SUBHARMONIC vs. FUNDAMENTAL MIXERS FOR HIGH CAPACITY MILLIMETERWAVE RADIOS

Introduction

The microwave and VSAT radio market in the past decade has significantly grown from primarily voice and data communication to a mix of data, video, internet, and voice services. These newer standards require complex digital modulation schemes which have higher bandwidth requirements, which in turn require higher transmit frequencies. The point to point frequency spectrum ranges from 2.11 GHz to 42 GHz.

To meet the low cost and reliability requirements of these microwave radios Hittite Microwave Corporation has designed integrated MMIC circuits that meet these new market demands. These new devices include components such as mixers, VCOs, prescalers, attenuators and amplifiers to integrated down-converters, up-converters, frequency multipliers, phase-locked oscillators (PLOs) and multi-chip modules (MCMs). Figure 1 shows a block diagram of a typical microwave radio transmit and receive chain in a typical super-heterodyne architecture.

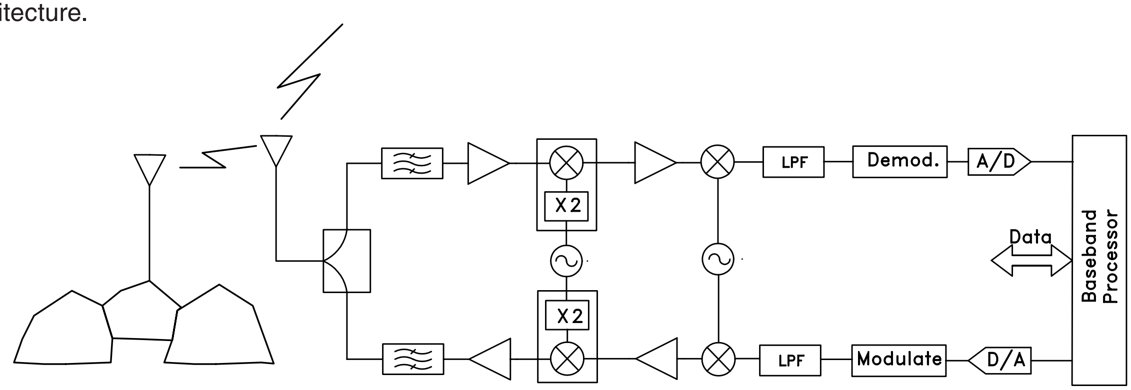

Figure 1 - Microwave super-heterodyne point-to-point radio

The transmit and receive chains both contain amplifiers and mixers which are realized as Microwave Monolithic Integrated Circuits (MMIC). The amplifiers typically incorporate some type of automatic gain control to prevent saturation of succeeding components, particularly the analog to digital converter. There are filters at the transmit and receive frequency to reject interference and spurious products generated by the amplifiers and mixers as well as out-of-band interferers. The mixers shown in figure 1 are comprised of both subharmonic and fundamental mixers. The subharmonic mixers require a local oscillator (LO) signal which is at approximately ½ the RF frequency. These mixers create the majority of spurious signals present in the receiver and transmitter. Since the levels of the spurious emissions will drive the complexity of the filters, a mixer with good spurious performance and a carefully-designed frequency plan is required.

Hittite Microwave Corporation offers a variety of millimeter-wave subharmonic and balanced mixers that meet the requirements for millimeter-wave radios. Hittite's line of sub-harmonically pumped mixers range in frequency from 14 – 42 GHz making them ideal for millimeter-wave radio applications. These mixers are available with an integrated LO and IF amplifier in a SMT leadless chip carrier package as well as die. The excellent 2LO to RF and IF isolation minimizes the transmit and receive filter requirements. The mixers with integrated LO and IF amplifiers require only a single DC bias and -4 dBm of LO drive.

This product note will discuss and compare the use of a subharmonic mixer and double-balanced mixer in the 27 GHz millimeter-wave radio band.

