

Proposal for a Remotely Operated Intrusion Alarm

Team 6

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Introduction

The design project is to develop a remotely operated intrusion alarm, which will alert the user via email and text message that there has been an intrusion. For this project a radar working in stand-alone mode will be used to detect the intrusion. This information about the intruder will then be sent to the user's cell phone. This project has been developed as a less complex version by other students, which was previously developed by MIT Lincoln Laboratory as a classroom project. However, the earlier system has many shortcomings such as a lack of speed, accuracy, and portability. These three parts are key to fulfilling the design requirements.

A major piece of this design is to build a 2.4 GHz radar which will detect an intruder in a given area. The radar will calculate the range and speed of the intruder, which will be sent to the user when an intrusion occurs. For the radar, there will need to be an interface constructed to a smart phone, laptop, or a basic cell phone. The antenna is the first component for this design, leaving the data processing section as a major design component. This would eventually pass the data to the laptop for transmission to a cell phone via text message, and send an email to the user. A way to incorporate the processing between the antenna and the laptop is using a TI ADC PCM1808 in combination with TI Stellaris LM3S9D92 microcontroller. By using these two components, most of the interfacing is already incorporated between the two. After that, the information on the Stellaris is ported to the PC via Ethernet, and the PC sends the message to the user. This design is small, power efficient, and will allow an optimal sampling rate in order to obtain real-time data, as well as system portability.

Background

The remotely operated intrusion alarm is a modification to a system previously developed by MIT Lincoln Lab. The previous system was used in a classroom environment as a teaching tool¹.

The intrusion detection system utilizes a frequency modulated continuous-wave radar. The system functions by constantly transmitting a high frequency wave that is varied from 2.26GHz to 2.59GHz. The signal is reflected off of an object, and received at an antenna which is located near the transmitting antenna. This received signal is identical to the transmitted signal, only with a delay in time due to the propagation speed of the electromagnetic wave, and reduced in amplitude. This time-delayed signal is then mixed with the original signal, producing an output signal with a frequency below 20kHz, which can be easily measured with a microphone input to a computer.

A ramp signal generator is used to vary our signal source over our full 330MHz range. A ramp signal with a frequency of 25Hz, and a peak-to-peak voltage of five volts is given as the modulation input to a voltage controlled oscillator, which produces the transmitted signal. This also generates a synchronization signal which is used to identify periods when data is to be processed for target identification.

The audio range signal created from the mixing of the transmitted and received signals is measured using the right channel of a stereo microphone input on a computer. The synchronization signal created from the ramp signal generator is measured using the left channel of the same stereo microphone input. This

¹ <http://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/index.htm>

stereo audio signal is recorded for some period of time by a user, and later processed using a MATLAB program. The result of the output from this MATLAB program is to be interpreted by the user to extract any useful information.

The intrusion alarm radar was developed as a teaching tool, which can be assembled by students, and allow them to quickly design the signal processing required to detect objects. This has several shortcomings which need to be addressed, including speed, accuracy and portability, which make the radar designed by Lincoln Lab impractical for use in an intrusion detection system.

Speed is crucial to the proper operation of any intrusion monitoring system. The system developed by Lincoln Lab requires a significant amount of user interaction, a result in which is very slow operation. Currently, the audio signal, which comes from this system, is recorded for a duration of time by the user. This signal is then processed by MATLAB, which returns an image displaying range to an object versus time. Due to the very slow operation of this system, an intruder cannot be detected in real time. Instead, the intrusion can only be detected after the event has passed. For any sensor to be used in a secure environment, this response time is not acceptable.

In addition to the slow response time of this system, accuracy is another area of potential failure. Currently, the image MATLAB returns of the processed signal must be interpreted by a user. This image can be difficult for a user to interpret. The image is color coded to convey the amplitude of the signal returned by the detected object. Should the received signal be of sufficiently low amplitude, it may be difficult to distinguish from colors of other received signals with similar amplitude. As a result, should this low-amplitude signal be shown to change range over time, a user can misinterpret the data and fail to detect an intruder.

