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Design of Downconverter for 870 MHz to 2.0 GHz Using MMIC

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Abstract: The performance of signal processing circuits at very high frequencies is very poor. At such higher frequencies that is in the order of GHz range active components like transistors cannot deliver much gain. Therefore, the signal is shifted to lower frequency band. Another problem is that higher frequency signal needs waveguides and strip lines. If we use intermediate frequency, signal can be easily carried through ordinary coaxial cable. The lower frequency transistors generally have higher gains so fewer stages are required. It's easier to make sharply selective filters at lower fixed frequencies. RF upconverters and RF downconverters are integrated assemblies that convert microwave signals to another frequency range for further processing. Generally, they are designed to produce an output signal frequency for a particular frequency band. RF upconverters are designed to convert microwave signals to a higher frequency range. By contrast, RF downconverters are designed to convert microwave signals to lower frequency range. In this paper we present a downconverter for frequency range of 870 MHz - 2000 MHz. This downconverter will convert 870 MHz to 2GHz frequency to 45 MHz to 870MHz using MMIC.

Keywords: upconverter, downconverter, intermediate frequency, mixer etc.

I. INTRODUCTION

The performance of signal processing circuits at very high frequencies is very poor. At such higher frequencies that is in the order of GHz range active components like transistors cannot deliver much gain. Therefore the signal is shifted to lower frequency band. Another problem is that higher frequency signal needs waveguides and strip lines. If we use intermediate frequency, signal can be easily carried through ordinary coaxial cable. The lower frequency transistors generally have higher gains so fewer stages are required. It's easier to make sharply selective filters at lower fixed frequencies. RF upconverters and RF downconverters are integrated assemblies that convert microwave signals to another frequency range for further processing. Generally, they are designed to produce an output signal frequency for a particular frequency band. RF upconverters are designed to convert microwave signals to a higher frequency range. By contrast, RF downconverters are designed to convert microwave signals to lower frequency range [1, 2].

The up-conversion mixer is one of the important blocks used to convert an input intermediate frequency (IF) signal to an output RF signal. The signal is then transmitted to transmission line. Similarly, down conversion mixer is used to convert incoming RF signal to a required IF signal. Then the signal is carried towards the RF receiver mostly a heterodyne receiver [2]. A worldwide network called Compound Astronomical Low-cost Low frequency Instrument for Spectroscopy and Transportable Observatory (e-CALLISTO) is observing solar activity. The CALLISTO spectrometer is a heterodyne receiver. It uses commercially available TV tuner whose frequency range is 45 MHz to 870 MHz. For observing frequencies above 870MHz, a downconverter has to be used. For CALLISTO receiver, Up converter is used to convert frequency band below to 45 MHz to acceptable frequency band (45 MHz to 870MHz) and downconverter is used to convert frequency band above 870MHz to acceptable frequency band (45 MHz to 870 MHz).

RF upconverters and RF downconverters differ in terms of technology and form factor. There are two choices for technology: synthesized and crystal controlled. Synthesized devices use a use a synthesizer circuit (normally a PLL) to produce the desired frequency. Crystal-controlled devices use a crystal oscillator to produce the desired frequency. Generally, these products are more accurate than synthesized converters. In terms of form factor, RF upconverters and RF downconverters are available as integrated circuit (IC) chips and printed circuit boards (PCBs). Some devices are rack-mounted while others are designed to sit at top of table or desk [3].

RF upconverter and downconverter consist of different building blocks such as LNA, RF mixer, Local Oscillator, Low pass filter and Amplifier. Difference between RF upconverter and RF downconverter is that, When the desired output frequency is lower than the second input frequency, the process is called down-conversion, other when the desired output frequency is higher than the second input frequency, the process is called up-conversion [4].

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Block Diagram of Downconverter:

