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Design of Active Mixer for Satellite Command Receiver

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***Abstract-* In this paper design and development of active mixer is discussed. The mixer is designed using Silicon Germanium based HBT at UHF band, it is designed and developed over the RF band of 500-600 MHz, LO band of 340-440 MHz and for an IF of 160MHz. This mixer is used to provide second down conversion in Ku band command Receiver. The mixer provides a gain of 3 dB .The basic design approach is put forward in the paper. A Non-linear based simulation has been carried out to design the mixer and the realized mixer measured results are tabulated with the spectrum plots .The performance of the mixer is characterized over temperature variation. The mixer shows a wideband performance with no oscillations, very low harmonics over the frequency range and temperature variation.**

***Index terms:* Active mixer, Down-conversion, Harmonic Balance, Impedance matching, LO (Local Oscillator) drive, Conversion gain**

I. Introduction

Since the invention of super heterodyne receiver, mixers have been an essential part of radio communication. Mixers are used to translate a signal spectrum from one frequency to another. As the frequency translation forms an integral part of communication system, the mixers find its application where these translations are involved. A mixer basically is an analogue device that can multiply two signals together and provide the difference of two signals. A fundamental property of mixer is frequency conversion, this property is put to use in virtually all receivers. For a typical operation of mixer, an information bearing radio Frequency (RF) signal operating at a frequency is injected into one port of mixer, and a local oscillator (LO) signal at a frequency is injected into second port. The resultant output Intermediate frequency (IF) signal is down converted to a difference or sum of RF and LO frequency.

The ideal mixer, represented by Figure 1, is a device which multiplies two input signals. If the inputs are sinusoids, the ideal mixer output is the sum and difference frequencies.

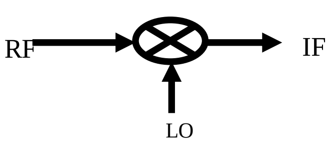

Figure1. Ideal Mixer

Given for an RF as $V_{RF} = A_{RF}\cos(\omega_{RF}t)$ and LO as $V_{LO} = A_{LO}\cos(\omega_{LO}t)$, the IF output is as

$$V_{IF} = [A_{RF}\cos(\omega_{RF}t)].[A_{LO}\cos(\omega_{LO}t)] = \frac{A_{RF} . A_{LO}}{2}[\cos(\omega_{RF} + \omega_{LO})t + \cos(\omega_{RF} - \omega_{LO})t]$$

Typically, either the sum, or the difference, frequency is removed with a filter.

The fundamental reason for frequency conversion is to allow amplification of the received signal at a frequency other than the RF, or at UHF frequency. Typically a Ku command receiver usually requires as much as 100-110 dB of gain, but practically it might not be possible to put more than 10-15 dB of gain into the RF section without risking instability and potential oscillations. Likewise the gain of the UHF section might be limited to 60 dB because of parasitic feedback paths. The additional gain needed for a sensitive receiver is normally achieved in an intermediate frequency (IF) section of the receiver.

Mixers are broadly categorized as Active and Passive. The Passive mixers primarily use either Schottky-barrier diodes or the FET resistive mixer. The FET based resistive mixers use the resistive channel of MESFET to provide low-distortion mixing, with approximately the same conversion loss as a diode mixer. The Active mixers are based on either FET or bipolar devices. FET s (either MESFET or HEMT) are used for most microwave and RF applications where active mixers are employed. BJT and occasionally HBTs are used most frequently as Gilbert multipliers for modulation, phase detection, and mixing process.

To mention a few comparisons between Active mixers and Passive mixers, the Passive mixers provide no power gain; instead they have conversion loss. Active mixers provide power gain using active devices. The advantage of active mixers is that its gain reduces the contribution of the noise of the subsequent blocks. The advantage of passive mixers over active mixers is the superior linearity and speed. Passive mixers design involves high LO drive, and high conversion loss. Active mixers can supply conversion gain instead of loss, they require far less LO drive power, less sensitive to port terminations, have better LO-to –IF isolation, and produce less mixer spurs. Thus to meet the Ku band receiver requirements of down conversion with added the advantages over passive one, a single ended active mixer was designed, developed and realised.

II. Design

A. Design Approach

The design of mixer is carried out using HBT based SiGe based device. The mixer operates for an input frequency of 556 MHz, LO frequency of 396 MHz and IF of 160MHz. The basic requirement of using an active mixer is to avoid implementing of an additional amplifier in down conversion stage .The low LO drive of the order of -2 dBm performs the mixer operation over the operating temperature range .The simulation has been carried out with the non linear model the device .The transistor is biased for class AB operation for minimum and stable gain over the variation of LO drive level. The design was carried out using ADS tool Harmonic balance feature, by biasing the device in non-linear region, the I-V curve was plotted and bias point was selected for mixer to operate on. The transistor chosen for the design is BFY405 which comes in Micro X package. The maximum I_C sustainable by the transistor is 12mA, with transition frequency f_T=20GHz.Since this is a large signal nonlinear circuit, substantial harmonics will be generated; therefore the chosen simulation method is the Harmonic Balance Method.