Portability is a significant factor in the design of any intrusion detecting system. The system designed by Lincoln Lab requires a computer near the radar platform to receive and process the audio signal generated by the system. This is, quite often, not a practical requirement in an environment to be secured. In this configuration, a power source must be available for the computer to operate for any significant duration. This requirement increases the difficulty of moving the platform to a new location, should it be discovered it was not originally placed in an optimal location. The system should be easy to adapt to changing conditions.

For any system to be used to detect an intruder, the system must respond quickly enough to detect when an object moves. The system should be easy to deploy in a multitude of locations, as well as easy to change the desired location of the sensor. Finally, the system should be able to operate with autonomy. Unfortunately, the intrusion detection system as currently designed is not capable of fulfilling any of these requirements.

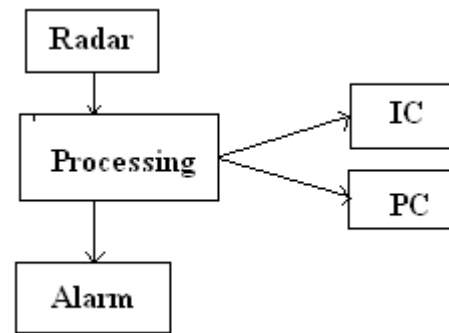
Objectives

The overall mission of this project is to develop a stand-alone radar intrusion system that alerts the user of an intruder via email or SMS. The project begins with recreating the MIT Lincoln Lab IAP 2011 Laptop Based Radar, and testing and calibrating the system to ensure proper performance for ranging mode. The system must then be modified for real-time analysis, with a customer emphasis on implementing an Analog to Digital Converter (ADC). The system must then send an alert message conveying important information such as range, speed, and possibly a photograph. This message can be sent through email, text, or a smartphone application.

There are several important design specifications to this project. The first is speed; the device must be fast enough to monitor a room in real time and alert the user of an intruder within a few seconds. The second is size; the device must be small enough and flexible enough to mount on a wall, ceiling, or table in a corner or side of the room. The third design spec is communication; the device must be able to communicate over long distances in order to immediately alert the user of an intrusion. The fourth design spec is remote ability; the device must be able to be powered, function, and communicate remotely.

Conceptual Design Descriptions

This system can be designed in one of two ways, as shown in Figure 1. One way to design the system is to do the processing on a PC and the other way is to do the processing on an on board chip. The basic system includes a radar antenna, a means of processing, and a way to set off an alarm or alert. The alert could be an e-mail, text message, or a combination of the two. The radar stage of the system which has been provided will not change unless an antenna with different dimensions is used. If a different sized can is used, minor calculations will be required in order to achieve the same signal.



If a PC is chosen to do the processing, MATLAB and LabView can be used to do the processing and C# can be used to send the alert. In order to send the signal from the radar system to the PC an analog to digital converter and a digital to analog converter will be required. More ICs are required to send information to do this. The advantages to using a PC for processing are simpler coding, large amounts of memory, and an interface to monitor code. The disadvantages to using a PC to do the processing are added noise due to the added complexity with the digital to analog converter and added ICs to couple with different interfaces. The time needed to send a full signal to the PC will limit the time that the system is able to scan and take in information.

Figure 1 - Processing Options

The signal from the RF/antenna stage can be sent via a wired connection or a wireless connection. Wireless connections include Wi-Fi and Bluetooth. Advantages of wireless communication include mobility, being able to deploy the system anywhere, and not being limited to the length of a cord. A disadvantage to using a wireless communication system is that the radar will not be able to sweep while communication with the PC due to frequency interferences. The rate at which the signals can be transmitted over a wireless connection is limited to 256kbps. A faster transmission time is required in order to spend more time detecting and less time transmitting signals to process. Another major disadvantage to a wireless connection is the systems vulnerability to an intruder jamming the system.