Criteria for the Front-end Mixer

The subharmonic mixer is the primary front end mixer found in the majority of millimeter-wave radio designs. What makes this mixer unique is that it operates with a LO frequency at ½ the RF frequency, therefore eliminating the requirement for a more complex and costly high frequency LO. The subharmonic mixer also naturally rejects even-order spurious emissions. A carefully designed mixer can achieve 2*LO isolation as high as 35 dB. Prior to the introduction of MMIC mixers these devices were traditionally hybrid topologies consisting of discrete diodes with supporting distributed circuitry on alumina or equivalent substrates. Manufacturing tolerances of these assemblies limited the performance of these designs and manual tuning of these mixers increased manufacturing costs. A MMIC mixer eliminates these drawbacks via the monolithic manufacturing process and eliminates the need for individual device tuning.

Subharmonic Mixer Background

Figure 2 shows the basic architecture of a subharmonic mixer. The mixer consists of an anti-parallel diode pair, a band-pass filter for the RF and LO signal, and a low-pass filter at the IF output. What is essential in a subharmonic mixer is that the diodes are anti-parallel. Many subharmonic mixers are merely a balanced mixer with a frequency doubler in the LO path. This topology requires additional circuitry which complicates the design and adds cost. Hittite utilizes the ant-parallel diode configuration in all of its' subharmonic mixers therefore giving "true" subharmonic mixer performance using a simple design at lower cost.

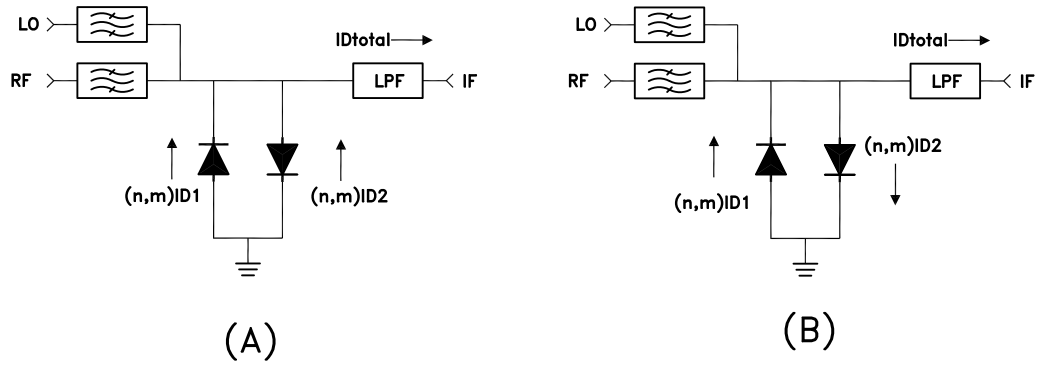

Figure 2 - IF current distribution for (a) odd order products, and (b) even order products.

Like other mixers, when an LO signal with sufficient power is incident on the diodes, the diodes will switch on and off in a complimentary fashion creating a waveform rich in harmonics. Figure 2(a) shows the currents through the diodes when m+n=odd (where m and n are the harmonic order of the RF and LO respectively). These currents will add at the IF port thereby generating a signal. Conversely, figure 2(b) shows the currents in the diode when m+n=even. The currents are now 180° out phase resulting in the cancellation of the currents at that particular harmonic. Therefore, a subharmonic mixer will cancel all harmonics with an even order such as the RF±LO (1+1=2) while passing the odd order harmonics RF±2*LO (1+2=3). The fundamental LO will still be present at the RF and IF ports of the mixer, but it will be significantly lower in frequency therefore making it easier to filter.

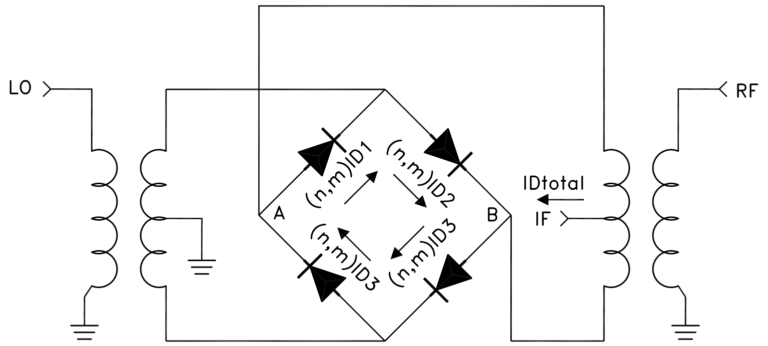

Figure 3 - Double-balanced mixer

The operation of a double-balanced mixer is similar to subharmonic with the exception that the currents add differently due to the configuration of the diodes. Unlike the subharmonic mixer, the diodes in a double-balanced mixer are configured in a ring as shown in Figure 3.