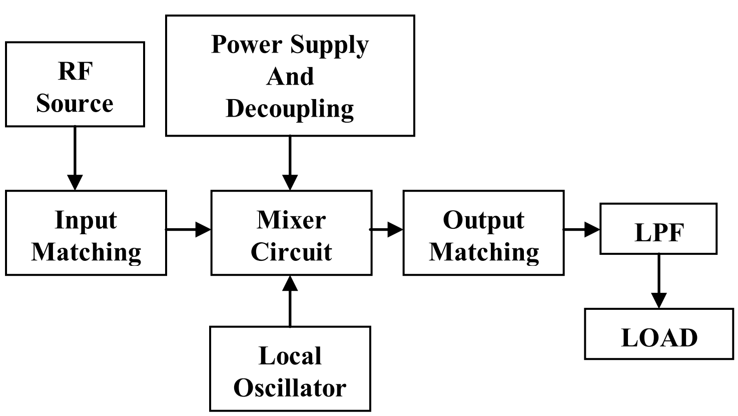

Figure 2.Active mixer block diagram

The transistor is biased in common-emitter configuration. The block diagram of the mixer is shown in Figure 2.

B. Simulation

The basic circuit harmonic simulation schematic of the single ended mixer is shown in Figure 3.

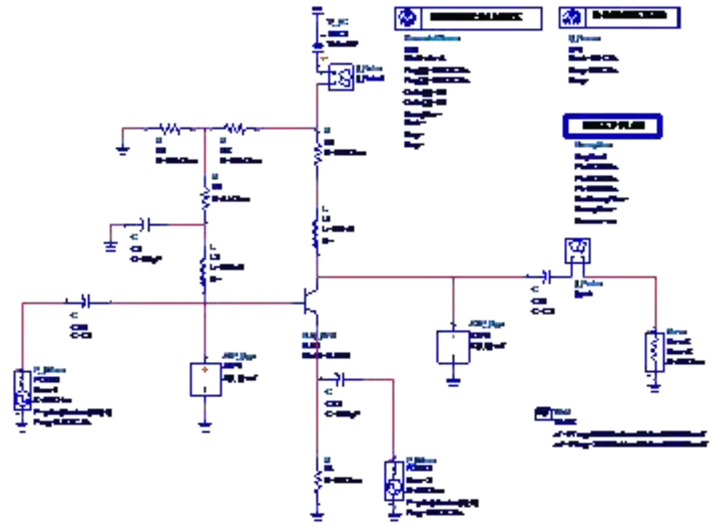

Figure.3. Simulation schematic for the mixer

The LO signal is pumped into the emitter of transistor while RF signal is imposed on the base. This configuration improves isolation between the LO, IF and RF signals. Each signal is connected to different pin of the transistor. As the LO signal is quite large, feeding the BE junction with RF Source at the input serves to attenuate the LO power. To further improve isolation, the IF and RF port lumped components are implemented so that at the IF port, RF signal should be shunted, only allowing low frequency signal (IF) to pass and at RF port, IF signal should be shunted, only allowing high frequency signal (RF) to pass. These characteristics are simulated and then implemented be inserting artificial elements at both ports. During simulation in ADS, this is implemented using the equation based linear elements .Once the performance of the mixer is verified with this equation based elements, these are replaced with Lumped elements at RF and IF port. In order to illustrate the effect of having proper impedance matching circuits at both RF and IF ports, Harmonic balance analysis of the mixer circuit is carried out. The final schematic is shown in Figure 4. In carrying out the impedance matching procedure, we are assuming the transistor to be operating in a quasi-linear mode. It is nonlinear so as to produce the mixing effect, yet the linearity is small enough so that the usual linear procedure and concept of impedance are applied. This is followed by a sharp cut off low pass filter designed with lumped components having a cut off frequency of 200MHz performing high rejection of harmonics.
The schematic of the designed down conversion stage is as mentioned in the Figure 4 below. This mixer is used in the 2nd down conversion stage of the receiver. It is implemented with cascadable amplifiers before and after down conversion. The layout is judiciously made to avoid

any undesired couplings and oscillations as these stages are providing high gain in minimum size.

