EEC134 Application Note

System Design of FMCW Radar

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Introduction

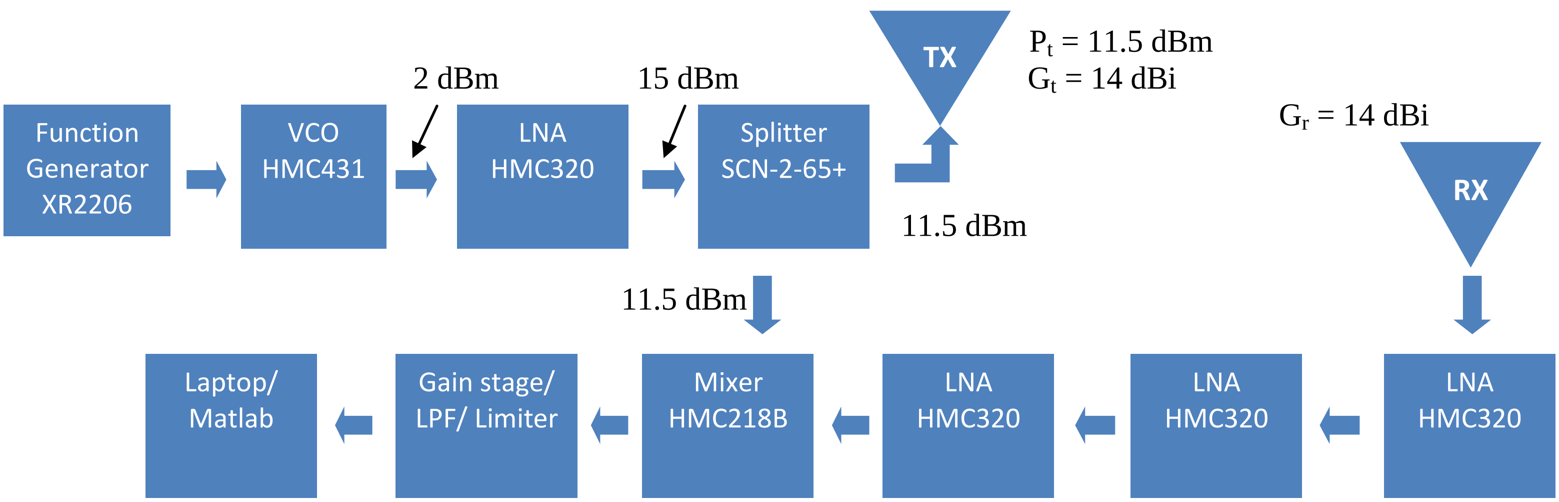
This application note presents the design aspects of the RF system and baseband system of a radar with the ultimate objective of providing range measurements. The RF system incorporates the RF subsystem and antenna. The baseband incorporates the gain stage and filtering of the down converted signal in preparation for sampling. In detail this paper will provide an overview of design specifications used to meet specific performance requirements. Once these system characteristics are well defined, the implementation process of component selection will be covered.

Overview

The system technology implemented is classified as frequency modulation continuous wave (FMCW) radar that can detect distances of targets and the speed of a moving object with relatively lower power.

System Design

The size of the microwave radar system can be reduced by using higher frequencies. A 24 GHz radar design was considered but was disapproved of due to the increase losses associated with systems operating at such high frequencies. Therefore a 5.8 GHz system has been selected for the design which also has the advantages of having readily available components. The following block diagram depicts the basic layout of the coherent FMCW radar.



Design Specifications

The proposed RF subsystem is bi static radar type which incorporates transmit and receive paths. It is implemented to increase the isolation between the two paths. The transmit path starts with the voltage controlled oscillator (HMC431) which is able to output a 2 dBm signal to sweep in the range of 5.6 to 6 GHz according to modulation voltage signal from the function generator. The swept signal is amplified by way of a low noise amplifier (HMC320) which provides a power amplification of 13 dBm at the operating frequency. After that the swept signal is divided by way of a splitter (SCN-2-6+) which introduces a 3.5 dBm insertion loss. A portion of the swept signal is coupled to the mixer as reference signal. The final transmitted power of the system is 11.5 dBm which is transmitted through a 14 dBi TX antenna. The received path starts with a series of low noise amplifiers. The required RF amplification at this stage will be discussed later in this section. This amplified signal from the RX antenna is inputted to the mixer where it is down converted by mixing with the reference signal. This down converted signal is amplified at the gain stage and passed through low pass filter before it is sampled by the PC.