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Like the subharmonic mixer, the LO switches the diodes on and off resulting in harmonics that are multiples of both the RF and LO. The currents at the IF output, in figure 3, will either add or subtract depending on their phase. If m or n is even, the currents will add out of phase and the IF signal for that particular harmonic will be equal to zero. Therefore the product RF ±2*LO is naturally suppressed in a double balanced mixer making it unworkable as a subharmonic mixer. Consequently, when m and n are both odd, the currents will add in phase and a harmonic output is present at the IF port. In essence the double balanced mixer rejects more spurious products but requires a more complex and costly frequency generation unit due to the higher LO frequency requirement.

In both double-balanced and subharmonic mixer topologies, the symmetry, balance, and match of each diode are critical to the performance of the mixer. Degradation of these characteristics will generally result in degraded mixer performance.

Simulating Mixer Performance

In order to illustrate the differences in performance between the subharmonic mixer and double-balanced mixer, a simulation using a traditional spurious calculator and =SPECTRASYS=[1] was performed. The simulations show the locations and relative strengths of the spurious signals for each mixer type. The two mixers used in the comparison are Hittites' HMC264LM3 subharmonic mixer and the HMC292LM3C double-balanced mixer. Both of these mixers cover the frequency range from 20 - 30 GHz.

Hittite's "Spurchart Calculator" which is found on our website at www.hittite.com was used to determine spurious location and level of a double-balanced mixer being used in both the downconverter or upconverter mode.

Figure 4 shows a sample output of the Spurchart calculator. In this case, an upconverter is chosen and the IF input band ranges from 2.9 - 3.1 GHz which corresponds to the horizontal length of the specification box. The RF band is set to 27.5 - 29.5 GHz. The RF band is plotted as the vertical length of the specification box. The IFmin and IFmax parameters correspond to the scale of the X axis while RFmin and RFmax scale the Y axis.

