Novel Design of Passive Mixer for Communication System

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Abstract— **This paper presents design and analysis of microstrip mixer using low pass filter, power divider using open stubs, patch antenna and PIN diode. The simulation response of each element in mixer and measured response of fabricated mixer are presented. Maximally flat Low pass filter with cut-off frequency of 3GHz is used as element of mixer. Modified microstrip patch antenna composed of defected ground, slotted patch, feed point variation and some optimization. Simulation is done using IE3D, Serenade software for various parameters. FR4 substrate with dielectric constant of 4.4 and height 1.6 mm was considered for simulation. Isolation between RF input and output of final design is -29.28 dB and between RF input and LO input is -13.11 dB at frequency of 3 GHz and between LO and mixer output is -13.38 dB at 3 GHz. Simulation and measured results for different parameters are reported.**

Keywords-patch; ground; line-feed; probe-feed ;surface

I. INTRODUCTION

Mixers are three port active or passive devices, are designed to yield both a sum and a difference frequency at a single output port when two distinct input frequencies are inserted into the other two ports. This process, called frequency conversion (or heterodyning), is found in most communication's gear, and is used so that we may increase or decrease a signal's frequency. One of the two input frequencies will normally be a CW wave, produced within the radio by a local oscillator (LO), while the other input will be the RF signal received from the antenna [1].

If we would like to produce an output frequency within the mixer circuit that is lower than the input RF signal, then this is called *down conversion*; if we would like to produce an output signal that is at a higher frequency than the input signal, it is referred to as *up conversion*. Indeed, most AM, SSB, and digital transmitters require mixers to convert up to a higher frequency for transmission into space, while super heterodyne receivers require a mixer to convert a received signal to a much lower frequency. This lower received frequency available at the mixer's output port is called the *intermediate frequency* (IF). Receivers use this lower-frequency IF signal because it is much easier to efficiently amplify and filter with the IF stages tuned and optimized for a single, low band of frequencies, which increases the receiver's gain and selectivity [1].

Passive mixers permit a much higher amplitude RF input signal level than active mixers before severe distortion products within the output IF becomes unacceptable. These distortion products are in the form of *intermodulation distortion* (IMD), along with *compression distortion*. The IMDs may fall in band, or cause other signals to fall in band, possibly swamping out or creating interference to the baseband signal. This causes additional noise, which will degrade system performance and BER. Most passive mixers also possess a lower noise figure than active mixers, which is very important for any stage within the front end of a low-noise receiver. But instead of an insertion gain as many active mixers will enjoy, passive mixers will have an insertion loss of around 7 dB. The passive mixer conversion losses are caused by the mixing diode's internal resistance, port impedance mismatches, mixer product generation, and the inevitable 3 dB that is wasted in the undesired sum or difference frequency. (This sum or difference frequency is removed by filtering, cutting the mixer's final output power in half.)[1].

II. DESIGN

A. Steps for Passive Mixer

Figure 1 shows block diagram giving an overview of each element for fabricating RF mixer.

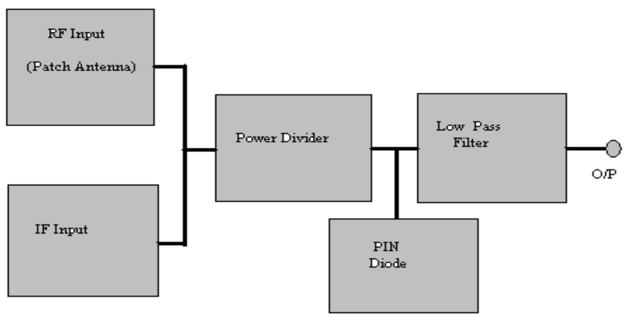

Figure 1. Block diagram of Mixer

978-0-7695-4941-5/13 $26.00 © 2013 IEEE
DOI 10.1109/ACCT.2013.51

For design purpose FR4 substrate with dielectric constant of 4.4 and height of 1.6 mm and frequency of 3 GHz was taken.

RF mixers are highly useful and effective for many low-cost high-frequency consumer wireless products. As with any practical design calculation at these frequencies, parasitic capacitance and inductance, as well as component and PCB pad/trace length and distributed reactance, will modify ideal circuit behavior, sometimes extremely, so accurately modeling and tuning the mixer will always be necessary.

