Analysis of the Doppler Effect in a K-LC6 Radar Unit

A Major Qualifying Project

Submitted to the Faculty of Worcester Polytechnic Institute

In partial fulfillment of the requirements for the Degree in Bachelor of Science in Physics

By

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Project Advisor

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Abstract

This MQP utilizes a commercial-off-the-shelf radar 24 GHz module, a signal conditioning circuit, and data acquisition board and software to develop a continuous-wave radar system to monitor the velocity of objects in a confined area of a room. We determined the necessary characteristics of the signal condition circuit to be able to accurately record the Doppler-shifted signature of a slow-moving object. We demonstrated the relationship between the Doppler shifted frequency and the velocity of a target.

Acknowledgements

I would like to thank my friends and family for their continued support over the last 5 years.

I would also like to thank Jake Bouchard and Nicole Burns for their help in the lab.

Most importantly, I want to thank my advisor Professor Doug Petkie for his help and patience throughout the project in and out of the lab.

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1.Introduction

For the last century and a half, the Doppler effect has been used to develop tools to help us measure velocities and distances, whether that be how fast a galaxy is moving through the universe to how fast you are approaching a car in front of you on the highway. Doppler radar has been one of the most effective tools in determining how fast an object is traveling and how far away it is from a radar unit. We use it in everyday life, when the meteorologist tells us the forecast, measuring vital signs [1] , police use it to track speeding, and even our cars now use it to helps us prevent accidents through collision avoidance radar. By looking at the Fourier transforms of wave time-based-signals we see the frequencies within said signal that can be used to calculate the relative velocity between a radar unit and an object. With the discovery of this technology, we have been able to forward scientific discoveries and will continue to throughout the future.

Since its conception in the early 20th century, radio detection and ranging (radar) has been used in a variety of applications ranging from missile detection and navigation to motion detection sensors [2]. In a basic radar unit, radio waves are transmitted from an antenna, then as the radio waves hit an object, they bounce back toward the radar unit, shifted in frequency due to relative motion. Doppler radar operates off the same principles as a basic radar, but it differs slightly when measuring the distance and velocity between the radar and the target that depends on the radar system. The Doppler effect occurs when a wave's frequency changes in relation due to relative motion between the radar unit and the object. The Doppler effect was first proposed in the mid-19th century by Christian Doppler, an Austrian physicist, in studying the spectral lines of stars, that is now used today in many modern radar systems, such as Doppler weather radar [3]. Doppler radar gained popularity throughout the 1940's and has remained a prominent piece of technology, for example its use in meteorology and aircraft navigation.

Doppler radar is a radar system that uses the Doppler effect to produce velocity data about an object at a certain distance. To do this, the radar system will bounce an electromagnetic wave (often in the microwave region) off the desired target and then analyze how the object's movements affected the returned signal's frequency. A radar Doppler shift can be calculated using this formula

$$f_r = f_t\left(\frac{1+\left(\frac{v}{c}\right)}{1-\left(\frac{v}{c}\right)}\right) \qquad 1$$

Where f_r represents the received or detected frequency and f_t is the original transmitted frequency. This is equation can be simplified to

$$f_r = f_t\left(\frac{c+v}{c-v}\right) \qquad 1.1$$

The doppler frequency is then calculated as the difference and given by:

$$f_D = f_r - f_t = 2v\left(\frac{f_t}{c-v}\right) \qquad 1.2$$

however, when talking about radars the term *c-v* can be simplified to *c*. The final equation used to find the doppler frequency is:

$$f_D = \frac{2v}{c} f_t \qquad 1.3,$$

where f_D is the Doppler shifted frequency, f_t is the transmitted frequency, c is the speed of light and v is the velocity of the target. There are four main radars that use the Doppler effect, a coherent pulse (CP) radar, a pulse-Doppler radar, a continuous wave (CW) radar and a frequency modulated (FM) radar. The goal of this project was to work with a dual channel CW radar module to see how the radar measures the distance and speed between an object and the radar unit.

2.Background

2.1 The Michelson-Morley Experiment

The Michelson-Morley experiments is one of the most famous “failed” experiments to occur in the field of physics. In the late 19th century Albert Michelson and Edward Morley conducted a series of experiments to determine the existence of the aether. During this time, the aether was thought to be a medium which acted as a transmission medium for propagation of light to occur. Their experiment consisted of an invention of Michelson’s called the interferometer. The interferometer worked by emitting a beam of either yellow or white light which would hit a beam splitter, causing the light beam to split into two. As the two beams traveled past the beam splitter, they would travel down these arms on the device until the beam was reflected off mirrors at the end of each arm. As the reflected beams traveled back, they would recombine together into an eyepiece that would display the interference patterns. Michelson and Morley would then look at these interference patterns to determine the existence of the aether.[4] Their first hypothesis was that if there was a fringe shift of 0.4 fringes, then the existence of an aether would be true. However, after their first experiment, the fringe shift that was seen was only 0.005 fringes.[5] It was later determined that Michelson and Morley had made a mathematical error and their expected fringe shift should have been 0.02 fringes instead of 0.4 fringes. After several rounds of testing, it was determined that the results that were being seen were too small to count as evidence of the existence of the aether. Although these experiments failed, they did prove useful in the scientific community. First, they impacted the theory of electromagnetics by refuting the existence of aether and that electromagnetic waves can propagate through a vacuum. Secondly, one could consider the Michelson- Morley experiments the first radar test. The interferometer uses the same principles of a radar unit, by having the two waves combine to create an interference pattern between the two waves when one of the mirrors is moving, namely a Doppler shift in the frequency of one wave. This is the same way that modern radar systems operate, by comparing the original transmitted signal to the signal that is reflected by the targeted object and combines with the original signal to sense the Doppler shifted frequency.

2.2 Radar Systems

The principal idea behind radio detection and ranging (radar) was started by Heinrich Hertz during the 19th century [6]. Through a series of experiments, he was able to show that, for the first time outside of the visible part of the spectrum, electromagnetic waves can be reflected off metallic objects and surfaces. In the early 20th century German inventor, Christaan Hulsmeyer, took the ideas of Hertz and applied them to an innovative technology, which he called the telemobiloscope.[7] As technology advanced it gave way too many distinct types of radar systems, one of the most notable, the doppler radar system.

2.2.1 Doppler Radar

A Doppler radar system is a type of radar that uses the Doppler effect to determine the velocity between the radar system and the target. The Doppler effect is a principle that describes the change in frequency of a wave produced by a moving source with respect to the target represented by equation 1. As a source moves closer to a target, the frequency of the waves being emitted will increase, and as the source moves away from the source the frequency of the waves will decrease [8]. The Doppler effect in radar units allows for the elimination of signals from slow moving targets that could produce false signals, such as trees and clouds. There are three distinct types of radars that use the Doppler effect and a description of each will be described as follows.