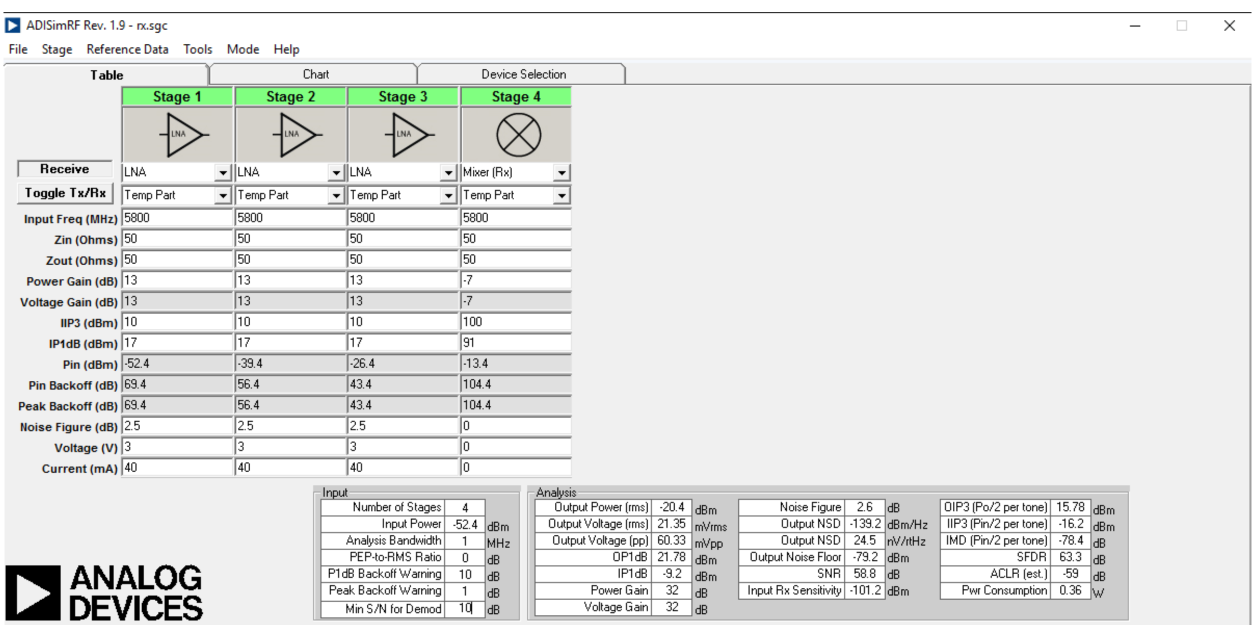
Once the transmit power of the radar is realized, Frii's equations is used to determine the received power. The goal is to design the receiver to detect a 0.3 meter squared target ranging at distances between 5 to 50 meters.