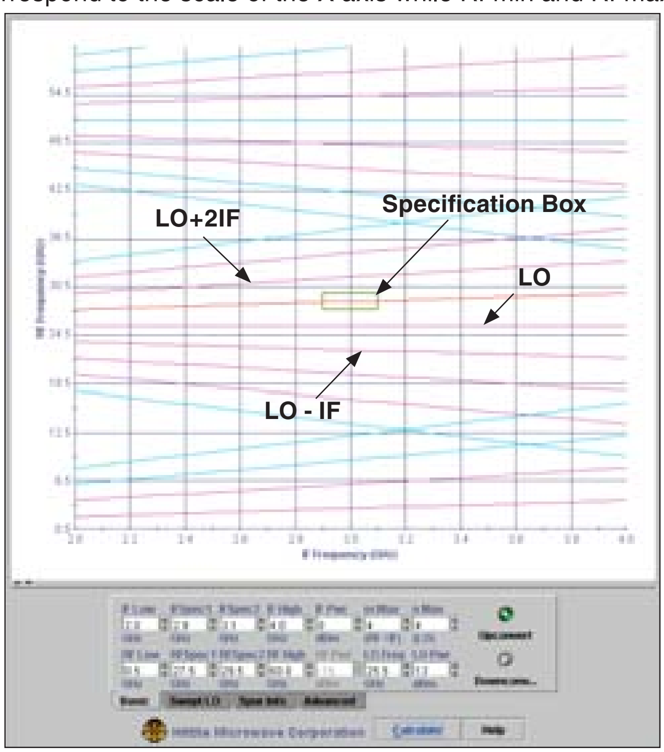

Figure 4 - Sample of Hittite's Web-Based Spurchart Calculator Output

The LO frequency can be set to a fixed frequency or swept in frequency. In this case, the LO is fixed at 25.5 GHz with an input power of +13 dBm. The maximum order of products is specified to be 8 (4x4). The graph shows the mixer spurious products and how they spatially relate to the chosen IF and RF bands. The 1X1, or desired up-converted product, is shown running through the entire specification box as expected. Three other spurious products are shown close to the specification box edges. These spurious signals are the LO, LO+2IF, and LO-IF. Figure 5 shows the spurious response in tabular form where "m" is the order of the RF product and "n" is the order of the LO product. The table lists the relative power in dBc with respect to the desired 1x1 output. These levels are calculated using equations that predict the level for each spurious product.[2] The calculator does not determine the LO leakage and its' harmonics due to restrictions in the model.

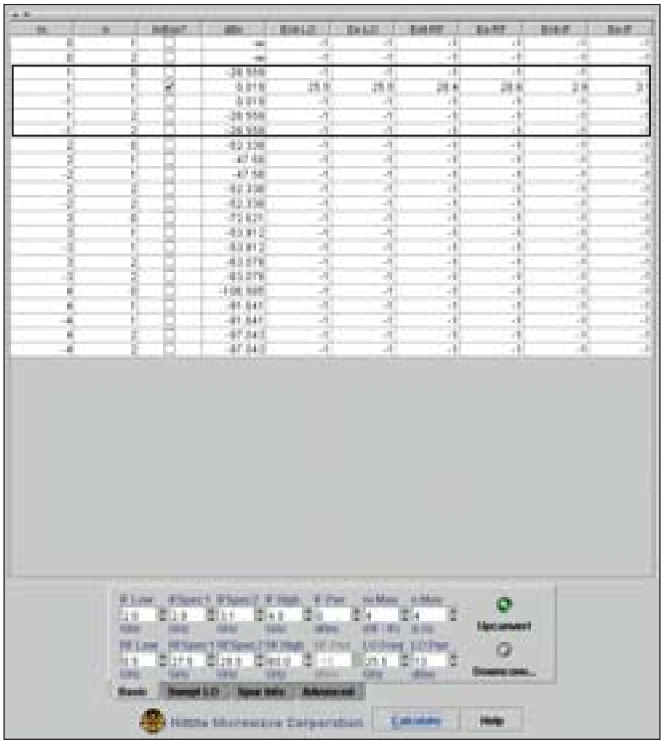

Figure 5 - Spurchart table output

While Hittite's mixer spur calculator presents the spurious data in a convenient chart format, it is often desirable to see the same information in a traditional spectrum analyzer view. To achieve this, =SPECTRASYS= is used to compare the double-balanced mixer with the subharmonic mixer. To make this comparison, a behavioral model of the HMC264LM3 and the HMC292LM3C was created using =SPECTRASYS=. There are several types of mixer models available in =SPECTRASYS= including a model that allows for a table containing the spurious levels to be entered directly. As a result, the model will generate spurious levels that are based on measured mixer performance. Figure 6 shows the dialogue box used to input parameters for the subharmonic mixer into =SPECTRASYS=.

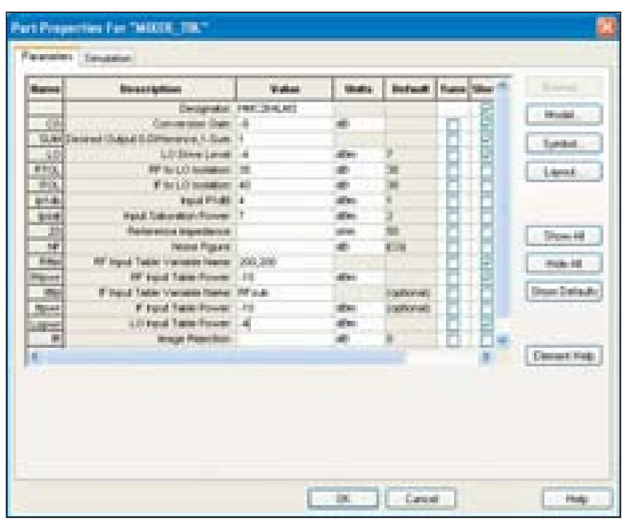

Figure 6 - =SPECTRASYS= mixer parameters

The values entered in the parameter box were obtained directly from the data sheet for the HMC264LM3. Since the mixer was used as an upconverter the "sum" option is selected. The spurious table was created in the =SPECTRASYS=

equation block and given the variable name “RFsub”. The spurious table can be referenced in two fields in the parameter box. One field is for the RF port and the other is for the IF port. Since the mixer was simulated as an upconverter, the IF port was selected and the table is referenced to this port.