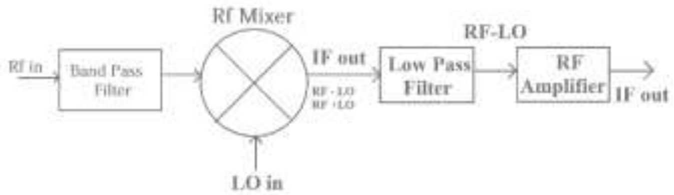

Fig.1. RF Downconverter for CALLISTO Heterodyne Receiver

RF Mixer:
A mixer is an RF (or IF) mixer and may be an active or passive device and can be classified as balanced or unbalanced type which converts a signal from one frequency to another. The input signal can be either modulate or demodulated. The mixer has three signal ports; the radio frequency (RF) input, the local oscillator (LO) input, and the intermediate frequency (IF) output.
A mixer takes an RF input signal, mixes it with a LO signal at a frequency of LO, and produces an IF output signal which consists of the sum and difference frequencies, RF ± LO. It is found that if two signals go through a non-linear circuit, then the signal with new frequency is formed which appears at frequencies equal to the sum and difference of frequencies that of the original signals, i.e. signals of frequency f1 and f2 enters in the mixer, then additional signals at frequencies of (f1+f2) and (f1-f2) will be generated at the output [5].
Local Oscillator: This generates the local oscillator signal and it is at the specified level, higher than that of the RF input. LO input level is key parameter to be considered in downconverter or upconverter. LO is chosen such that mixer will produces output in desired band of frequencies.
Low Pass Filter: Next stage followed by mixer is Low Pass Filter (LPF). This stage selects the desired band of frequencies. Depending on LPF, final output will be selecting the sum (RF + LO) or difference (RF – LO) frequency.
When the sum of frequency (RF+LO) is used as the IF, the mixer is called an upconverter whereas if the difference (RF – LO) is used, the mixer is called a downconverter. Selection of local oscillator depends on selection of intermediate frequency.
RF Amplifier: Low noise RF amplifier (LNA) is used to amplify IF signal.

II. DESIGN OF DOWNCONVERTER

RF Mixer:
In our design we are going to design downconverter using MMIC ADE-25MH Double Balanced Mixer by minicircuit.
Schematic:

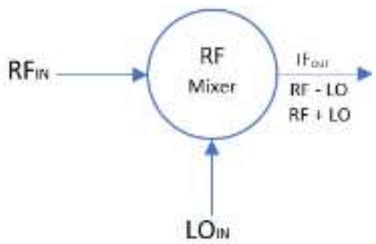

Fig.2. Mixer symbol

This RF Mixer is surface mount type that operates on maximum 13dBm power from local oscillator. While selecting the mixer parameters such as conversion loss, (Conversion loss of a mixer is equal to the ratio of the RF input power to the IF single-sideband output power, expressed in +dB), Conversion Compression (measure of the maximum RF input signal for which the mixer will provide linear operation in terms of constant conversion loss), Isolation (Isolation is a measure of the circuit balance within the mixer. When the isolation is high, the amount of “leakage” or “feed through” between the mixer ports will be very small.) Dynamic Range, DC Polarity, DC Offset etc. [6]. Rf signal carrying track on PCB can be wave guide or coplanar wave guide. Both requires to calculate the width of waveguide and gap between them with Z0=50-ohm. In our case calculated width of waveguide for 50-ohm Z0 is 1.5mm and gap is 1.13mm for FR4 PCB material.

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Calculation of microwave strip:
As signal will be carried through copper track on pcb, track will act as microstrip wave guide [7]. We need to calculate the width and spacing of track. This can be done using different calculators.

Table 1 FR-4 MATERIAL PROPERTIES

Sr. No	Property	Value
1.	Dielectric Constant (ε_r)	3.9 – 4.7 @ 1 GHz (we take 4.6)
2.	Thickness (H) of PCB	1.6mm typical
3.	Copper thickness (T)	0.035 mm typical
4.	Loss Tangent (tanD)	0.02 typical

Table 2: Calculations based on FR-4 Material Properties

Sr. No.	Properties	Value
1.	Gap between track and ground plane	0.5mm
2.	Track Width	1.89mm
3.	Characteristic impedance	50 Ohm
4.	Operating Frequency	2GHz max

Designed PCB of RF mixer:
PCB is designed in Altium designer.

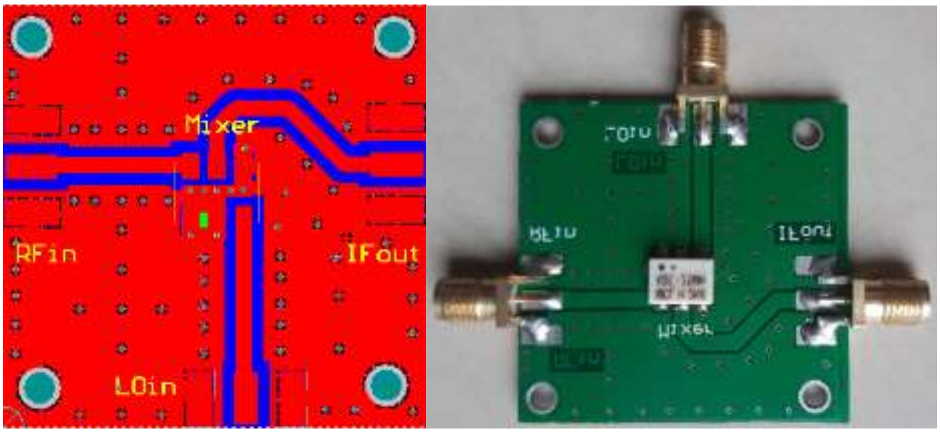

Fig.3: PCB Layout and Assemble PCB of RF Mixer.

