Design of S-Band Double-Conversion Superheterodyne Receiver Front-End for RADAR Systems

Ashwini M.¹, Moorthy T.G.S.¹ and Rajarao Y.S.²

¹Center for Emerging Technologies™, Jain University, Bangalore, Karnataka, India
²Ananth Technologies Limited, Bangalore, Karnataka, India

Publication Date: 23 September 2015


Abstract The design of double-conversion superheterodyne receiver front-end for RADAR systems. The specifications formulated by Ananth Technology Limited (ATL) have been verified and simulated using EDA software with low noise and less gain variation. Noise specification is however verified by calculation.

Keywords Superheterodyne Receiver; Low Noise Amplifier; Band-Pass Filter; Mixer; IF-Amplifier

1. Introduction

Radio Detection and Ranging (RADAR) is an electronic device for detecting the presence and location of objects. RADAR transmitter transmits a short duration pulses at a suitable power level. The reflected signal from the object is received by the RADAR receiver. The time it takes to travel from the transmitter to the object and back determines the distance from the object [1].

All RADAR receivers use superheterodyne principle where the Local Oscillator (LO) signal beats with the Radio Frequency (RF) signal to produce Intermediate Frequency (IF) signal. The advantage of superheterodyne receiver is to convert all RF signal to a single IF signal which has definite advantage in demodulation process [2].

The double-conversion receiver uses two conversions of RF signals to get the required IF frequency. It improves stability, image rejection and adjacent channel filter performance.
2. Receiver Concept

The specifications formulated by ATL for the design of the RADAR receiver are illustrated in the Table 1.

Table 1: Salient Specification

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameters</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frequency of operation</td>
<td>GHz</td>
<td>3.1-3.5</td>
</tr>
<tr>
<td>2</td>
<td>Frequency at the output of the receiver</td>
<td>MHz</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Receiver Overall Gain</td>
<td>dB</td>
<td>30±0.5</td>
</tr>
<tr>
<td>4</td>
<td>Receiver Overall Noise Figure</td>
<td>dB</td>
<td>3(Max)</td>
</tr>
<tr>
<td>5</td>
<td>Receiver Input Power</td>
<td>dBm</td>
<td>-102</td>
</tr>
</tbody>
</table>

The block diagram of the receiver is shown in the Figure 1. The proposed receiver down converts the input RF 3.1-3.5 GHz to 60 MHz IF with two Local Oscillators using low injection.

Figure 1: Receiver Block Diagram

2.1. Low Noise Amplifier (LNA)

LNA amplifies weak signals while adding little noise of its own [3]. Often devices with low noise figure are chosen for designing LNA. Commercial LNA uses Gallium Arsenide Pseudomorphic High-Electron Mobility Transistor (GaAs PHEMT) technology.

The high gain of LNA can result in the degradation of overall system linearity. For better efficiency Class-AB is used, though Class B gives better efficiency it results in distortion.

2.2. Radio Frequency-Band Pass Filter (RF-BPF)

A RF-BPF is used to reject all other RF frequencies than the desired band of frequencies (3.1-3.5 GHz) to reduce the noise [2].

Chebyshev BPF is used which has ripple in the pass-band and better role-off in stop-band.

Quality-factor (Q-factor) of the BPF is defined as ratio of the center frequency to the bandwidth of the filter. Higher the Q-factor, narrow will be the pass-band. Very high value of the Q-factor can affect the
stability of the system. Based on the band-pass specification and the Q-factor, using datasheet the suitable band-pass chip has been selected.

2.3. Mixer1

Mixer is used to multiply signals of different frequencies in an effort to achieve frequency translation [2].

Mixer1 uses the LO1 frequency of 2.5-2.9GHz and converts the incoming RF frequency of 3.1-3.5GHz to IF1 frequency of 600MHz. Crystal oscillator is used as Local Oscillator for achieving better frequency stability.

The mixer uses BICMOS active device which is fabricated on a single integrated chip using two technologies. Bipolar Junction Transistor technology that offers high speed, high gain, low output resistance and Complementary Metal Oxide Semiconductor Transistor technology that offers high input resistance and is excellent for constructing simple, low-power logic gates.

2.4. IF1-BPF

The IF1-BPF is designed to accommodate the difference of RF and LO frequency with a bandwidth 25MHz. IF1-BPF reduces the noise bandwidth which results in reduced noise power.

2.5. IF1-Amplifier

The IF1 amplifier has been designed with the gain of 20dB which amplifies the signal at the output of the IF1-BPF.

Indium Gallium Phosphide Heterojunction Bipolar Transistor (InGaP HBT) device is used as an amplifier which as the advantage of high power, high frequency, high speed and high efficiency.

2.6. Mixer2

Mixer2 converts 600MHz to 60MHz. Mixer2 uses 540MHz local Oscillator.

2.7. IF2-BPF

The BPF used at the output of the Mixer2 has been designed to accommodate 60MHz IF carriers with a bandwidth 16MHz which reducing the noise bandwidth of the receiver further.

2.8. IF2-Amplifier

The IF2-amplifier further amplifies the IF signal. 1-dB compression point of IF2-amplifier is 17.4dBm which is same as 1-dB compression point of the receiver system.

3. Calculated and Simulated Results

3.1. Gain of the Receiver

Gain of the receiver is 30.361dB where the input power of the receiver is -102dBm as shown in the Figure 2 and the output power of the receiver is -71.639dBm as shown in the Figure 3.
3.2. Overall Noise Figure

Noise figure (NF) is a measure of how much signal to noise ratio is degraded through the system.

The NF defines the noise performance and contributes to the receiver sensitivity. A low noise figure provides improved signal/noise ratio. Overall NF is a unique parameter because it is not only suitable for characterizing the entire system but also the individual system components such as LNA, mixer and IF amplifiers that make up the system. The noise figure of the overall system can be determined from the noise figure and gain of the system components [4].
The calculated value of the overall NF of the receiver is 1.98dB.

3.3. Bandwidth of the Channel

The relation between bandwidth (BW) of the channel, NF and sensitivity ($P_{in,\text{min}}$) is given [4] in Eq.1

$$P_{in,\text{min}} = -114(dBm/MHz) + 10\log(BW) + NF$$

The calculated value of bandwidth of the channel is 10MHz.

3.4. Gain Flatness

Gain flatness is the variation of the gain over the frequency range of the amplifier.

Gain is varied about 0.5dB over the frequency range of 3.1-3.5GHz as given in the Table 2.

3.5. Free Space Transmission Loss

Free Space Transmission Loss (FSL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction.

FSL of the receiver at center frequency 3.3GHz and distance 100miles is 147dB using a formula (2)

$$FSL = 36.6 + 20\times\log_{10}(f) + 20\times\log_{10}(D)$$

4. Conclusion

In this paper, the S-band double-conversion superheterodyne receiver front-end has been designed, verified and simulated using EDA software. The proposed receiver have met all the parameters
specified by ATL with output IF frequency of 60MHz, 30.361dB gains, low noise of 1.98dB (Noise specification is verified by calculation) and less gain variation.

**References**