A wired connection to the PC allows faster transmission time which can be done using a serial input, USB, or an Ethernet connection. Using a serial communication system is simple to interface, more secure than wireless, and easy to troubleshoot. Serial communication only allows a transmission rate of up to 200kbps, which again is too slow for the size of signal that will be sent.

Connecting to the PC with a USB interface allows faster transmission speeds. USB 2.0 enables transmission speeds up to 144Mbps, which is sufficient to transmit the signal to the PC. The main disadvantage to a USB connection is the short length of cable available, limiting the range of the processing unit. If more than one USB is connected together via a repeater, the signal to noise ratio is

increased as well as the cost of the system for extra controllers and connectors. The addition of controllers to drive the extra connectors makes the system more complex.

An Ethernet connection between the RF stage and the processing unit allows transmission speeds between 10 and 100 Mbps. These speeds are sufficient to transmit a signal to the PC for processing while the radar continues to sweep. Ethernet is inexpensive and provides as much distance between the RF stage and the PC as needed. Ethernet cables have been tested up to 100 yards with zero noise added to a signal. A disadvantage to using Ethernet is that an additional controller is required to interface the Ethernet as well as additional code to connect to the system.

Processing of the signals can also be done on an on board microchip. Processing of signals on a microchip eliminates the transmission time required to send the signals to a PC. The digital to analog converter will also be removed from the system because the signal will not be sent to the PC. There are many microchips available to do the necessary processing. The Microchip-PIC32 and TI-Stellaris 9000 series are two microprocessors that have everything needed to implement into the system.

Microchip PIC32 has an on board Ethernet interface which eliminates an extra controller and extra code to interface the Ethernet. In addition to the Ethernet interface, the controller has a USB, I²C, and UART interfaces. The disadvantage of using the PIC32 is that it does not have an I²S interface needed to communicate to the analog to digital converter. The Stellaris 9000 series controllers have all of the interfaces needed to communicate with the system as well as an I²S interface. Having an I²S interface on eliminates the need for a dsPIC to couple between I²C and I²S interfaces. Without the need for a dsPIC the cost of the system decreases as well as the systems complexity.

We used a feasibility matrix to help us make our design decisions, seen in Figure 2. The matrix shows that the best options are Ethernet for our communication, and the Stellaris microcontroller for the processing.

Criteria	Importance	Possible Solutions					
		Wireless	Serial	USB	Ethernet	PIC32	Stellaris
Speed	5	1	1	9	9	3	9
Size	3					3	9
Communication	4	3	3	9	9		
Remote	4	9	9	1	9		
Totals		53	53	85	117	24	72

Figure 2 - Feasibility Matrix

Proposed Design Solution

The following is a description of the design being implemented. This design can be broken into several components and subcomponents, each with a specialized function to allow for successful communication of an intrusion message. The high level block diagram of the complete system is shown in Figure 3.

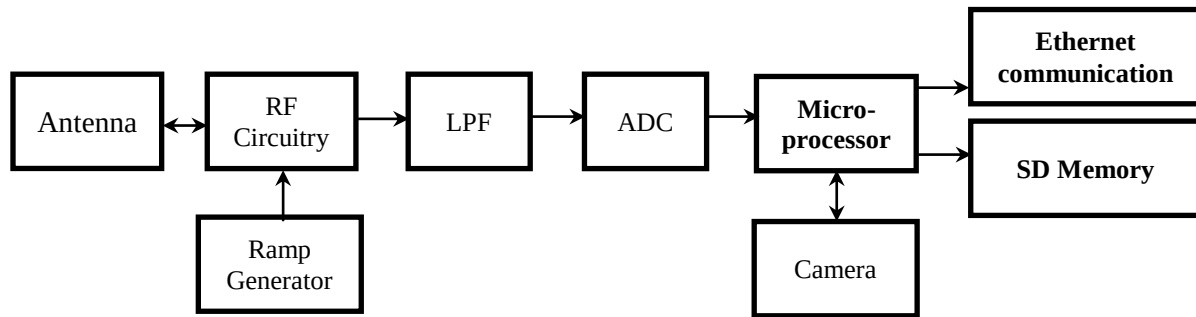


Figure 3 - Complete System

The RF circuitry is comprised of a group of subcomponents. The block diagram of the RF system is shown in Figure 4.