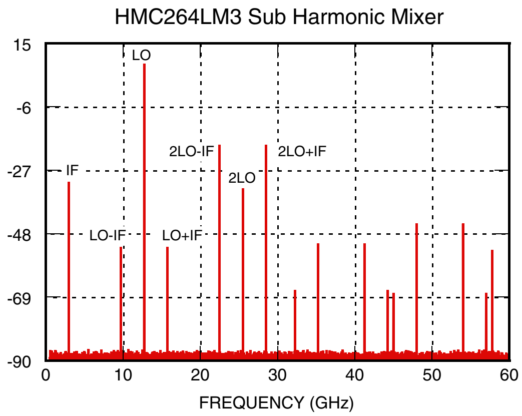

Figure 7 (a) - HMC264LM3 spurious response

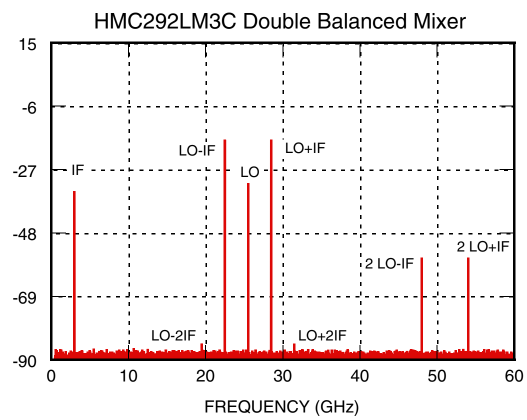

Figure 7 (b) - HMC292LM3C spurious response

Figure 7(a) shows the spurious response of the subharmonic mixer. The input frequency is 3 GHz at 0 dBm and the LO frequency is 12.75 GHz at -4 dBm. The spurious response of the double-balanced mixer is shown in figure 7(b). The input frequency is the same as the subharmonic mixer but the LO is now at 25.5 GHz with an input power of +13 dBm. The double-balanced mixer generates fewer spurs as expected since the architecture of the mixer naturally suppresses more harmonics than the subharmonic mixer.

Hittites’ Spurchart Calculator tool and the =SPECTRASYS= analysis of the behavioral mixer model provide a quick and convenient estimate of the spurious performance of the mixer alone. In order to see the complete system interaction of the mixer with the other transmit and receive components, a complete system simulation using =SPECTRASYS= was performed.

Complete system performance

The system simulation of a transmit chain was performed using =SPECTRSYS= using the HMC264LM3 (subharmonic mixer) as the final upconverter. The simulation was then repeated with the HMC292LM3C (double-balanced mixer) as the final upconverter. Figure 8(a) and 8(b) shows both transmit chains for the subharmonic mixer and double-balanced mixer respectively. The transmit chain consists of a low-pass filter, a double-balanced mixer (HMC316), IF band pass filter, IF amplifier, output mixer (HMC292LM3C or HMC264LM3), RF band pass filter and amplifier.