$$\mathrm{P_r} = \frac{P_t G_t \sigma G_r \lambda^2}{(4\pi R^2)^2 4\pi}$$

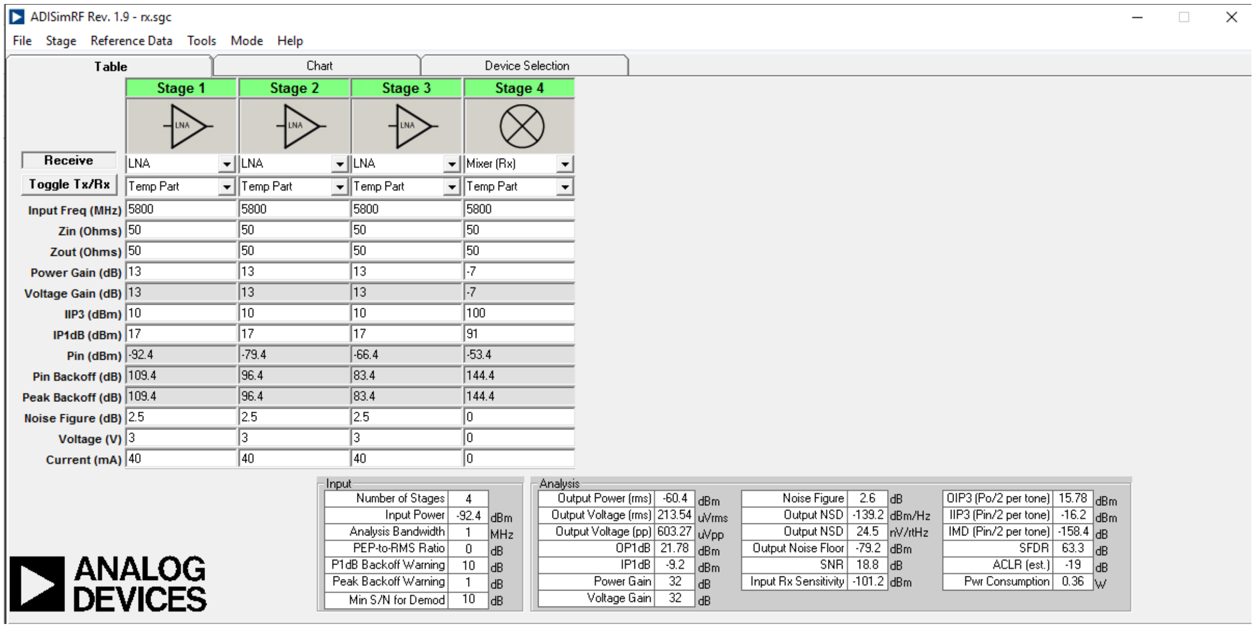
With an operating frequency of 5.8 GHz the power received ranges from -52.4 dBm to -92.4 dBm for target ranges from 5 to 50 meters. To reduce the amount of amplification required at the baseband gain stage, RF amplification is implemented at the RF receiver path with a cascade of three low noise amplifiers (HMC320) with each providing a power amplification of 13 dBm at a noise figure of 2.5 dBm.

To characterize the receiver path of the RF subsystem Analog Devices provides ADIsimRF to calculated total gain, noise figure, signal to noise ratio and peak to peak output voltage. The calculations for receiver path for targets at 5 and 50 meters are shown below.

ADIsimRF receiver path calculation for target at 5 meters



ADIsimRF receiver path calculation for target at 50 meters



The baseband circuit is designed to amplify the incoming signal and filter any noise received from the IF frequency of the RF circuit. The link budget table below summarizes the power received, mixer power output and mixer output voltage for targets at 5 and 50 meters. From this the gain required at the gain stage can be determined.

Range	Power Received	Mixer Power Output	Mixer Voltage Output
5m	-52.4 dBm	-20.4 dBm	60.3 mVpp
50m	-92.4 dBm	-60.4 dBm	603 uVpp

For weak signals detected at target ranges as far as 50m, amplification is required for the built in ADC of the PC’s microphone to detect noticeable measurements. For the ADC of the microphone a minimum 25mV peak to peak signal was determined to be sufficient. To detect targets at the maximum range of 50 meters, amplification provided by the gain stage should be x40. Any signal higher than 1.2 volts peak to peak would be limited by the limiter circuit.

Component Selection

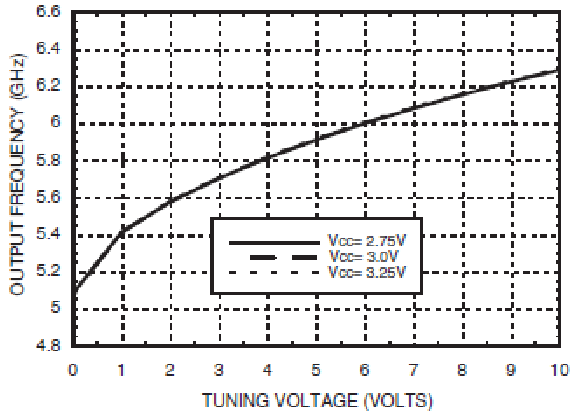
This section will cover the process involved in selecting components that meet system design specifications detailed in the previous section. The selection process has been divided into RF components and baseband components. The table below summarizes the main components selected in this process.