The output of Mixer is Rf ± LO depending on our interest we can use HP filter or LP filter. To use as a down converter low pass filter is used.

Low Pass Filter:
As our intention is to get frequency in the range of 45MHz to 870Mhz we use low pass filter of cutoff frequency 1200Mhz max. figure 5 and 6 shows design of lowpass filter according with datasheet [11].

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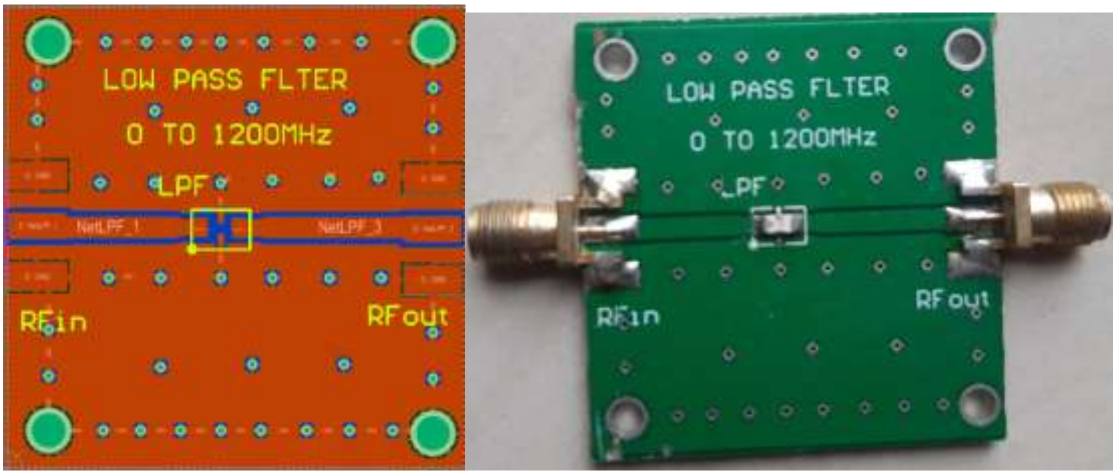

Fig.4: PCB Layout and Assemble PCB of RF Low Pass Filter.

Low noise amplifier:
We will use CMA-5043+ LNA because of its Low noise figure (typical 0.7dB) ang high gain up to 25dB.
Some features of MMIC CMA-5043+ [10]
- Ultra Low Noise Figure, 0.75 dB typ. at 1 GHz
- Gain, 18.4 dB typ. at 1GHz
- High Pout, P1dB up to 21 dBm typ.
- High IP3, up to 33.5 dBm typ. at 1 GHz
- Class 1B HBM ESD rating (500V)
- Small size - 3mm x 3mm x 1.14mm
- No external matching components required

Block diagram:

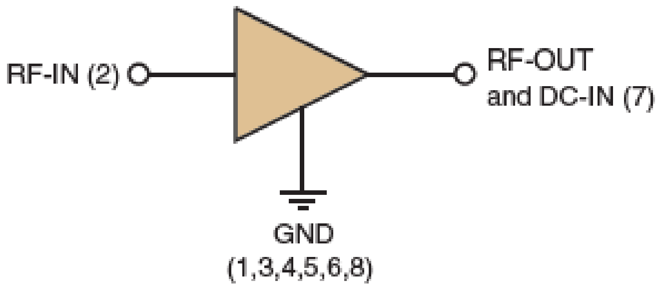

Fig.5. Block diagram of LNA

Schematic diagram:

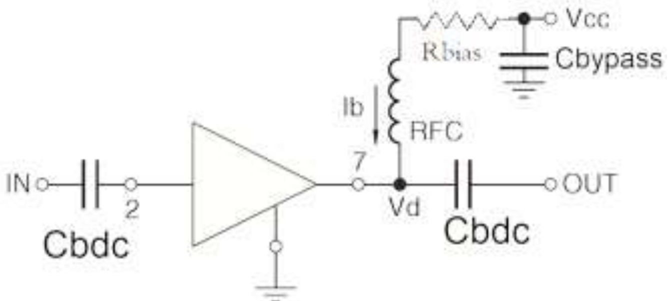

Fig.6. Schematic diagram of LNA with necessary components

Design of LNA:
Bias current calculation: Bias current is delivered from a voltage supply Vcc through the resistor R bias and the RF choke (inductor) as shown in schematic figure 8. The resistor reduces the effect of device voltage (V_d) variation on the bias current by approximating a current source. The advantage of use of inductor reduces loss in gain.

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An RF choke should be chosen such that its reactance is at least 500 ohms (10 times the load impedance) at the lowest operating frequency. It must also be free of parasitic (series) resonance up to the highest operating frequency.
Bias current is given by the equation:

$I_{bias} = (V_{cc} - V_d) \div R_{bias}$ 1)

According to datasheet of CMA-5043+ Vd is 3v and I_{bias} 33mA for Vd=3v [10]. If we use 12v power supply we get,

$R_{bias} = 272\ \Omega$ 2)

Design is intended for transmission line impedance Z_0 of 50 ohm. Capacitor (XC) chosen such that it is much less than Z0, and the impedance of the inductor (XL) is chosen to be much greater than Z_0:

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C} \ll Z_0 \qquad (1)$$
$$X_L = \omega L = 2\pi f L \gg Z_0 \qquad (2)$$

where ω is the angular frequency. Bias tees are designed to operate over a range of input signal frequencies. The reactance is chosen to have minimal impact at the lowest frequency [5].

As we are using same FR4 PCB we used same parameters shown in table 1 and table 2 for PCB design.

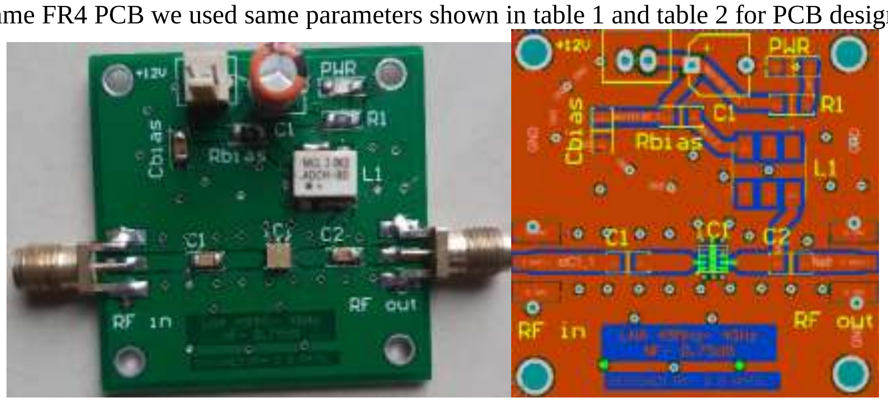

Fig.7: PCB Layout and Assemble PCB of RF Low Pass Filter.

Selection of local oscillator:
Local oscillator is selected based on required IF frequency band. We will observe the higher frequency of 870MHz to 2000GHz. And we require output frequency of mixer between the range of 45MHz to 870MHz.

Therefore, 870 MHz -45 MHz = 825MHz and 1695 MHz -870 MHz =825MHz.
This shows that we can use local oscillator that have frequency 825MHZ to get IF of 45MHz to 870MHz.
Similarly, to observe frequency between 1695MHz and 2000MHz, 1695MHz - 45MHz =1650MHz and 2000MHz-870 MHz = 1130MHz, but in this case we will stuck with 1650MHz as we are observing up to 2000MHz.
We will choose LO=825MHz so that we will have 45MHz to 870Mhz IF frequency for 870 MHz to 1695 MHz and another LO= 1650 MHz for frequency 1695MHz to 2000MHz.


Fig.8: Assemble PCB of VCO Control Board. **Fig.9: ADF4351 VCO**

Figure 8 shows assemble PCB of ADF4351 VCO Control board. And figure 9 shows VCO board. This boards communicate using SPI communication protocol to each other.