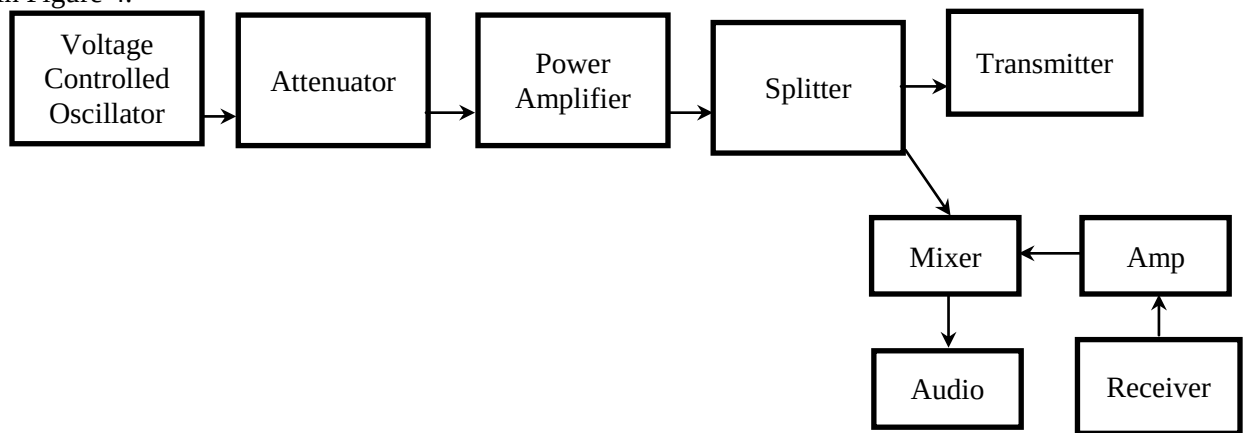


Figure 4 - RF Block Diagram

In order to analyze the differences between successive analog signals from the RF component, the mixed analog signal will be passed through a low pass filter into the PCM1808 analog to digital converter (ADC). The PCM1808 is a 24 bit ADC; 24 bit resolution is desirable because the output digital signal will allow for high sensitivity to motion. Filtered digital signal will then be passed using an I2S data link into a Stellaris LM3S9D92 microprocessor. The microprocessor will be used to perform a Fourier Transform on the input to the microprocessor. The output from the Fourier transform will be an array of frequencies and amplitudes. Successive Fourier transforms will be compared to determine if there is a change in amplitude at each frequency. These changes will correspond to motion in the room being scanned. If motion is detected a flag on the microprocessor will be set to trigger an alert. The alert as well as the data from the successive Fourier transforms will be sent to a PC using the Ethernet port on the Stellaris microprocessor.

Once the computer receives an alert package, it creates an email containing the speed and range of the intruder, as well as a timestamp of when the intrusion occurred. This email is then sent to a person or list of persons that should be alerted, as designated by the user.

Risk Analysis

Impact (Level)	Probability (Level)	Risk Assessment
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Battery Overload resulting in injury (Low – 2)	Low (2)	Broadly acceptable (4)
RF electronics overload – no injuries, but high impact on project performance (High – 4)	Low (2)	Narrowly acceptable (8)

Figure 5 - Risk Analysis Table

Currently there are two main risks involved in this project: one safety related risk and one performance related risk. These are shown in Figure 5. Risk Acceptability was performed using the chart in Figure 6. If a battery power supply is used, there is a low risk of a battery overload, which could cause injury to one of our group members. However, since both the probability and impact (magnitude of likely injury) are both low, this risk has been ranked as “broadly acceptable”. Additionally, there is a low probability that a wiring error could cause an overload in the RF electronic portion of the project, burning the components. While this would not result in injury, the RF component would need to be replaced, which does not fit in the budget; thus, the impact is high. This risk falls into the “narrowly acceptable” ranking. Care should be taken by all group members to ensure this does not occur – it is recommended that all wiring be checked by at least two group members before using the RF circuitry.