B. *Passive RF Diode Mixer*

A huge limitation of unbalanced mixers in general is excessive LO radiation from the RF ports, limited only by any possible RF filtering. Another issue is the close-in RF feed through into the IF, with the stronger, but typically more distant, LO feed through being more easily filtered out from the IF. In fact, we could add further filtering to all mixer ports, but this would substantially add to cost and complexity, which is exactly what we are trying to avoid with the use of a single-ended mixer in the first place.

C. *Passive Mixer Terminology*

- *Conversion compression*—Specification that indicates the maximum value of the input RF signal level that will obtain a linear increase in IF output power.
- *Conversion loss*—The rated signal level difference between the input and the output of a mixer at the rated LO input power.
- *Cross modulation*—Describes the undesired transfer of the modulation between a modulated and a CW signal within the mixer stage.
- *High-side injection*—When the LO frequency is higher than the RF frequency in a mixer stage.
- *Intercept point*—Superior two-tone third-order product suppression demands a high mixer intercept point. This value is approximately 10 dB higher at the mixer's input than the *conversion compression* rating discussed above. The *cross modulation* distortion and desensitization are also reduced with a high intercept point.
- *Interport isolation*—Rating of the feed through between the mixer's LO, RF, and IF ports. This is the value, in dB, that one port's signal is attenuated at another port's input or output. The most important of these isolation specifications is the LO attenuation at the IF and RF ports, since LO feed through is a major problem in receiver and transmitter system's design, and the RF to LO isolation is normally of little concern due to the RF's low input levels. Typical mixer LO to IF isolation will range from 0 to 50 dB, depending on topology and port filtering.
- *Low-side injection*—When the LO frequency is lower than the incoming RF frequency in a mixer stage.
- *Noise figure* (NF)—The noise added by the mixer itself, and equals the difference between the noise at the input of the mixer and the output of the mixer, in dB. When the mixer is driven with the proper LO drive level, the NF will equal the conversion loss.

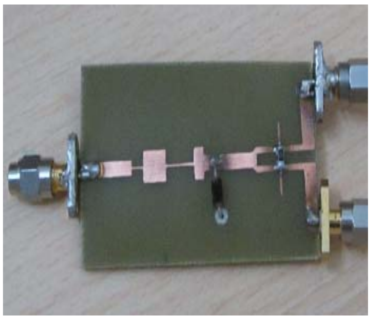

Figure 2. Photograph of top view of fabricated RF mixer

Top view of fabricated mixer is shown in figure 2. Here power divider with stub is used as it reduces the size .

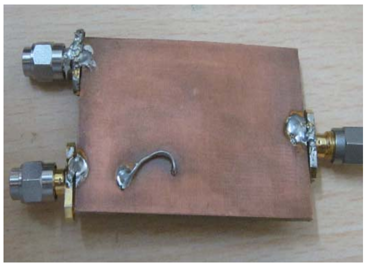

Figure 3. Photograph of bottom view of fabricated RF mixer

Figure 2 and 3 shows the photographs of fabricated mixer using microstrip line. One end of the diode is grounded using connecting wire to ground plane. Total area of the mixer is 24 cm^2.

D. *Simulation for mixer*

Simulation for the proposed mixer was done using Serenade software. Different S (scattering) parameters such as S_{11}, S_{12}, S_{13} and S_{23} are shown in tabular form for frequency range from 1GHz to 7 GHz. Here port 1 is connected to low pass filter and LPF is further connected to power divider using stubs. Diode is connected between LPF and power divider for the function of mixer. Screen shot of the simulation of mixer is shown in figure 4.

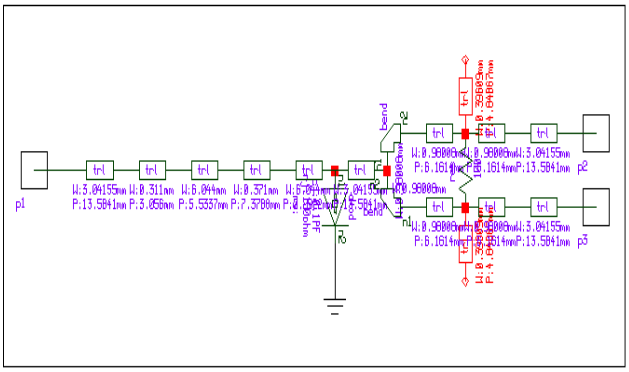

Figure 4. Screen shot of the simulation of mixer using Serenade Software

The width and length of 50 ohm transmission line, inductor element 1, capacitor element 1, inductor element 2,capacitor element 2, impedance line of two arms of power divider, open stub of power divider for 3 GHz frequency calculated using the Serenade software