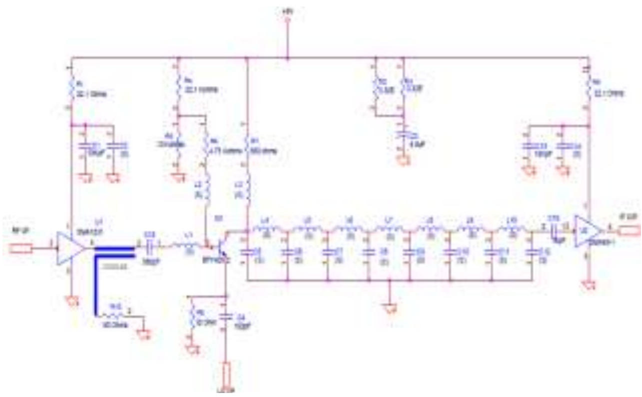

Figure 4.Down conversion Stage Schematic incorporating active mixer

Figure 5.Compact Layout for the down convertor

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III. Measured Results

A. Operating conditions

The down conversion stage incorporating the mixer has been implemented on High Tg FR4 substrate. The mixer has been designed for a gain of 3dB with the bias point as 0.7V and 2mA. The performance of the mixer has been characterized over the UHF band, optimum LO drive and temperature. The mixer designed to operate over temperature of -30degrees to +60degrees as it is to be used for satellite applications. The measured results are as mentioned in Table.1 for an LO drive of -2.0 dBm.

RF Freq (MHz)	LO Freq (MHz)	IF Freq (MHz)	Gain (dB)	LO- RF Iso(dB)	LO- IF Iso (dB)
500	340	160	3.1	15	20
540	380	160	3.0	15	20
556	396	160	3.0	15	20
600	440	160	2.9	15	20

Table 1: Mixer performance over UHF band

The table shows the mixer operation for and RF band of 500 to 600 MHz for an LO of 340 to 440 MHz to generate an IF frequency of 160MHz.As seen form the table, the gain variation is 0.2 dB over the frequency band.

C. Mixer Characterization

For detailed characterization of mixer, the LO drive is varied with RF of 556 MHz and LO as 396 MHz to find out the optimum LO drive level to be fed to the mixer. The plot below shows that the mixer gain saturates after LO drive of -2dBm.The mixer is made to operate in the saturated gain levels so that the mixer output is immune to LO power variations over temperature.

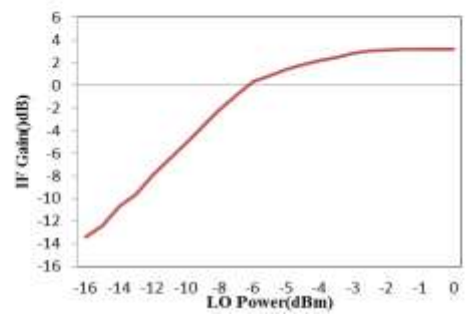

Figure 6.Gain compression plot of Mixer gain v/s LO drive level displaying the saturated gain output

The performance of mixer with the LPF and associated gain stages for down conversion was verified at various stages of testing and associated spectrum plots as each test phase. The DC performance was verified in which the spectrum had no oscillations in the entire band as in Figure.7.The hump seen is till 200 Mhz ,is because of the of the cut off frequency of LPF .The Figure.8 shows the plot with the optimum LO drive,as seen the fundamental LO and its second harmonics are seen which are at -50 dBm and -80 dBm respectively with no inband oscillations.As seen in Figure 9 and 10 spectrums , the desired If component of 160Mhz is seen with all the harmonics -30 dBc and below.