2.2.2 Pulse-Doppler Radar

A basic pulse radar system will transmit an electromagnetic wave from an antenna in short pulses toward a target. Then the system switches from transmitting to receiving mode and waits for the pulsed signal to be reflected off the target.[9] The total time that it takes the pulsed signal to be received after being transmitted is called the running time, which can be used to determine the distance between the radar and the target using the following equation:

$$\Delta x = c\frac{\Delta t}{2} \qquad 2$$

where c is the speed of light, Δt is the return time of pulse travel (to the target and back) and Δx is the distance between the target and the radar unit. In this case, the position is tracked and the velocity would be determined through the changing position.

A pulsed-Doppler radar is based off similar principles, where the radar system uses the same pulse-timing methods and pairs it with the Doppler effect. The pulse-Doppler radar will determine the range using the running time of the pulse and then the Doppler effect is applied to the returned pulse signal to determine the target's velocity. The Doppler frequency of the returned signal is dependent on the radial velocity of the target because the reflected pulse has a phase shift from pulse to pulse that causes a Doppler modulation on the reflected signal. The Doppler frequency in a pulsed radar system can be calculated from Equation 2. The pulse-Doppler radar is mostly used for weather radar.

2.2.3 Continuous Wave Radar (CWR)

The main difference between a continuous wave modeled radar and a pulsed model is that a continuous wave radar transmits a continuous beam of a certain frequency as opposed to a series of pulses at a frequency. Once the beam has hit the target, a portion of it is reflected toward the system and has a different phase from the original beam.[10] This phase change, or the Doppler shift, can be used to determine the displacement between the radar and the target and can be calculated using the following equation:

$$\Delta\phi = 2\pi\left(\frac{2\Delta r}{\lambda}\right) \qquad 3$$

where delta Δr is the difference in the paths between the radar and the target and λ is the wavelength of the beam. If Δr is a function of time, then $\Delta\phi$ will be as well. The continuous wave radar system has certain advantages by being able to be produced inexpensively, low failure rates and easy to maintain. They are particularly good when only looking at one target but start to fail when introducing more than one target because the reflected beams will combine by the time, they reach the antenna simultaneously and continuously which makes it difficult to try and extract the signal from each target and limit the capacity of the system.

2.2.3 Frequency Modulated Radar (FMR)

Frequency modulated radar, or frequency modulated continuous wave radar (FMCWR), is a type of continuous wave radar that emits a beam where the transmitted frequency can change while a measurement is happening. Continuous wave radar is at a disadvantage technologically because it does not have the time marking necessary to determine a target range. [11] However, the FMCWR systems transmit a signal which then either increases or decreases frequency within the period. Once an echo signal is received by the system the changed frequency is then delayed much like pulse radar, however with pulse radar the time is measured directly. The time it takes for the reflected wave to return is related to the difference between the originally transmitted frequency and the current radar frequency and this frequency difference is related to the distance to the target [12]. In FMCW radar measures the differences in phase and frequency between the original and echo signal. This allows the FMCWR the ability to determine range and velocity simultaneously, and high measurement accuracy.

3. Methodology

The goal of this project was to use two dual channel radar units to track the movements of objects within a defined area. We decided to use two K-LC6 radar units and a data acquisition board (DAQ) to collect the data that the radar units received. The K-LC6 radar we used is a 24 GHz short range transceiver, that could be used for ranging and distancing using FMCW or for object speed measurement systems shown [specification sheet is in the Appendix].The output of each radar unit is a measure of the Doppler frequency and the dual channel allows the direction of relative motion (toward or away) and Doppler frequency to be determined rather than just the Doppler frequency. Before we could track movements with the radar units that would require a significant level of signal processing, we needed to make sure that they functioned properly and that the return signal was sufficient. To do this we connected the radar unit to an oscilloscope to see if it was recognizing movement, so we waved our hands in front of the radar unit and looked at the scope to see if we observed a Doppler frequency that was consistent when we moved our hands. Once we saw that the radar was functional, we started to collect basic data to make sure that the DAQ was functioning properly as well. We used two programs for data collection, LabView and MATLAB, where we developed a code in both that would give us a graph of the wave collected. In LabView, we built a code that would collect 10000 data points over a 10 second period. We built the code using the built-in functions in LabView that allowed us to collect the data and then save it as a text file. Fig. 1 shows the MATLAB code we developed for data collection. First, we had to import the DAQ into MATLAB, and then using the plot function, a graph was built to display the data collected. To test the codes, we waved our hand in front of the radar unit to get an initial wave form. Fig. 2 shows one of the initial tests in MATLAB where we produced a graph of our hand moving toward and away from the radar unit.

While we were able to produce a graph, however, the return signal was small enough that there was digital noise of about +/- 1 millivolts.

Figure 1. Matlab radar data collection code using a National Instruments (NI) DAQ board. The digitization rate and collection time can be set.

```
% Alexandra de Heer
% MQP Data Acquisition Code

clc; clear all;


% DAQ Info
dq= daqlist("ni");
deviceInfor=dq{1,"DeviceInfo"};

 %Add Channels
dq= daq("ni");
dq.Rate= 20000;
ch=addinput(dq,"Dev3","ai0","Voltage");


% Read Data
tabledata =read(dq);

% Plotting
data=read(dq, seconds(10));
plot(data.Time,data.Variables);
xlabel("Time");
ylabel("Amplitude (V)");

A = [data.Time',data.Variables']
writematrix(A,'4.6data1.xlsx')

```

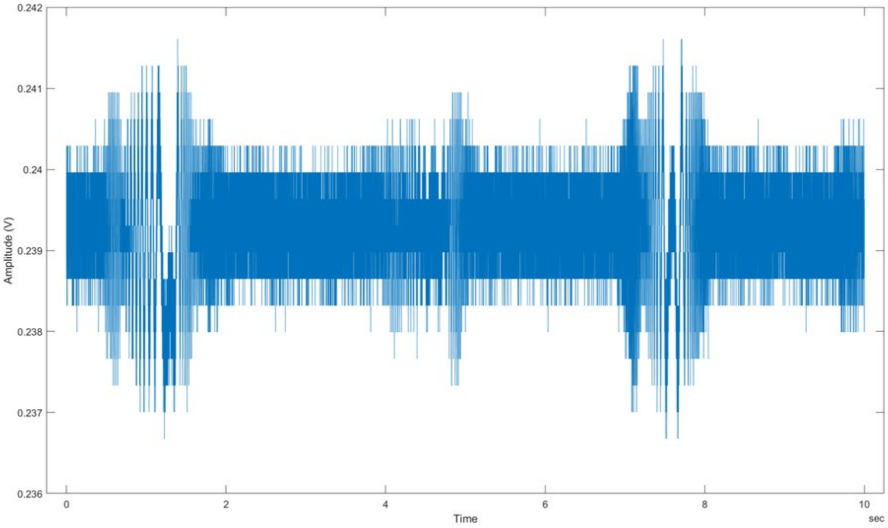


Figure 2. Data collected with Matlab directly from the radar unit to the NI DAQ of hand motion in front of the radar. While some peaks are discernable at 7 and 10 seconds, digital noise and a low radar signal are problems.