Device	Model	Manufacturer	Specification
Function Generator	XR-2206CP	Exar/Jameco	Frequency Range: 0.01-1MHz I = 14 mA
Voltage Controlled Oscillator	HMC431LP4ETR	Analog Devices	Power Output: 2dBm Vcc = 3V I = 33mA
Power Splitter	SCN-2-65+	Mini-Circuits	Insertion loss: 3.5 dBm Passive
Low Noise Amplifier (13 dBm)	HMC320MS8GE	Analog Devices	Noise Figure: 2.5 dBm Power Gain: 13 dBm I = 40 mA
Mixer	HMC218BMS8GE	Analog Devices	Conversion Loss: 7 dBm LO Power: + 13 dBm Passive
Antenna	5.8GHz 4-Patch Array	Ripafire	Gain = 14 dBi Bandwidth: 350 MHz Range: 5.6 – 5.95 GHz
Gain Stage Amplifier	TL972IP	Texas Instruments	
Active Low Pass Filter	MAX291CPA+	Maxim Integrated	Corner Frequency Range: 0.1 Hz - 25 kHz

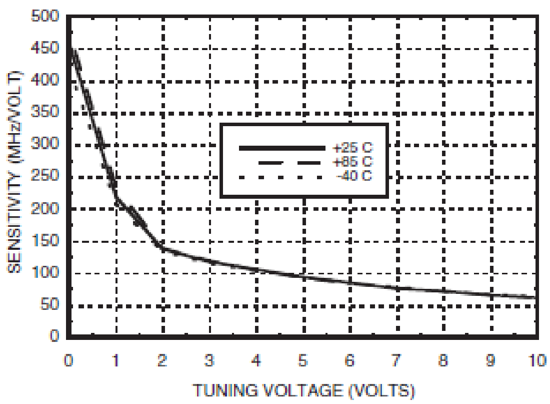
HMC431LP4ETR Voltage Controlled Oscillator:

The Voltage Controlled Oscillator (VCO) generators the RF signal transmitted by the radar. The VCO requires many considerations when selecting. For range measurements applications an optimal VCO would have a tuned voltage to oscillate linearly in conjunction to a linear output in the frequency of operation. Constant power output over this range would be ideal. In addition the VCO should have low phase noise. The VCO chosen for the design was the HMC431LP4ETR manufactured by Analog Devices. The graphs below, taken into account for the analysis, are obtained from the datasheet provided by Analog Devices. The expected operating frequency is between 5.6 to 5.95 GHz. To operating in this range the tuning voltage would span between 2 to 6 volts. Based on the sensitivity vs. tuning voltage graph in this range there is a deviation of 50 MHz/Volt. Although this is not perfectly linear it is acceptable for radar applications. The output power remains constant at just above 2 dBm for the entire frequency range.