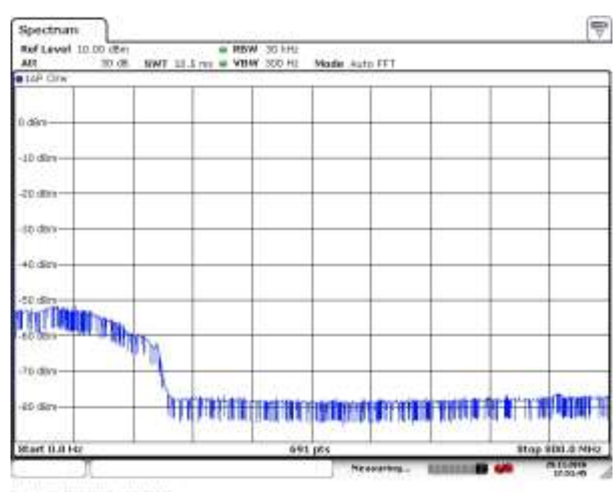

Figure 7.Spectrum plot with DC ON and no RF, LO

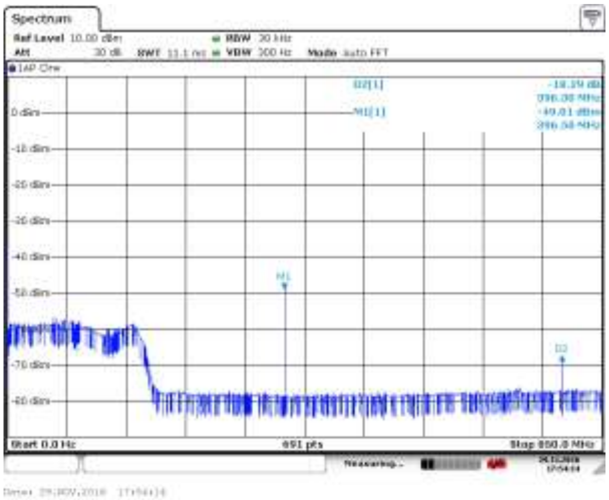

Figure 8.Output spectrum with optimum LO drive

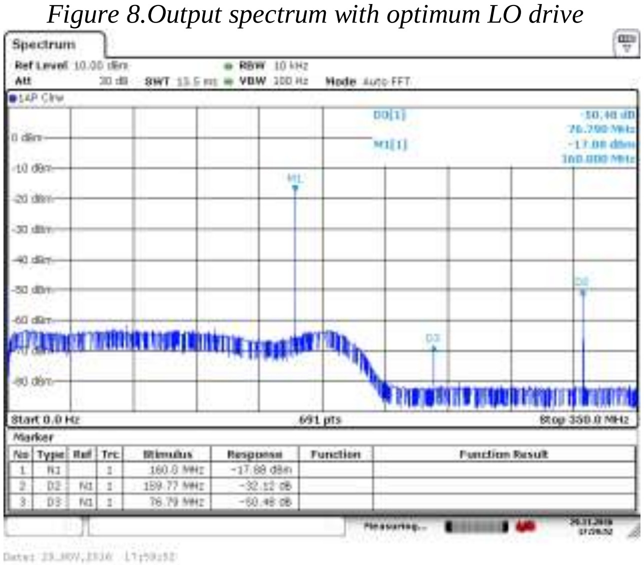

Figure 9.Downconverter output spectrum

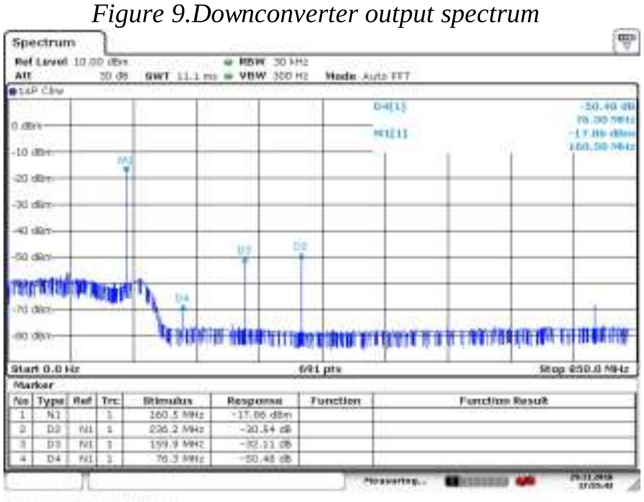

Figure 10.Wideband output spectrum with desired down converted component and undesired harmonics rejection

The spectrum plots are with no oscillations under operating conditions making it a suitable down converter candidate with a stable gain.

LO Level Variation	Gain		
	-30 degrees	+25 degrees	+60 degrees
-3.0	3.3	3.0	2.8
-2.0	3.2	3.1	2.9
-1.0	3.2	3.1	2.9

Table 1: Mixer gain over temperature variation

The mixer was subjected to temperature variation with 3 hours soak at extreme temperatures .The gain of the Mixer gain is stable and within 0.3 dB gain variation with a ± 1 dBm LO drive level variation over the temperature range. There is no oscillations build up during the temperature transition and during the temperature soak. The mixer operates with low LO drive which makes the LO generation stage to have minimum saturated stages and thus fewer harmonics.

IV. Conclusion

An single ended active mixer with low LO drive has been designed and implemented which provides required gain in down conversion stage to knock off a cascadable amplifier in receiver architecture. The designed mixer is biased at quasi linear mode of operation to provide gain stability over temperature and LO drive variations. The mixer is designed using ADS and covers broad UHF band .The same design concepts can be used for RF frequency band with appropriate device selection. This paper establishes the design for down conversion stage of Ku band command receiver with the desired gain and isolations.

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