		Impact				
		Very Low	Low	Medium	High	Very High
		1	2	3	4	5
Probability	Very High	5	10	15	20	25
	High	4	8	12	16	20
	Medium	3	6	9	12	15
	Low	2	4	6	8	10
	Very Low	1	2	3	4	5

Figure 6 - Probability/Impact Table

Green: Broadly acceptable
Yellow: Narrowly acceptable
Red: Unacceptable

Project Management Plan

Personnel

Peter Deacon: Antenna construction, signal generator assembly, filter assembly, central control programming

Ryan Hunt: Signal generator assembly, filter assembly, communication system programming

Chris Leonard: Antenna construction, PCB layout, central control programming

Darci Koenigsknecht: Transmitter assembly, PCB layout, communication system programming, signal processing

Chris Oakley: PCB layout, PCB assembly, communication system programming, storage programming, signal processing

Resources required:

Testing equipment:

Network Analyzer capable of minimum 2.6GHz operation

Signal generator capable of minimum 2.6GHz operation

Anechoic chamber

Oscilloscope

Power supply

Multimeter

Logic Analyzer

Equipment Assembly

Drill

Soldering station

Programming of microcontrollers

Code Composer

Project Schedule

See Appendix

Budget

The requirements of this project will be fulfilled with less than \$500. The RF stage of the system can be completed with \$235.55. The antenna design will be completed with \$53.48. The rest of the circuit, including the analog and power requirements, will be completed with \$71.60. An additional cost of \$11.72 has been added to the budget due to technical complications. An analog to digital converter break-out board needed to be designed and fabricated which added another \$13.08 to the budget. With these five sections of the system, the project comes to a grand total of \$384.76.

Radar RF Stage					
Callout	Quantity	Part #	Description	Cost Each	Subtotal
OSC1	1	ZX95-2536C+	2315-2536 MC VCO +6dBm out	\$42.50	
ATT1	1	VAT-3+	3dB SMA M-F attenuator	\$9.95	
PA1/LNA1	2	ZX60-272LN-S+	Gain 14 dB, NF=1.2 dB, IP1= 18.5 dBm	\$39.95	
SPLTR1	1	ZX10-2-42+	1900-4200 Mc, 0.1 dB insertion loss	\$34.95	
MXR1	1	ZX05-43MH-S+	13 dBm LO, RF to LO loss 6.1 dB, IP1 9dBm	\$46.45	
SMA M-M Barrels	4	SM-SM50+	SMA-SMA M-M barrel	\$5.45	
					\$235.55

Cantennas					
Callout	Quantity	Part #	Description	Cost Each	Subtotal
Can	2	TBD	Coffee Can	\$5.00	
L Bracket	2	NA	L-bracket, 7/8", zinc plated	\$0.35	
SMA F Bulkhead	2	901-9889-RFX	SMA bulkhead F solder cup	\$4.27	
6-32 Screws	1	NA	6-32 machine screw, 5/8" length	\$3.49	
6-32 Nuts	1	NA	6-32 hex nuts	\$1.09	
6-32 Washers	1	NA	lock washers for 6-32 screws, pk of 100	\$0.71	
6" SMA M-M cables	3	086-12SM+	SMA-SMA M-M 6" cable	\$9.65	
					\$53.48