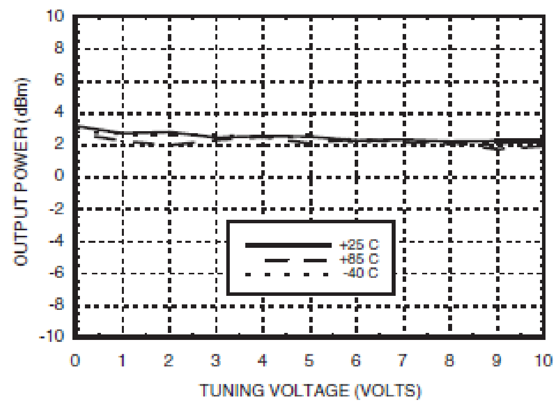
Frequency vs. Tuning Voltage, T= 25°C



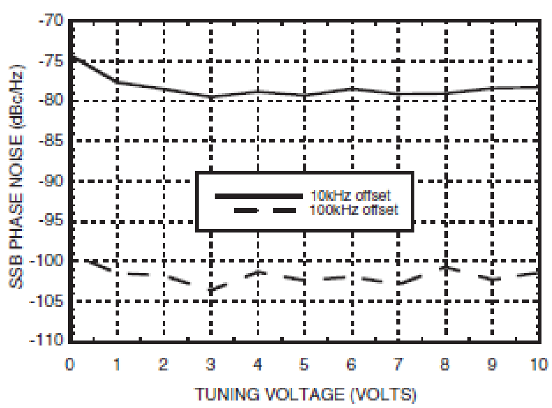
Sensitivity vs. Tuning Voltage, Vcc= +3V



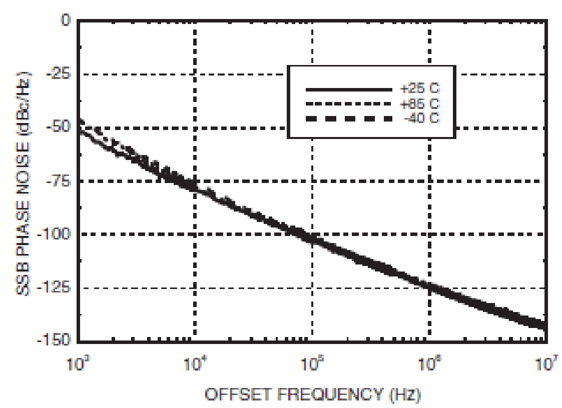
Output Power vs. Tuning Voltage, Vcc= +3V



Phase Noise vs. Tuning Voltage



Typical SSB Phase Noise @ Vtune= +5V

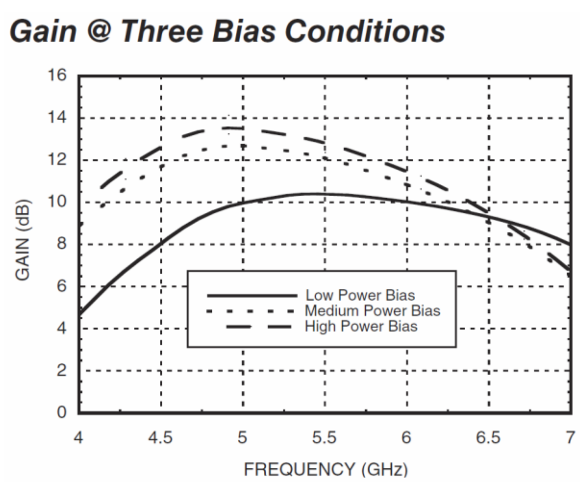


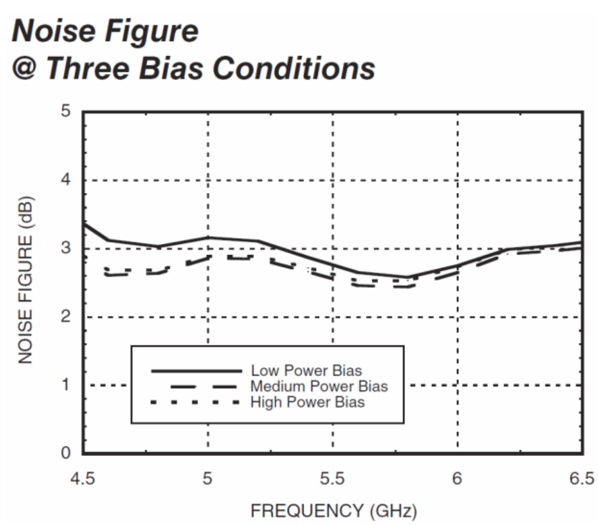
XR-2206CP Function Generator:

Once a VCO has been selected a function generator must be taken into account. Initially the Teensy 3.1 in conjunction with the MCP4921 DAC was taken into consideration but due to size and power constraints another option was chosen. The XR-2206CP is a monolithic function generator Exar that is able to produce the required triangle waveform to drive the VCO without a microcontroller and digital to analog converter.