To improve the return signal when compared to the digital noise, we tested by moving our hand back and forth with a reflectometer that had three-inch diameter. In Fig. 3 we can see that there was improvement, but the digital noise of about +/- 1 milivolt was still comparable to the signal voltage as well as evidence of higher frequency noise. Although we saw an improvement in noise reduction, we wanted to improve the signal-to-noise ratio so that the noise would not be an issue. We decided to create a low-pass operational amplifier with a gain of ~1000 and a low frequency of ~500 Hz following the radar instead of having the radar connect directly to the DAQ, as shown in Fig. 4. When we ran the radar through the circuit, our data did not show any evidence of digital noise with the much larger radar signal and lower noise.

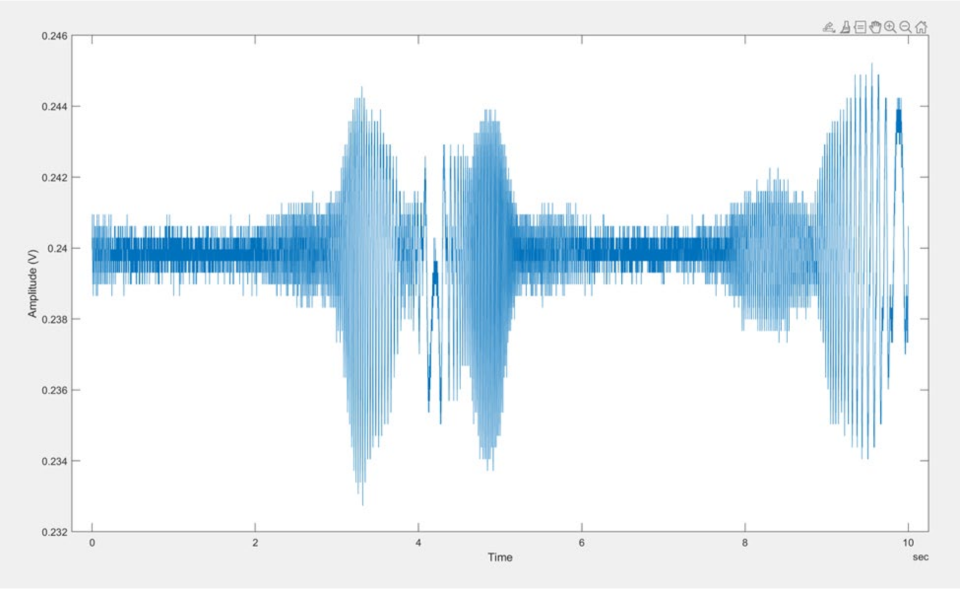


Figure 3. Radar data directly from the radar unit to the DAQ while using a 3-inch diameter retroreflector as a radar target, moving it back and for close to (~20 cm) the radar unit.

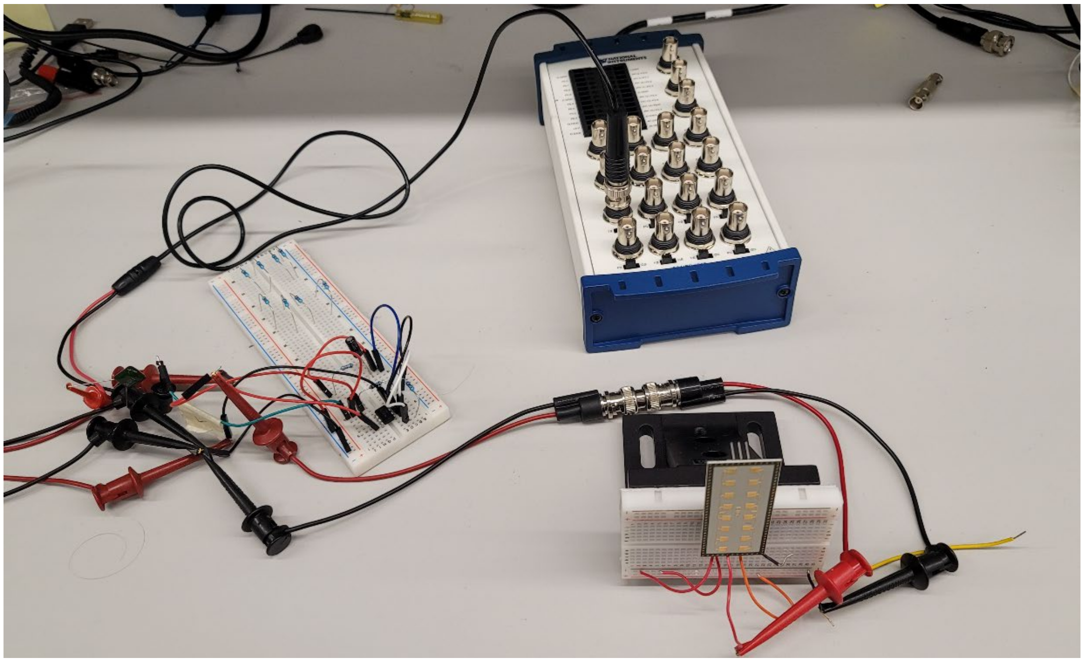


Figure 4. The radar unit connected to a low-pass operational amplifier circuit with a gain of ~1000 and a low-pass filter of ~500 Hz.

We repeated the testing process with the other radar unit to ensure that all functions were working properly, however when testing we discovered that the dual channel on one of the radar units did not function properly. Since the dual channel was damaged, we needed to shift the project's focus to one radar unit and one channel. We decided to focus on using the Doppler effect to track the movements and velocity of an object in front of the radar using the retroreflector. At this point, we also did not use the frequency modulated capability (kept the transmit frequency fixed) and this study effectively used a CW radar unit.