Analog, Power, and misc					
Callout	Quantity	Part #	Description	Cost Each	Subtotal
Wood Screws	1	NA	brass #2 wood screws 3/8" long	\$3.70	
Measuring Tape	1	NA	50' long measuring tape	\$11.22	
Wood Screws	1	NA	12" wide by 1" thick 8" long wood	\$14.37	
Modulator1	1	XR-2206	Function Generator Chip	\$4.05	
Video Amp 1	1	MAX414CPD+	low-noise quad op-amp	\$14.46	
Solderless Breadboard	1	EXP-300E	6.5x1.75" solderless breadboard	\$7.00	
C1-4	4	SA105A102JAR	1000 pf 5% capacitor	\$0.22	
R1a_1	1	MFR-25F8F-8K45	8450 ohm 1% resistor	\$0.11	
R1b_1	1	MFR-25F8F-102K	102K ohm 1% resistor	\$0.11	
R2_1	1	MFR-25F8F-7K15	7150 ohm 1% resistor	\$0.11	
Rf_1_2	3	MFR-25F8F-1K00	1K ohm 1% resistor	\$0.11	
Rg_1	1	MFR-25F8F-12K1	12.1K ohm 1% resistor	\$0.11	
R1a_2	1	MFR-25F8F-17K4	17.4K ohm 1% resistor	\$0.11	
R1b_2	1	MFR-25F8F-28K0	28K ohm 1% resistor	\$0.11	
R2_2	1	MFR-25F8F-4K12	4120 ohm 1% resistor	\$0.11	
Rg_2	1	MFR-25F8F-1K62	1620 ohm 1% resistor	\$0.11	
Decoupling Cap	2	K104Z15Y5VE5TH5	0.1 uf	\$0.05	
Decoupling Cap	2	UVR1E101MED1TD	100 uF	\$0.03	
Trimmer Pot.	1	PV36Y103C01B00	10K	\$0.92	
Gain resistor	1	CFP1/4CT52R201J	200 ohm, 5%	\$0.05	
Battery Pack	2	SBH-341-1AS-R	4xAA battery pack	\$0.95	
AA Batteries	8	PC1500	AA battery	\$0.54	
5V Regulator	1	LM2940CT-5.0/NOPB	5V low dropout regulator	\$1.77	
Audio Cord	1	172-2236	3.5 mm plug to stripped wires	\$2.42	
Wire Ties	2	41931	4" cable ties	\$0.04	
Tuning Capacitor	1	FK28Y5V1E474Z	0.47 uf capacitor	\$0.21	
2M Trimmer Pot	1	PV36W205C01B00	2M trimmer potentiometer	\$0.92	
50K Trimmer Pot	1	PV36W503C01B00	50K trimmer potentiometer	\$0.92	
1 uF Cap	1	UVR1H010MDD1TD	1 uF electrolytic cap	\$0.04	
10 uF Cap	1	UVR1H100MDD1TA	10 uF electrolytic capacitor	\$0.03	
5.1K Resistor	2	MF1/4DCT52R5101F	5.1K resistor	\$0.05	
10K Resistor	2	CCF0710K0JKE36	10K resistor	\$0.04	
LED	1	TLHR5400	Red LED	\$0.07	
1K LED resistor	1	CCF071K00JKE36	1K resistor	\$0.04	
100K Resistor	2	CCF07100KJKE36	100K resistor	\$0.04	
47K resistor	12	CCF0747K0JKE36	47K 5% resistor	\$0.04	
1 UuF Cap Unpolar	1	T356A105M020AT7301	1 uf tantalum capacitor	\$0.31	
					\$71.60

Extras					
Callout	Quantity	Part #	Description	Cost Each	Subtotal
	2	1MAX414CPD+	MAX414CPD+-ND	\$5.86	
					\$11.72

ADC Board					
Callout	Quantity	Part #	Description	Cost Each	Subtotal
24.576MHz Oscillator	1		24.576MHz Oscillator	\$2.25	
10uF electrolytic Cap	10		10uF electrolytic Cap	\$0.12	
0.1uF ceramic Cap	10		0.1uF ceramic Cap	\$0.07	
5V regulator	3		5V regulator	\$0.42	
3.3V regulator	3		3.3V regulator	\$0.55	
Low ESR Cap	4		Low ESR Cap	\$0.63	
Header	1		Header	\$3.50	
					\$13.08

Grand Total
\$384.76

Appendix