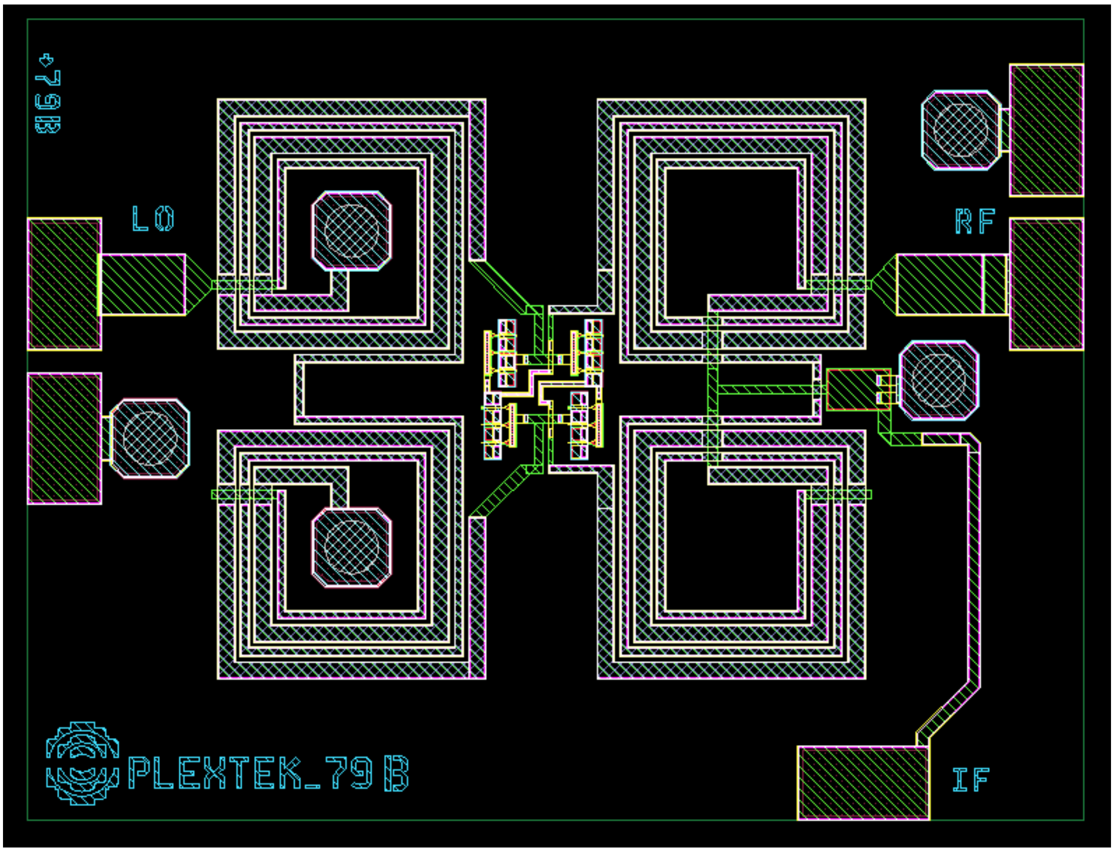

Figure 5: Layout of the 6 to 23GHz double balanced mixer MMIC

A simplified schematic of the 6 to 23GHz double balanced mixer MMIC is depicted in Figure 6.