To start this process, we needed to collect data of objects moving in front of the radar unit. Our data collection process started the same way we tested the radar units, first with the hands, then with the reflectometer, except instead of all the data being collected in the same spots we tried starting in different spots and changing the way we moved toward or away from the radar unit. For example, in Fig. 5 you can see how we moved the reflectometer in front of the radar unit in a back-and-forth motion for 10 seconds based off where the peaks (sine waves representing the Doppler frequency) in the radar data. Where there are higher peaks is where you can see we got closer to the radar unit and the smaller peaks are us moving away from the radar unit. We repeated these tests from various starting points of a maximum of 12 feet away. When we looked at the data, in the points where we started the farthest away from the radar unit the more trouble the radar had picking up our movements as the signal to noise ratio was not good. After we collected enough data we could move onto analyzing the graphs we created in order to determine the velocity at which we moved toward the radar unit.

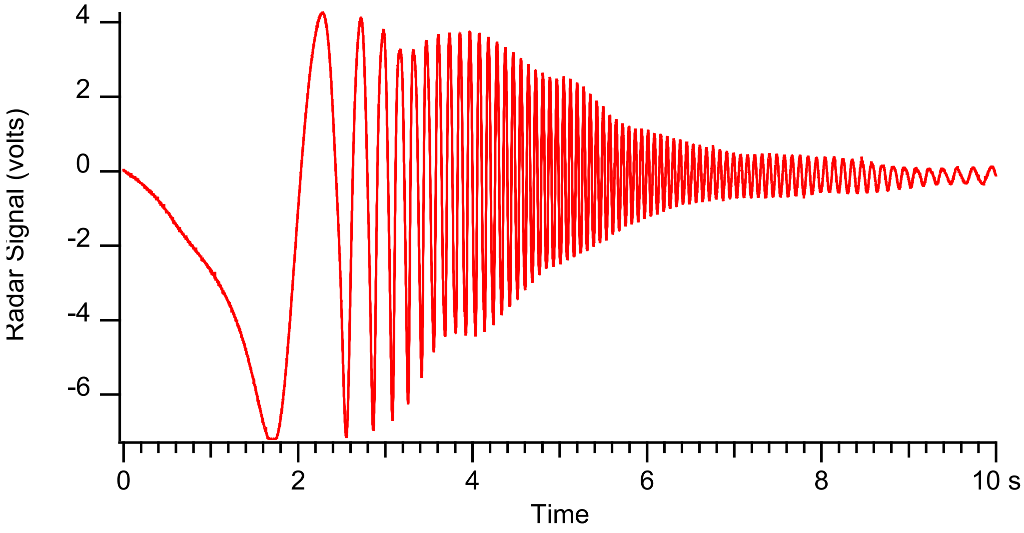


Figure 5. Radar data with the signal condition circuit (low-pass operational amplifier) with the retroreflector starting close to the unit and moving away slowly at first. The signal frequency is related to the velocity and the amplitude decreases with distance.

4. Data Analysis and Discussion

After we collected the data, we performed a Fast Fourier transform (FFT) in order to determine the velocity at which we moved toward the radar unit. At first, we used MATLAB to produce the FFTs and in Fig. 6 we can see the code we built. The code shows that we loaded the data from an excel sheet and created a standard plotted graph using the plot function. After loading a standard graph of the data, using the function fft(x), we were able to get a Fourier transform graph, for example like the one in Fig. 7 Going through most of the collected data, a lot of the FFT graphs looked like Fig. 7, which is not ideal. We decided to see how well we could analyze the data and produce FFTs in Igor Pro. Fig. 8 shows the data from Fig. 5 on the left side of the image and the FFT of Fig. 5 on the right. The FFT plot of Fig. 5 shown below is what we were looking for because we can clearly see that there is a Doppler frequency observed is 14 Hz within that data set. Knowing that there was a Doppler frequency of 14 Hz, we can use that to determine the velocity at which we moved away from the radar unit by rearranging equation 1.3.

$$f_D = \frac{2v}{c} f_t \qquad 1.3,$$

$$v = \frac{c * f_D}{2 f_t} \qquad 1.4$$

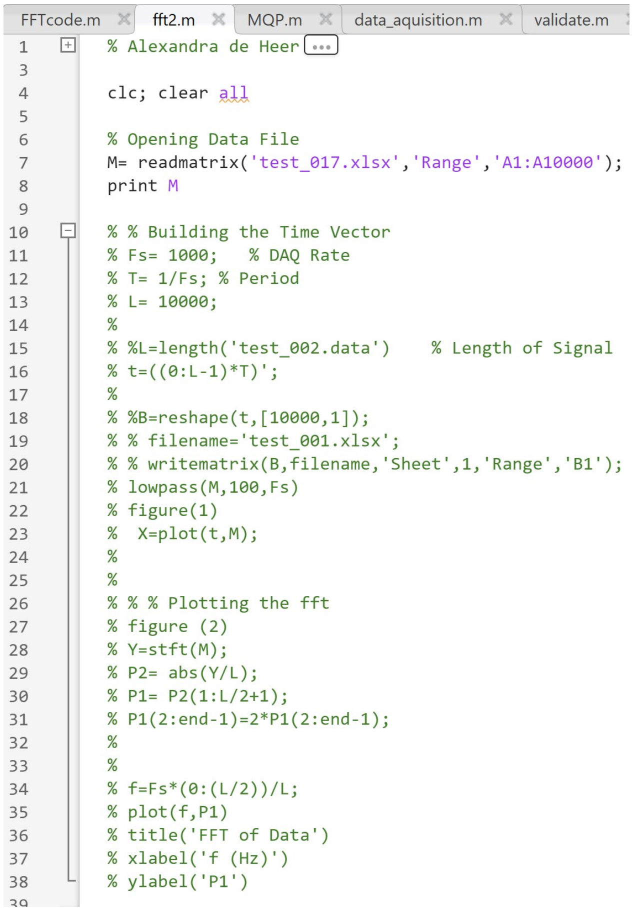
We can plug in 14 Hz for the Doppler frequency, f_D , while knowing that the original transmitted frequency , f_t, is 24 GHz, and that the speed of light, *c,* is 3×10^8 m/s, we can solve for *v*.

$$v = \frac{(3x10^8 m/s)(14Hz)}{2(24GHz)} \qquad 1.5$$

$$v = 0.0875\ m/s$$

When we solve for v we get that we were moving at 0.0875 m/s. We can follow the same steps to calculate the velocity of our movements of the plot in Fig. 9. In Fig. 9 the left-hand side displays the sine wave of the reflectometer moving back and forth in front of the radar, the FFT on the right-hand side of the image shows that the Doppler frequency peaks at about 18 Hz. When we calculate the velocity using equation, we get that $v = 0.1125\ m/s$. Since we were moving our hand back and forth about every 2 seconds.