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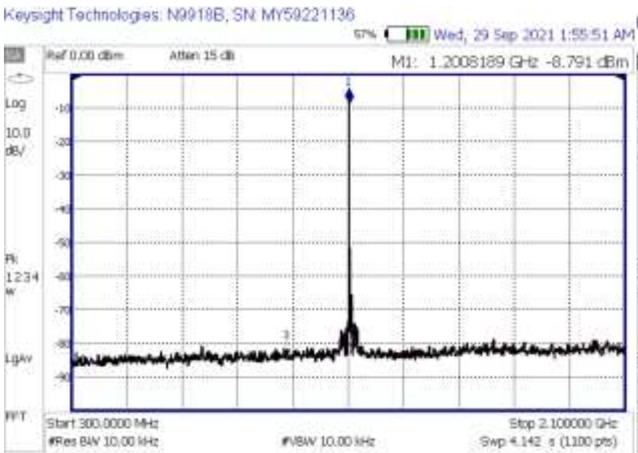
Following figure 10 shows complete designed Downconverter

Fig.10: Assemble VCO.

III.RESULTS

Design was simulated in Advanced Design System (ADS) software. The software is intended to design rf circuits and simulate them within the software. ADS offer integrated design guidance to help get started faster. Extensive component libraries make it easy to find the part we want. Automatic sync with layout allows to visualize the physical layout while making schematic designs. Signal and power integrity are more important as frequency and speed increase in printed circuit boards (PCB). Losses associated with transmission line effects can cause failures in electronic devices and loss in signal as well as introduces noise, ADS overcome high-speed digital design challenges [12]. The actual results obtained from spectrum analysers are presented in next figures 11 to 16.

Figures 11 shows rf input to downconverter. The inputs are attenuated by 15dB. Figures 12 shows LO input (output from VCO). Figure 13 shows downconverter output before fetching to LNA.



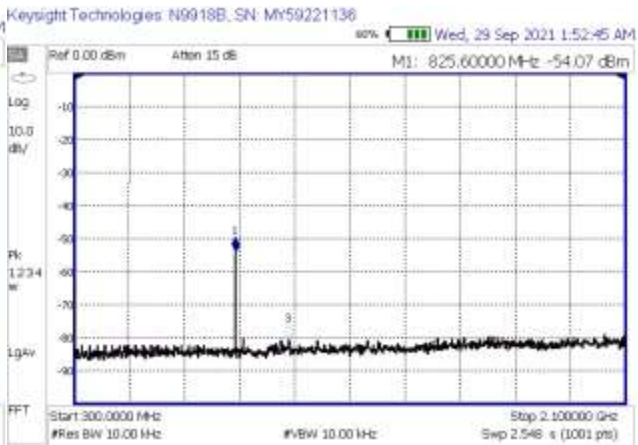


Fig.11. RF input signal to Mixer. **Fig.12. VCO input signal to Mixer.**

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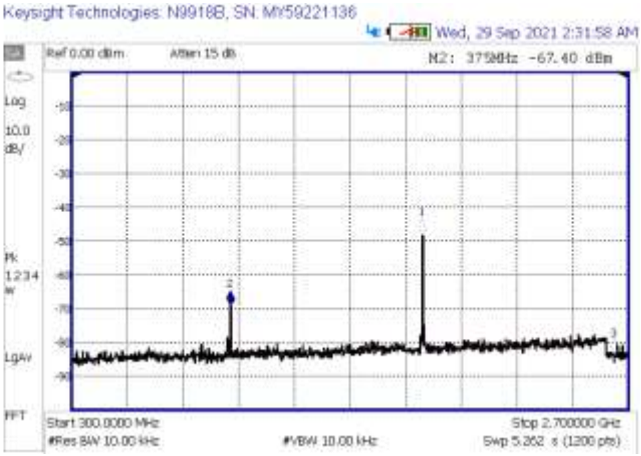

Fig.13. Final output of downconverter without LNA.

IV. CONCLUSION

We have designed RF downconverter for the frequency range of 870 MHz to 2000 MHz because we have limitation of frequency band i.e. we will use this down converter along with callisto receiver. The receiver uses tv tuner that operates between the frequency range 45MHz to 870MHz. frequency of local oscillator is chosen such that mixer will provide IF frequency output between the 45MHz to 870MHz.

In this design we used double balanced mixer which output is RF+LO and RF-LO. As we are going to down convert frequency to desired band, we use low pass filter so that we get RF-LO frequency i.e. lower sideband. The output is need to be amplified. Therefore, low noise amplifier is used to amplify the signal. Figure 13 shows unamplified signal of downconverter. We can clearly see in the figure that output upper side band is suppressed by rf low pass filter.

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