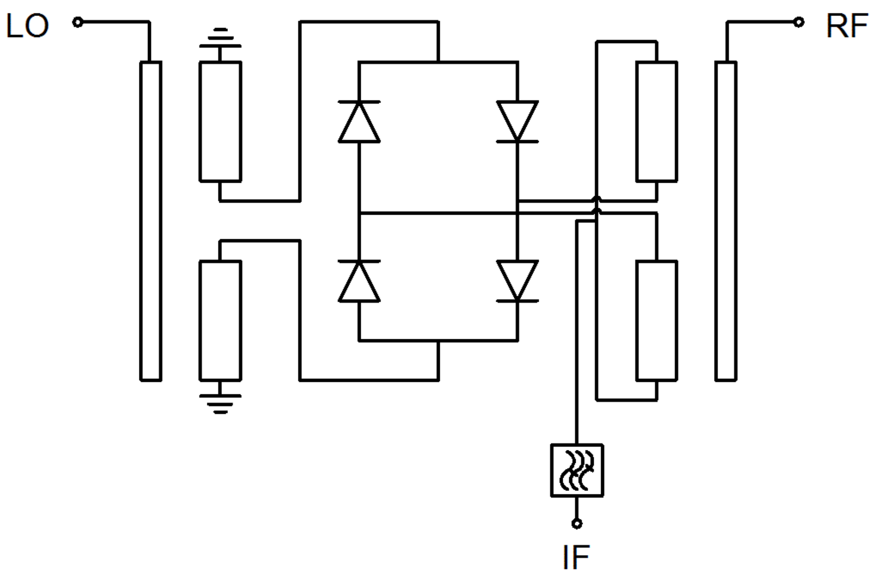

Figure 6: Simplified schematic of the 6 to 23GHz double balanced mixer MMIC

The RFOW measured conversion gain of the mixer is plotted against RF frequency in Figure 7. This was measured in downconvert mode with an IF of 100MHz and an LO drive of +15dBm, it shows a typical conversion loss of just 7dB.

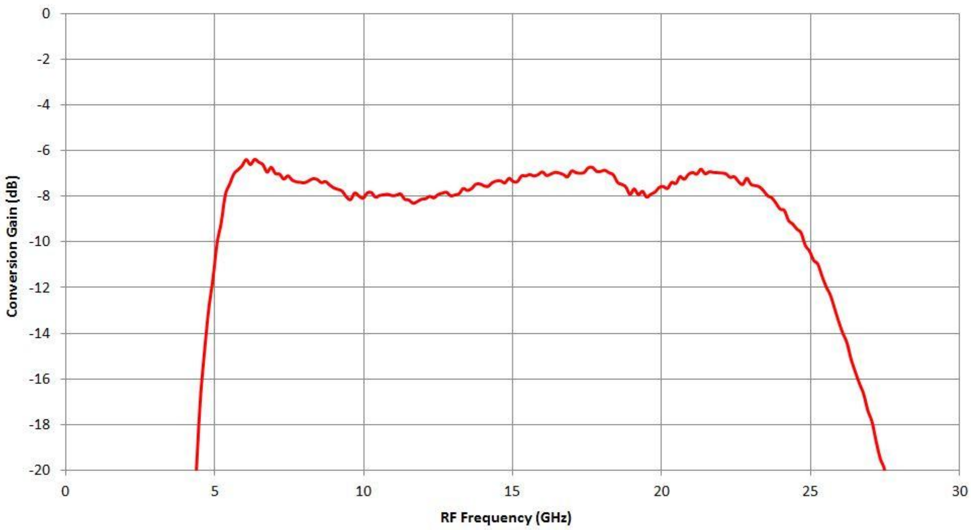

Figure 7: RFOW measured conversion gain of double balanced mixer MMIC

The conversion gain and input referred third order intercept point (IIP3) are plotted against RF frequency in Figure 8. This was also an RFOW measurement in downconvert mode with an IF of 100MHz and an LO drive of +15dBm and shows a typical IIP3 of over around 21dBm.