If we compare Figs 7 and 8, we can see that Fig. 8 clearly shows the frequencies that were observed in the peaks of the corresponding sine wave, whereas Fig. 7 has a more complex motion and complex combination of frequencies. We were unable to clearly recognize any Doppler frequencies from the plot given by Fig 7. To further our conclusions, we performed a short time Fourier transform (STFT) in Igor pro of Fig. 8. The STFT allows us to highlight a small portion of the data and see what the highest occurring frequency is at that certain time point. For example, Fig. 10 shows us the STFT of Fig. 8 in the form of a sonogram plot, where we can see the peak of the curve reaching the 14 Hz mark on the y axis. The x axis is the time of a 10 second period, so we can see the 1 4Hz mark occurring right around the 6 second marking.



```
% Alexandra de Heer

clc; clear all

% Opening Data File
M= readmatrix('test_017.xlsx','Range','A1:A10000');
print M

% % Building the Time Vector
% Fs= 1000;   % DAQ Rate
% T= 1/Fs; % Period
% L= 10000;
%
% %L=length('test_002.data')    % Length of Signal
% t=((0:L-1)*T)';
%
% %B=reshape(t,[10000,1]);
% % filename='test_001.xlsx';
% % writematrix(B,filename,'Sheet',1,'Range','B1');
% lowpass(M,100,Fs)
% figure(1)
%  X=plot(t,M);
%
%
% % % Plotting the fft
% figure (2)
% Y=stft(M);
% P2= abs(Y/L);
% P1= P2(1:L/2+1);
% P1(2:end-1)=2*P1(2:end-1);
%
%
% f=Fs*(0:(L/2))/L;
% plot(f,P1)
% title('FFT of Data')
% xlabel('f (Hz)')
% ylabel('P1')
```

Figure 6 showing the MATLAB code used to plot the FFTs of figures 2 and 3, where we uploaded the collected data from an excel sheet and then recreated the sine wave shown in figures 2 and 3. After recreating the waves, using the function fft(x), we ran the code to get the FFTs.

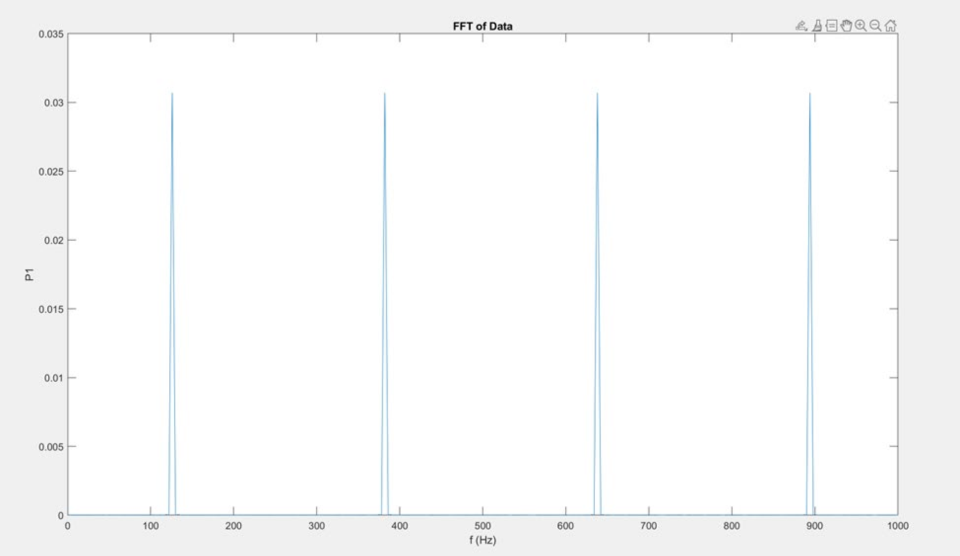


Figure 7: This is the plot of the FFT of figure 2 that was produced after running the code shown in figure 6. This is how all of the FFTs produced using the MATLAB code above looked and were therefore not able to give use the Doppler frequency we were looking for

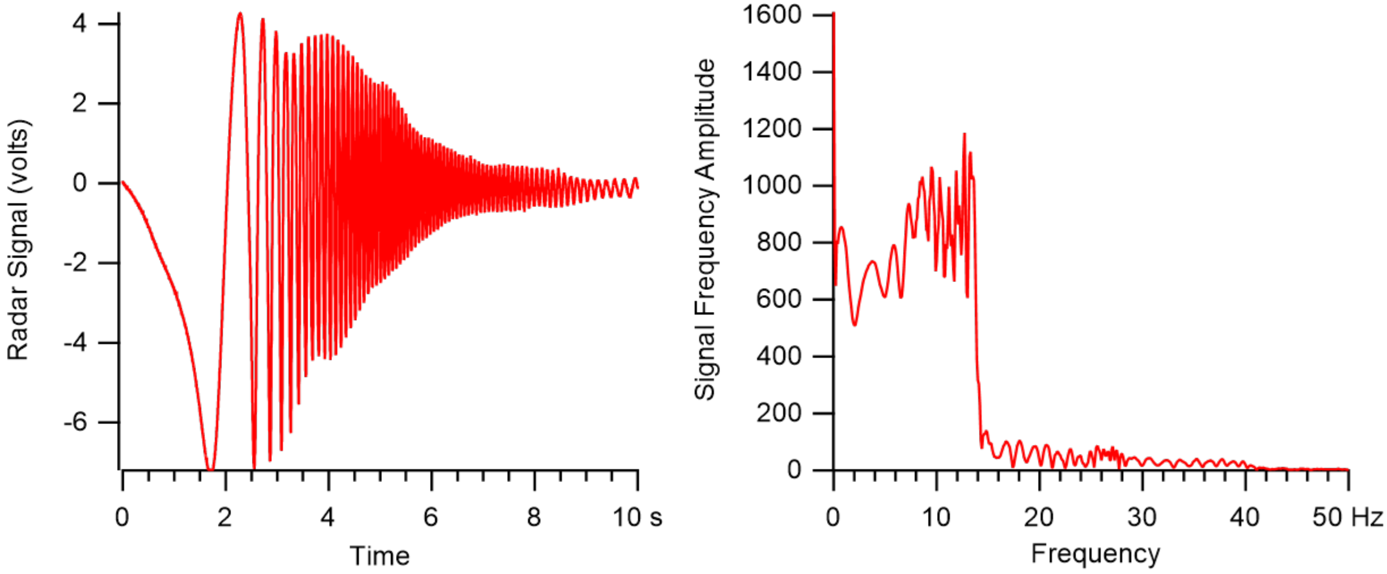


Figure 8: On the left-hand side is the plot of the data set where we started close to the radar unit and progressively moved away from the radar over a period of 10 seconds. On the right-hand side is the FFT plot of the left-hand side graph.