HMC320MS8GE Low Noise Amplifier:

The Low Noise Amplifier (LNA) is required before the splitter and the RF input of the mixer to allow for enough amplification of the signal entering the baseband circuit. When selecting a LNA, it is critical to choose one that provides high power amplification and relatively low noise figure which would reduce the signal to noise ratio introduced during cascading of multiple LNAs. Also an LNA that does not require a complicated bias network would simplify the assembly process. The HMC320MS8GE by Analog Devices was chosen for the radar design which provides the option for configuration with three bias conditions. The graphs below are obtained from the datasheet. To maximize power amplification of each LNA, a high power bias is chosen.





SCN-2-65+ Power Splitter

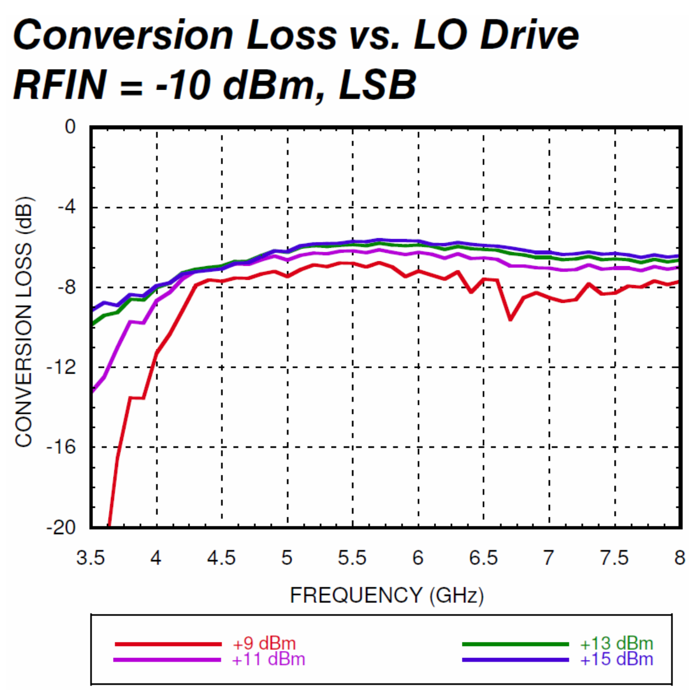
When selecting a power splitter it is important to pay close attention to insertion losses and a number of other key factors. The selection of the SCN-2-65+ Power Splitter by Mini-Circuits is justified in the following table. For a frequency range for 5500-6500MHz the insertion loss remains low between 3.5 and 3.8 dB. The splitter can provide a large isolation of about 17 dB which is good. Also the splitter had the added benefit of easy soldering and being low on cost.

Electrical Specifications

FREQUENCY (MHz)	INSERTION LOSS (dB) ABOVE 3.0 dB		ISOLATION (dB)		PHASE UNBALANCE (Degrees)		AMPLITUDE UNBALANCE (dB)		RETURN LOSS (dB)	
	Typ.	Max.	Typ.	Min.	Typ.	Max.	Typ.	Max.	INPUT Typ.	OUTPUT Typ.
5500-6500	**0.8**	**1.1**	**17**	**11**	**3**	**5**	**0.1**	**0.4**	**18**	**16**
5700-5900	0.5	1.0	17	11	2	4	0.1	0.3	22	16

HMC218BMS8GE Mixer

The ideal mixer would be a double balanced mixer which has the advantages of good port isolation, noise protection and linearity. Fortunately Analog Devices provides the HMC218BMS8GE that meets these specifications in a passive double balanced topology. The graph below shows the conversion loss for a given LO drive of the mixer. With an expected LO drive of about +11dBm for our system design, the conversion loss remains constant at 6.5 dBm under the expected operating frequencies.



TL972IP Amplifier (Gain Stage) and MAX291CPA+ (Low Pass Filter)

The gain stage and active low pass filter in consideration is a modified version from the baseband design implemented in lab 1 for the quarter 1 radar which had a cut off frequency of 15 kHz. Modifications include the cascading of 2 amplifiers (TL972IP) in the gain stage to achieve the required amplification of x40 and an improved dedicated active lowpass filter IC (MAX291CPA+) which can provide a maximally flat passband response as a 8th order Butterworth filter.