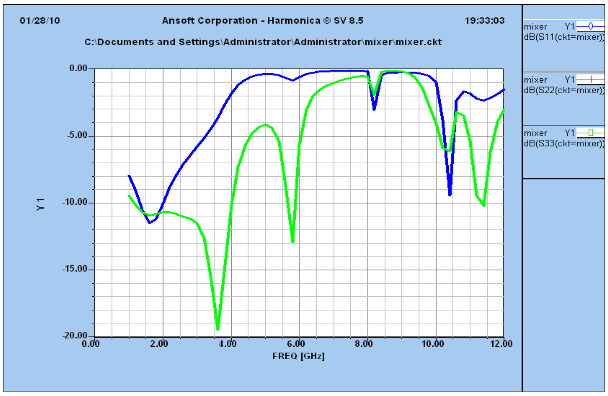

Figure 5. Simulation response shows S_{11}, S_{22} and S_{33}

TABLE I. LENGTH AND WIDTH OF DIFFERENT ELEMENT OF MIXER

Transmission Line	Length (mm)	Width (mm)
50 ohm	3.04155	13.5841
Inductor Element 1	0.371	3.056
Capacitor Element 1	6.044	5.5337
Inductor Element 2	0.371	7.3788
Capacitor Element 2	6.044	2.2922
Two arms of divider	0.98008	6.1614
Open stub of divider	0.39609	4.84867

TABLE II. VARIOUS S PARAMETERS OF MIXER

Freq. (GHz)	S11 (dB)	S12 (dB)	S13 (dB)	S22/S33 (dB)	S23 (dB)
1	-7.89	-5.38	-5.38	-9.51	-6.22
1.2	-9.03	-5.36	-5.36	-10.19	-6.91
1.4	-10.46	-5.28	-5.28	-10.69	-7.79
1.6	-11.44	-5.21	-5.21	-10.84	-8.86
1.8	-11.17	-5.17	-5.17	-10.70	-10.02
2.0	-10.05	-5.16	-5.16	-10.58	-11.08
2.2	-8.94	-5.16	-5.16	-10.66	-11.87
2.4	-8.09	-5.17	-5.17	-10.93	-12.47
2.6	-7.41	-5.21	-5.21	-11.19	-13.11
2.8	-6.74	-5.35	-5.35	-11.30	-13.84
3.0	-6.03	-5.62	-5.62	-11.52	-14.15
3.2	-5.30	-6.00	-6.00	-12.50	-13.32
3.4	-4.53	-6.52	-6.52	-15.13	-11.70
3.6	-3.64	-7.23	-7.23	-19.32	-10.26
3.8	-2.66	-8.25	-8.25	-15.32	-9.56
4.0	-1.79	-9.62	-9.62	-10.23	-9.75

Table II shows different S parameters in the tabular data format for frequency from 1 to 4 GHz. It is observed that mixer isolation between two input ports found to be satisfactory from 1.8 GHz to 3.6 GHz.

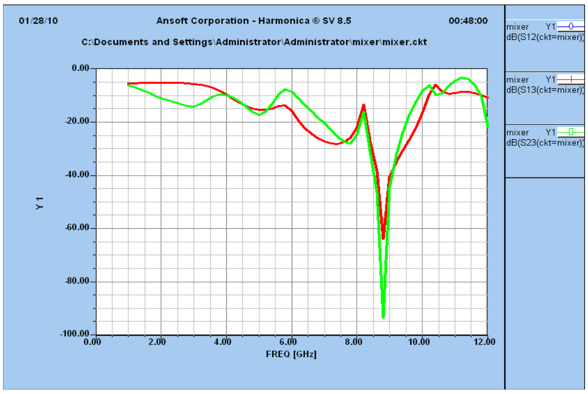

Figure 6. Simulation response shows S_{12}, S_{13} and S_{23}

E. Antenna Designing

Width of patch using standard formula was found to be 3.04290 cm. Here with certain optimization length was chosen to be 1.491609 cm instead of 2.34308 cm found using formula for length. This design was fed by coaxial feed at two different points.