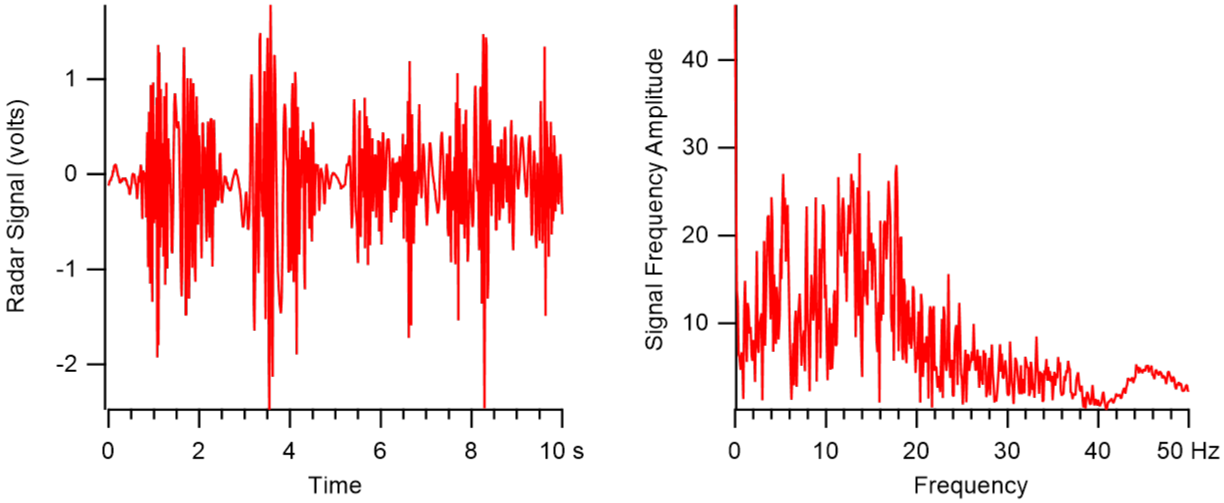


Figure 9: On the left-hand side is the plot of the data set where we waved our hand back and forth from the radar unit for 10 seconds. On the right-hand side is the FFT plot of the graph to the left.

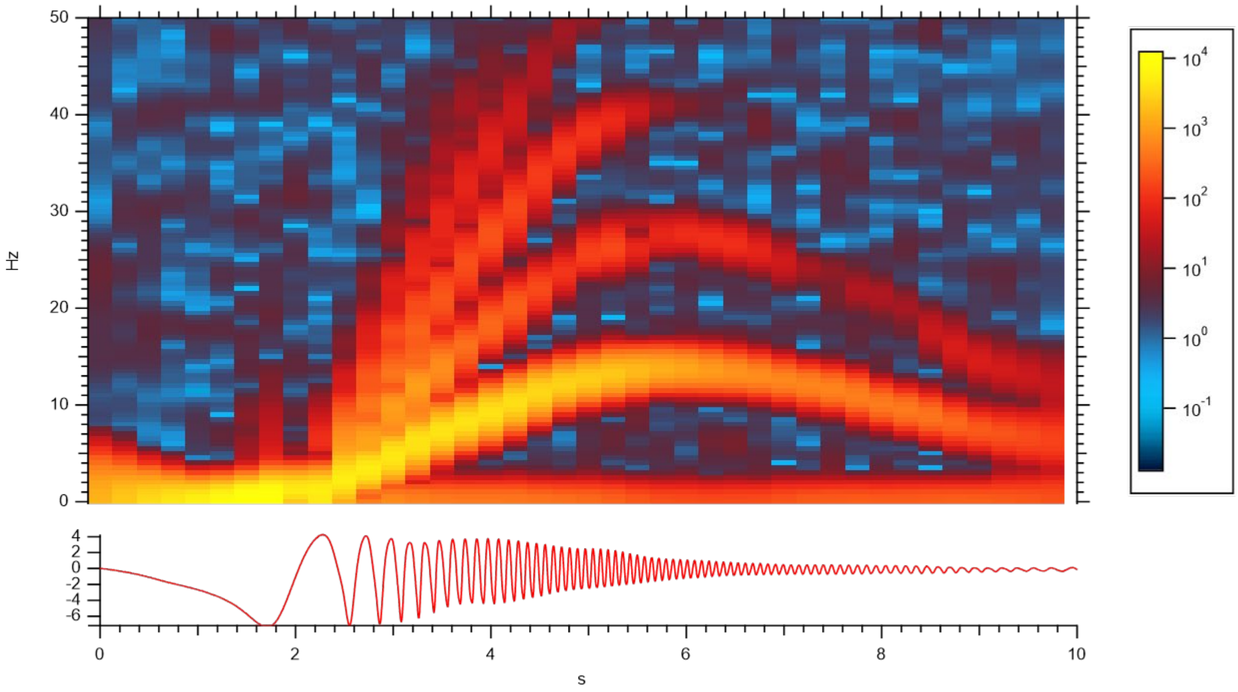


Figure 10This is a Short-Time-Fourier-Transform with a 2 Hz frequency resolution and a 0.25 second time resolution. The peak in the Doppler Frequency of 14 Hz occurs at approximately 6 second and corresponds to a velocity of 8.75 cm/s. The higher frequency components are harmonics of the fundamental frequency.

1. Conclusions

In conclusion, this experiment overall showed a relationship between velocity and the Doppler frequency for slow moving objects that that it could be tracked over time frames of tens of seconds. We showed the radar signal required signal conditioning to interface to the data acquisition system. One channel of the radar unit appeared to fail likely due to a static discharge and care should be taken to prevent this. For two dual channel radar units, four signal conditioning circuits will be needed as well as a four channel DAQ. The 24 GHz operating frequency causes a significant Doppler shift for slow moving objects and should be sufficient for tracking people and objects in a confined area.

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Appendix

K-LC6 Radar Transceiver Data Sheet

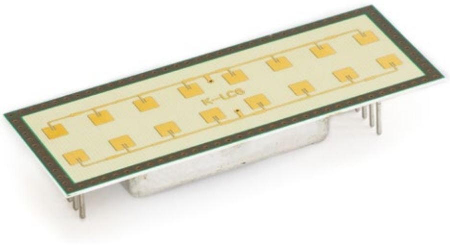
This appendix contains the K-LC6 radar data sheet for the radar used in this project.