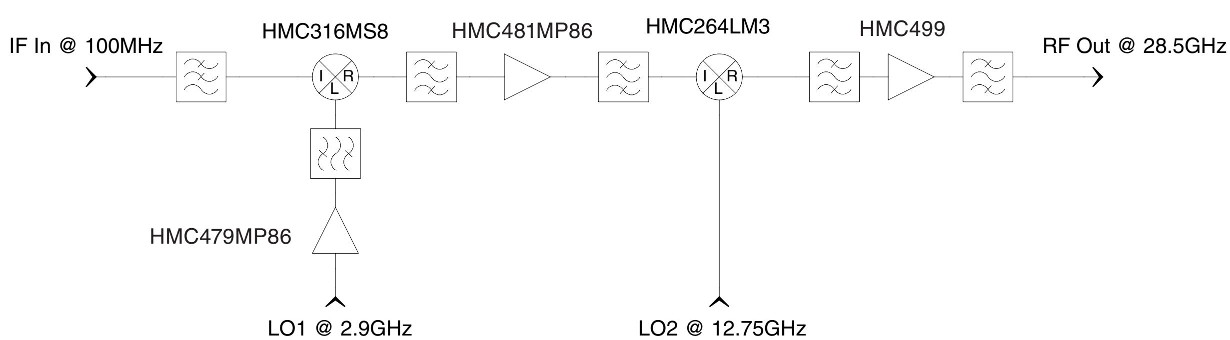

Figure 8a - Transmit chain using HMC264LM3 subharmonic mixer

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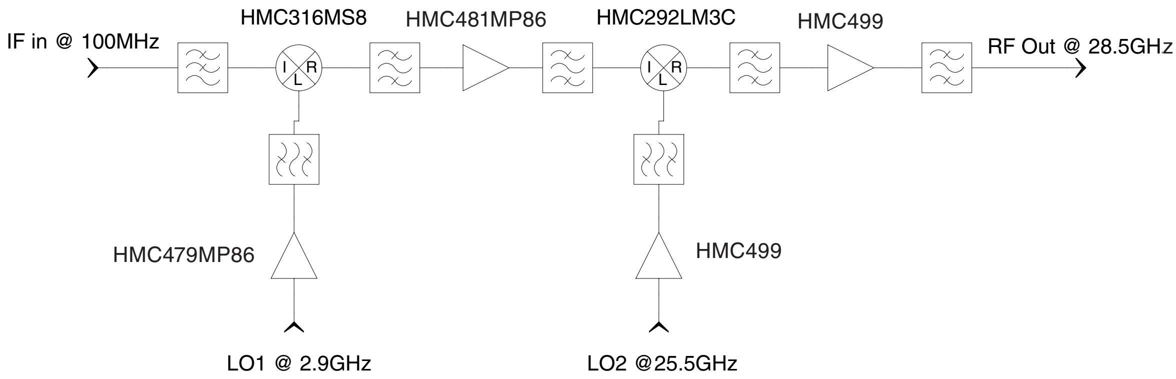

Figure 8b - Transmit chain using HMC292LM3C double-balanced mixer

The HMC292LM3C double-balanced mixer in figure 8(b) required an additional filter and amplifier in the LO path to account for the higher required LO power for the mixer and higher second harmonic output of the LO amplifier. Since LO amplifiers used to drive the double-balanced mixers are normally driven into saturation to maintain constant output power over temperature, their second harmonic output tends to be relatively high. This, in turn, results in increased levels of inter-modulation products at the RF output of the final mixer which will require a higher order filter to suppress. Figure 9 shows the output spectrum of both chains.