TABLE III. VARIOUS PARAMETERS OF CO-AXIAL FEED

Frequency (GHz)	**S11(dB)**	**VSWR**
1	-0.1515	114.7
2	-7.93	218.9
3	-1.337	13.02
4	-0.711	24.42
5	-1.63	10.64
6	-2.344	7.456
7	-4.23	4.188
8	-1.66	10.5

In second case coaxial feed was connected at point x= 11mm and y = 26.65 mm. Here value of return loss was -4.22 at 7 GHz and VSWR of 4.18. This feeding point was also rejected.

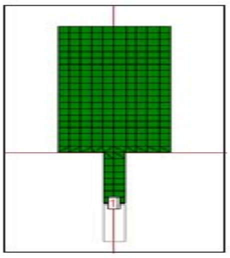

Figure 7. Screen shot of microstrip line feed on wide and narrow dimension

Now line feeding was made along narrower dimension means length in this case.

Results of coaxial feed points were compared from 1 to 8 GHz frequency range for S11 and VSWR. The detailed values were placed in tabular form. Idea of using coaxial feeding was dropped after comparing the results.

Instead of coaxial, now microstrip line feeding through wider dimension, width in this case was done. Values of return loss at 4, 5 and 7 GHz were -1.55 dB, -1.49dB and -1.37 dB. VSWR was above 11.

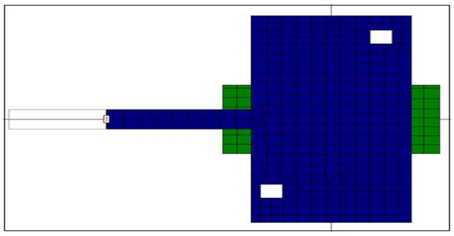

Figure 8. Screen shot of top view of proposed antenna design

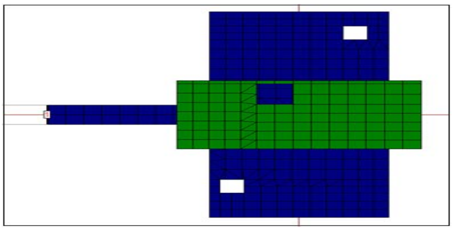

Figure 9. Screen shot of bottom view of proposed antenna design

TABLE IV. S PARAMETER OF PROPOSED ANTENNA

Frequency	**S_{11}(dB)**
1	-4.6
2	-9.02
3	-0.36
4	-1.145
5	-0.8531
6	-20.74
7	-0.6398

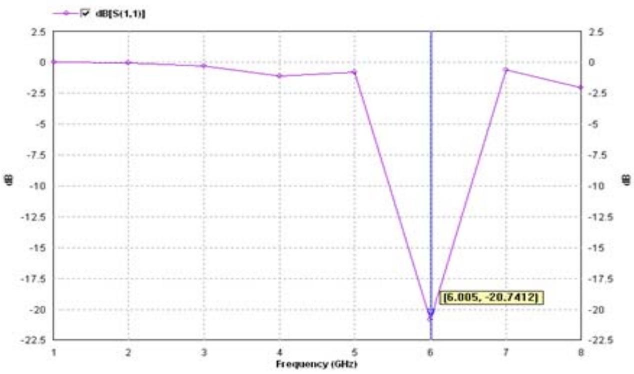

Figure 10. S_{11} for modified proposed antenna design

Defected ground structure technique was used to improve the results. Ground with three rectangular strip of dimensions 10 x 20 mm and two strips of 12x20 mm were used.

A defected ground structure of dimension 4x 3 mm was introduced in the middle strip of the ground. On the top surface two slots of 2 mm x 2mm at two corners were introduced. As value of return loss degrades to -5 dB for 5 GHz resonant frequency, so this design is further modified.

Modification of design in the sense that two side strips of ground structure in green colour were removed but the middle ground strip was kept as it is and using simulation its result was compared with previous results.

The value of VSWR was near 1, a desirable value and also S11 for 6 GHz was found to be -20.74 dB. This design with modification was better to previous results for patch antenna found using step by step changes. Bandwidth was more than 1 GHz.

III. MEASURED RESULTS

The measurement of fabricated mixer was done using vector network analyzer. Response for frequency of 3 GHz was considered and measured. Along with S parameters, group delay was also measured whose value is in pico farad.