RFbeam Microwave GmbH

data sheet

K-LC6

radar transceiver



Features

- 24 GHz short range transceiver
- Narrow–wide asymmetrical field pattern
- Beam aperture 80°/12°
- High sensitive LNA receiver
- 300 MHz wide sweep FM input
- I/Q IF outputs
- Optional IF amplifier (K-LC6-RFB-01x)
- Compact size: 66 mm × 25 mm × 6 mm
- Available as 3.3V or 5V version

Applications

- Indoor and outdoor lighting control applications
- Traffic supervision and counting
- Object speed measurement systems
- Ranging and distance detection using FSK or FMCW
- Industrial sensors
- Home automation

Description

K-LC6 is a dual channel Doppler Radar module with an asymmetrical narrow beam for short to medium distance sensors. It is ideally suited for person and vehicle movement and presence sensors.

This module includes an RF low noise amplifier (LNA) for best signal to noise performance. Dual IF I and Q allow movement direction detection and high performance signal processing.

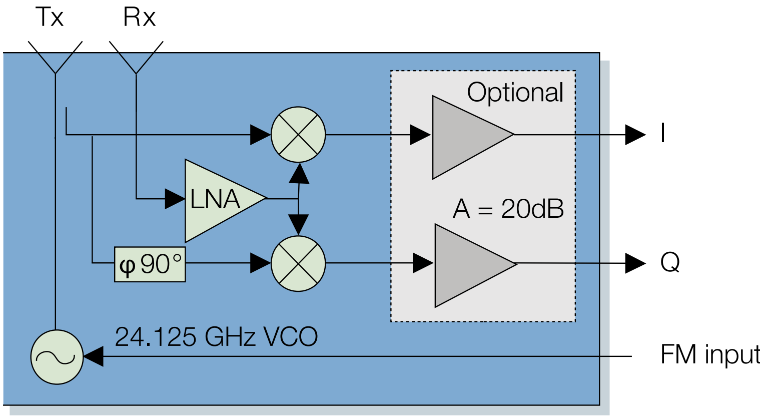
The optional internal IF amplifier is available in version K-LC6-RFB-01x.

An extremely slim construction with only 6 mm depth gives you maximum flexibility in your equipment design.

Powerful starterkits with signal conditioning and visualization are also available. (ST100/ST200)

Block Diagram

Figure 1: Blockdiagram



Optional amplifier is present in the K-LC6-RFB-01x version.

CHARACTERISTICS

Parameter	Conditions/Notes	Symbol	Min	Typ	Max	Unit
Operating conditions K-LC6-RFB-xxC (3.3V version)						
Supply voltage [Note 1]		V_{cc}	3.13	3.3	3.47	V
Supply current		I_{cc}		85		mA
VCO input voltage		U_{vco}	0		3.3	V
VCO pin resistance	Internal voltage divider [Note 3]	R_{vco}		20 k		Ω
Operating temperature		T_{op}	-20		+85	°C
Storage temperature		T_{st}	-20		+85	°C
Operating conditions K-LC6-RFB-xxD (5V version)						
Supply voltage [Note 1]		V_{cc}	4.8	5	5.2	V
Supply current		I_{cc}		85		mA
VCO input voltage		U_{vco}	0		10	V
VCO pin resistance	Internal pullup to 5 V	R_{vco}		4.7 k		Ω
Operating temperature		T_{op}	-20		+85	°C
Storage temperature		T_{st}	-20		+85	°C
Transmitter						
Transmitter frequency	VCO pin open, Ta = -20 °C .. +85 °C [Note 4]	f_{TX}	24.05	125	24.25	GHz
	VCO pin open, Ta = +20 °C	$f_{TX, Ta}$	24.075	24.125	24.175	GHz
Frequency drift vs temp.	-20 °C .. +85 °C [Note 3]	Δf_{TX}		-0.13		MHz/K
Frequency tuning range		Δf_{vco}		300		MHz
VCO Modulation Bandwidth	$\Delta f = 20$ MHz	B_{vco}		3		MHz
Output power	EIRP	P_{TX}		16		dBm
Spurious emission	According to ETSI 300 440	P_{spur}			-30	dBm
Turn-on time	Until IF signal is valid	T_{ON}		6		µs
Receiver						
Antenna gain	f_{TX} = 24.125 GHz [Note 2]	G_{Ant}		12.5		dBi
Receiver gain	f_{RX} = 24.125 GHz	G_{LNA}		10		dB
Receiver sensitivity	f_{IF} = 500 Hz, B = 1 kHz, S/N = 6 dB, R_{Load} = 1 kΩ	P_{RX}		-108		dBm
Overall sensitivity	f_{IF} = 500 Hz, B = 1 kHz, S/N = 6 dB, R_{Load} = 1 kΩ	D_{system}		-126		dBc
IF output K-LC6-RFB-00x						
IF output impedance		R_{IF}		100		Ω
I/Q amplitude balance	f_{IF} = 500 Hz	ΔU_{IF}		3		dB
I/Q phase shift	f_{IF} = 500 Hz	φ	80	90	100	°
IF frequency range	-3dB Bandwidth	f_{IF}	0		10	MHz
IF noise voltage	f_{IF} = 500 Hz	$U_{IFnoise}$		45		nV/√Hz
	f_{IF} = 500 Hz	$U_{IFnoise}$		-147		dBV/Hz
IF output offset voltage		U_{os}		0.2		V
Supply rejection	Rejection supply pins to outputs, 500 Hz	D_{supply}		-50		dB
IF output K-LC6-RFB-01x						
IF output impedance		R_{IF}		100		Ω
IF Amplifier gain		G_{IF}		20		dB
I/Q amplitude balance	f_{IF} = 500 Hz	ΔU_{IF}		3		dB
I/Q phase shift	f_{IF} = 500 Hz	φ	80	90	100	°
IF frequency range	-3 dB Bandwidth	f_{IF}	10		15k	Hz
IF noise voltage	f_{IF} = 500 Hz	$U_{IFnoise}$		450		nV/√Hz
	f_{IF} = 500 Hz	$U_{IFnoise}$		-127		dBV/Hz
IF output offset voltage		U_{os}	2.25	2.5	2.75	V
Supply rejection	Rejection supply pins to outputs, 500 Hz	D_{supply}		-50		dB

Parameter	Conditions/Notes	Symbol	Min	Typ	Max	Unit
Antenna						
Horizontal -3dB beamwidth	E-Plane	W_φ		12		°
Vertical -3dB beamwidth	H-Plane	W_θ		80		°
Horiz. sidelobe suppression		D_φ		-20		dB
Vert. sidelobe suppression		D_θ		-18		dB
Body						
Outline Dimensions	connector left unconnected			66 × 5 × 6		mm³
Weight				6		g
Connector				5 (+ 3)		Pins
ESD Ratings						
Electrostatic Discharge	Human Body Model Class 1A	VESD			500	V

Note 1 Use a low noise voltage source.