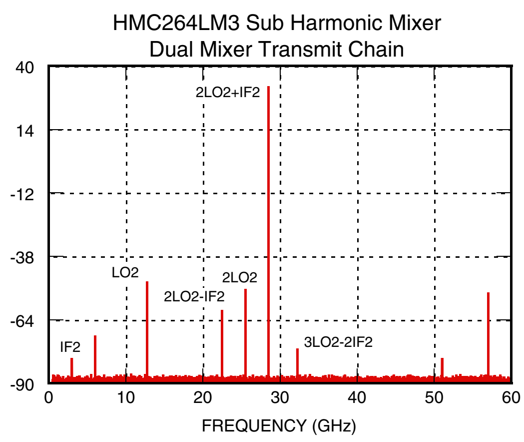

Figure 9 (a) - Transmit chain with subharmonic mixer

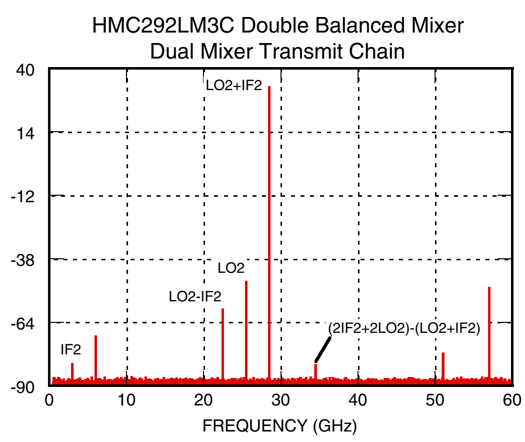

Figure 9 (b) - Transmit chain with double-balanced mixer

Both transmit chains have similar output spectrums near the desired transmit frequency. The subharmonic mixer has a slightly lower 2*LO2 leakage when compared to the LO2 level of the double-balanced mixer. To the right of the desired RF output signal, both transmit configurations have a small spurious products at different frequencies. The frequencies of these products are different since the topologies of the mixers are different.

The subharmonic mixer has a spurious product at 3LO2-2IF2, while the double-balanced mixer has a spurious product at (2IF2+2LO2)-(LO2+IF2). The (2IF2+2LO2)-(LO2+IF2) spur from the double-balanced mixer is dependent on the 2nd harmonic of LO2. Because the LO amplifiers are normally operated in saturation the 2nd harmonic of LO2 must be suppressed by a filter to minimize its contribution at the RF output. The filter requirements will depend on the amplifier used and the frequency plan. The subharmonic mixer, on the other hand, normally will not require an LO filter since the 3rd harmonic of LO2, which contributes to the RF output, will be significantly lower. Therefore, the transmit chain utilizing the subharmonic mixer produces essentially the same RF output with a simpler LO2 path and at half the LO frequency which greatly reduces the cost and complexity of the system.

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Conclusion

The increasing demands in the microwave and VSAT radio market have forced the frequency band of operation higher and the modulation schemes to become more complex. The challenge has become to design a millimeter-wave radio that can provide the required performance at a lower cost than its predecessors. This has forced manufacturers to replace the traditional and more costly hybrid mixer technology, with MMIC-based solutions.

This product note has compared the performance of a double-balanced mixer and a subharmonic mixer. Although the subharmonic mixer has a greater number of spurious products, they can be easily filtered if the proper frequency plan is chosen. The key advantage of the subharmonic mixer is that it uses ½ the LO frequency which simplifies the source and filtering requirements of the LO chain. This advantage directly translates to lower costs while maintaining the electrical performance of the system. Hittite Microwave Corporation offers a variety of millimeter-wave subharmonic and fundamental mixers, shown in table 1, that meet the design requirements of today's millimeter-wave radios.

Hittite Part Number	Type	RF Frequency (GHz)	IF Frequency (GHz)	Package Type
HMC258LM3	Subharmonic	14 - 20	DC - 3	LM3
HMC258	Subharmonic	14 - 21	DC - 3	DIE
HMC337	Subharmonic	17 - 25	DC - 3	DIE
HMC264	Subharmonic	20 - 30	DC - 6	DIE
HMC264LM3	Subharmonic	21 - 30	DC - 4	LM3
HMC265LM3	Subharmonic	20 - 31	0.7 - 3	LM3
HMC265	Subharmonic	20 - 32	0.7 - 3	DIE
HMC338	Subharmonic	26 - 33	DC - 2.5	DIE
HMC266	Subharmonic	20 - 40	1 - 3	DIE
HMC330	Subharmonic	25 - 40	2 - 4	DIE
HMC339	Subharmonic	33 - 42	DC - 3	DIE
HMC404	Subharmonic	26 - 33	DC - 3	DIE
HMC292	Fundamental	20 - 30	DC - 8	DIE
HMC292LM3C	Fundamental	17 - 31	DC - 6	LM3C
HMC329	Fundamental	26 - 40	DC - 8	DIE
HMC329LM3C	Fundamental	26 - 40	DC - 8	LM3C
HMC294	Fundamental	25 - 40	DC - 2	DIE
HMC260	Fundamental	14 - 26	DC - 8	DIE

Table 1 - Hittite's fundamental and subharmonic mixer product line

(Endnotes)

[1] =SPECTRASY= , System simulation software, Eagleware Corporation, Norcross, GA 30071

[2] B.C. Henderson, "Reliably Predict Mixer IM Suppression", Microwaves and RF, Vol.22, No. 12 November 1983.

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Notes:

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