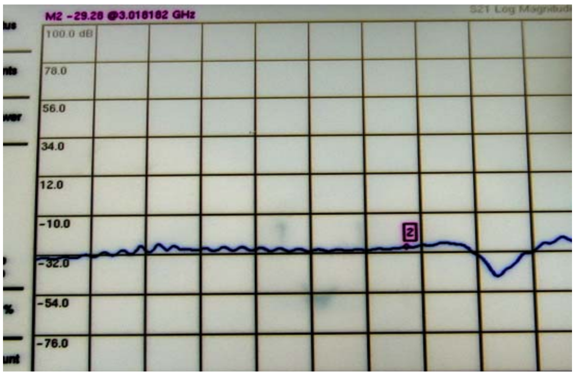

Figure 11. S_{13} in dB between RF input and mixer output

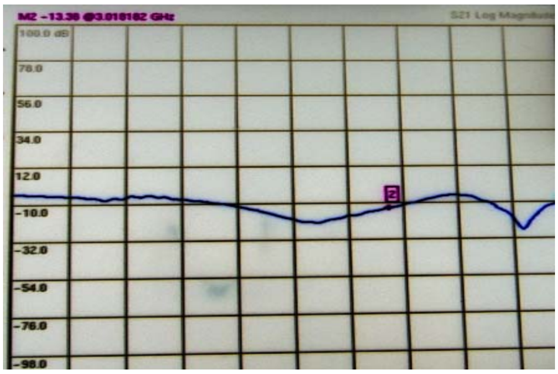

Figure 12. S_{23} in dB between LF input and RF input

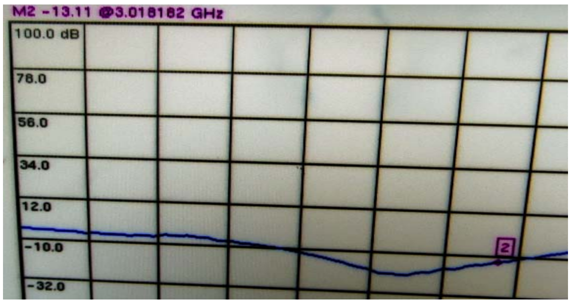

Figure 13. S_{12} in dB between RF and LF input

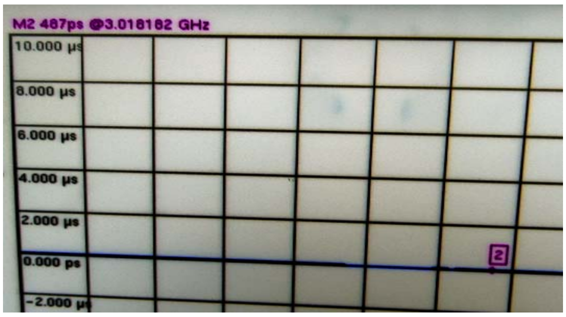

Figure 14. Group delay from RF to LF input

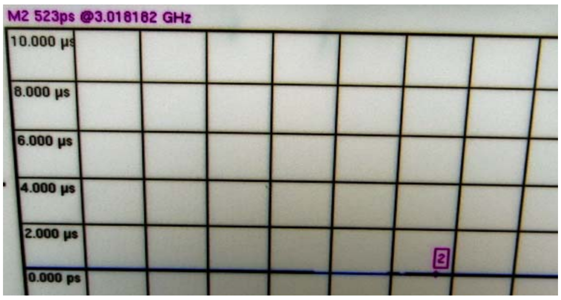

Figure 15. Group delay from LF to RF input

The measured group delay from RF input to LF input found 487 pico second and from LF input and RF input found equal to 523 picosecond. Figure 11,12 and 13 shows different measured S parameters. Figure 14 and 15 shows measured group delay.

CONCLUSION

A 3GHz single diode mixer has been fabricated and analyzed on different parameters. Total dimension of fabricated mixer is length equal to 6 mm and 4 mm width. Further modified design of patch antenna allows S and C band area for coverage with -9.02 db return loss for 2 GHz and -20.74 dB for 6 GHz with bandwidth more than 1 GHz. Good isolation between ports and other parameters are presented. Simulation and measured results are reported.

ACKNOWLEDGMENT

Authors like to give their thanks to 'Geetanjali Institute of Technical Studies', Udaipur (Raj.), India for the support.

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