Note 2 Theoretical value, given by design.

Note 3 The VCO Input has an internal voltage divider. If the VCO Pin is left open the voltage is typically 1.65V.

Note 4 Transmit frequency stays within 24.050 to 24.250 GHz over the specified temperature.

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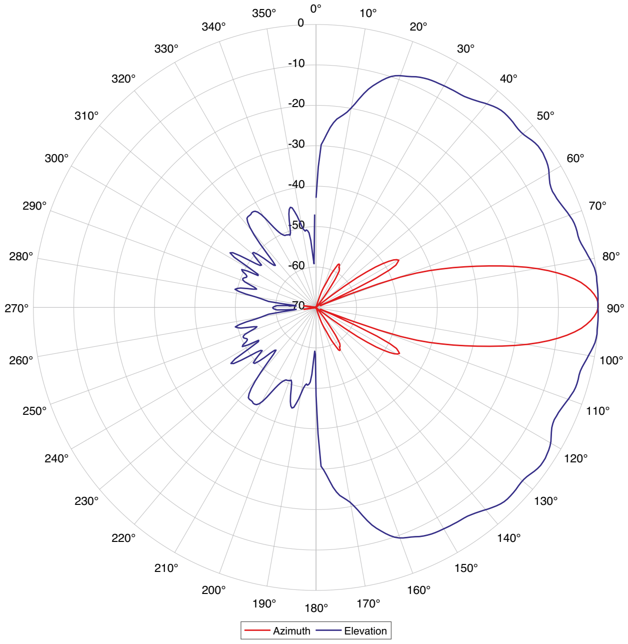
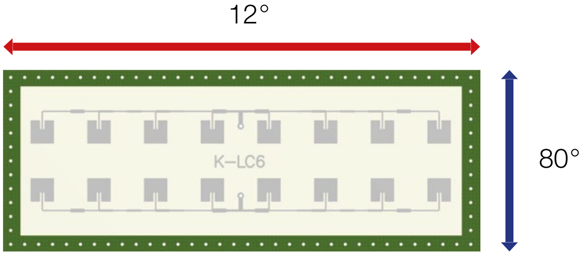
ANTENNA SYSTEM DIAGRAM

This diagram shows module sensitivity (output voltage) in both azimuth and elevation directions. It incorporates the transmitter and receiver antenna characteristics.

Figure 2: Antenna system diagram





PIN CONFIGURATION

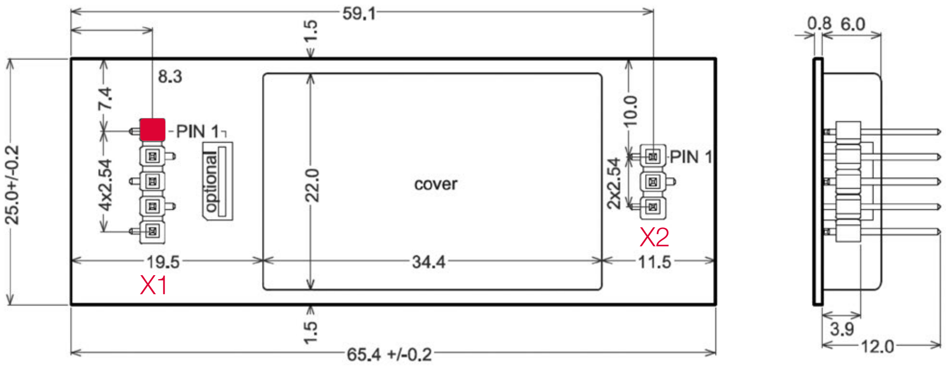
Table 1: Pin function description

Connector	Pin No.	Name	Description
X1	1	IF out Q	Intermediate frequency output Q, typical load: 1 kΩ
	2	Vcc	DC Supply V+
	3	IF out I	Intermediate frequency output I, typical load: 1 kΩ
	4	GND	Supply GND
	5	VCO in	U_{VCO} or left open
X2	1-3	Mounting	Leave this pins floating or connect it to GND

Do not touch open connector pins. RFbeam K-LC6 radar module is susceptible to electrical discharge as long as it is not placed in the circuit.

OUTLINE DIMENSIONS

Figure 3: Outline dimensions



APPLICATION NOTES

Sensitivity and Maximum Range

The values indicated here are intended to give you a ‘feeling’ of the attainable detection range with this module. It is not possible to define an exact RCS (radar cross section) value of real objects because reflectivity depends on many parameters. The RCS variations however influence the maximum range only by $\sqrt[4]{\sigma}$.

Maximum range for Doppler movement depends mainly on:

- **Module sensitivity**
  S: -126 dBc (@ 1kHz IF Bandwidth)
- **Carrier frequency**
  f_{TX}: 24.125 GHz
- **Radar cross section RCS “reflectivity” of the object**
  σ[1]: 1 m² approx. for a moving person
  > 50 m² for a moving car

note [1] RCS indications are very inaccurate and may vary by factors of 10 and more.

The famous “Radar Equation” may be reduced for our K-band module to the following relation:

$$r = 0.0167 \cdot 10^{\frac{-s}{40}} \cdot \sqrt[4]{\sigma}$$

Using this formula, you get
an indicative detection range of:
- 24 meters for a moving person.
- 62 meters for a moving car

Please note, that range values also highly depend on the performance of signal processing, environment conditions (i.e. rain, fog), housing of the module and other factors.

With K-LC6, you can achieve a maximum range of more than 100 m when using high resolution AD-converters and selective FFT algorithms.

EC-DECLARATION OF CONFORMITY

This product complies with the essential requirements of the RED Directive 2014/53/EU, and can be used in all countries within Europe.

ORDER INFORMATION

Figure 4: Ordering number structure

Product	–	Customer	–	HW variant	Supply
= **K-LC6**		= **RFB** for standard products		= **00** no IF Amplifier = **01** with IF Amplifier	= **C** for 3.3 V version = **D** for 5 V version

Table 2: Available ordering numbers

Ordering number	Description
K-LC6-RFB-00C	Standard K-LC6, 3.3V version
K-LC6-RFB-00D	Standard K-LC6, 5V version
K-LC6-RFB-01C	K-LC6 with internal IF Amplifier, 3.3V version
K-LC6-RFB-01D	K-LC6 with internal IF Amplifier, 5V version

DATASHEET REVISION HISTORY

04/2012 – Revision A:	initial release
04/2012 – Revision B:	Corrected values in chapter Using VCO and IF Amplifier
11/2018 – Revision C:	Changed footer to new address
10/2019 – Revision D:	Changes in specification because of redesigned module