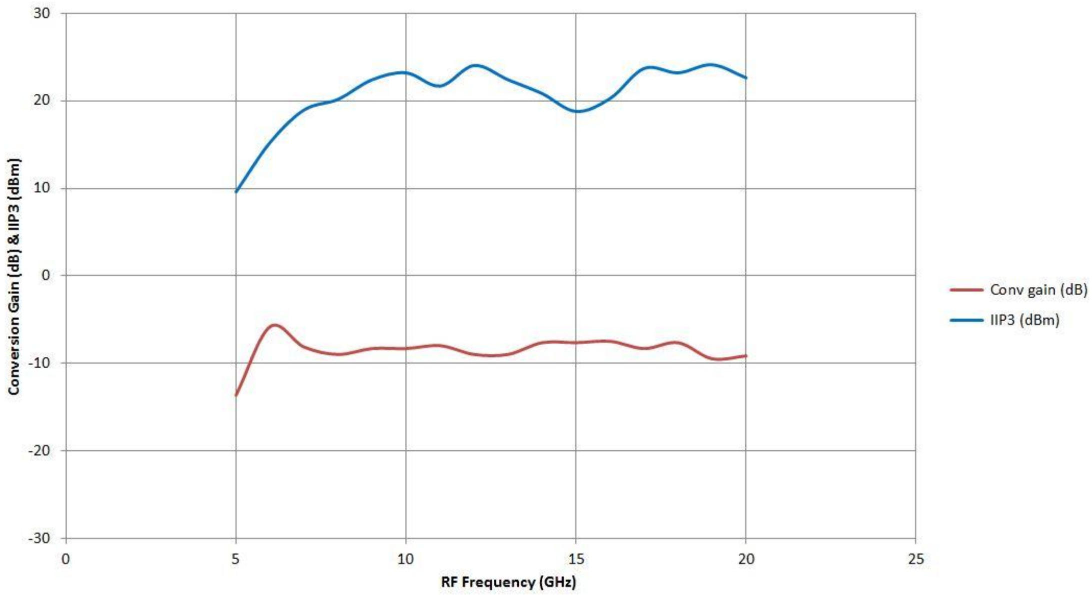

Figure 8: RFOW measured conversion gain and IP3 of double balanced mixer MMIC

The measured LO to RF rejection is plotted against RF frequency in Figure 9 and is higher than 30dB across most of the band. This demonstrates the balance of the baluns, the symmetry of the layout and the close matching of the diodes.

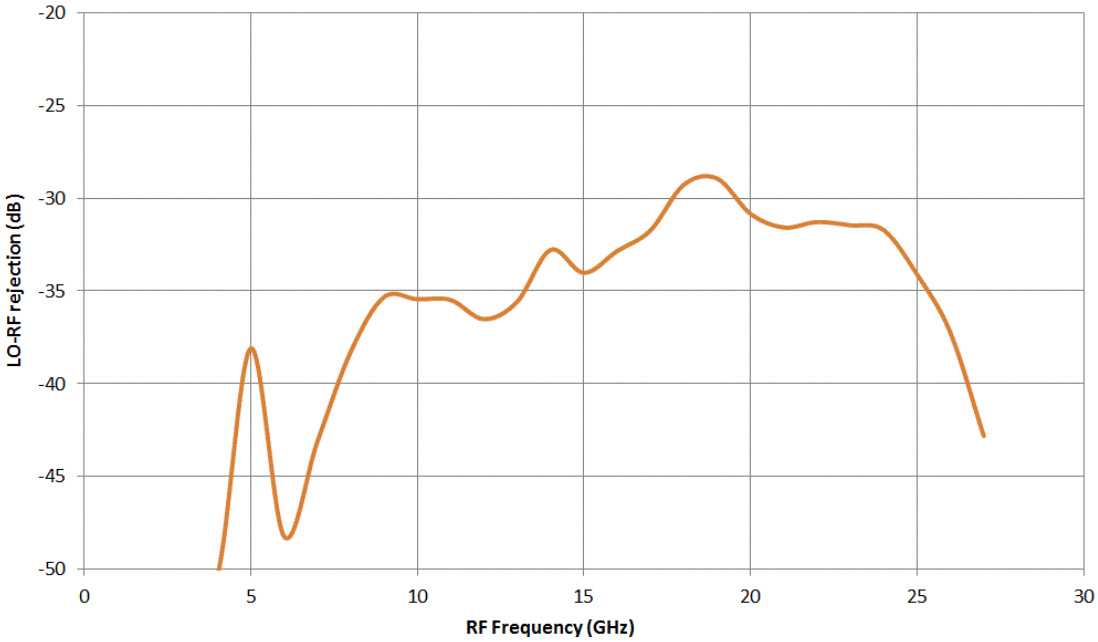

Figure 9: RFOW measured LO rejection of double balanced mixer MMIC

Summary

This article has described the operation of double-balanced diode ring mixers and has demonstrated the performance benefits using a practical measured example.

References

[1] Maas, S.A. “Microwave Mixers”, Artech House, ISBN 0-89006-605-1

[2] Liam Devlin, “Mixers”, IEE Tutorial Colloquium on “How to Design RF Circuits”, April 5th 2000, pp 9/1-9/20

[3] Marchand, N. “Transmission-Line Conversion”, Electronics December 1944, pp 142-145