

ECE 480: Electrical and Computer Engineering Capstone Design

An Interactive Radar Demonstrator for Children

Team 5

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Proposal

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Executive Summary

Team five's objective is to produce an electromagnetic (EM) learning platform based on the Massachusetts Institute of Technology (MIT) Lincoln Labs radar project. This platform is designed to increase children's interest in EM electromagnetism and Radar concepts. It will be a portable demonstration device that will be displayed at the MIT Museum.

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Introduction

Radio detection and ranging (Radar) is a fascinating field that plays a major role in many modern military and civilian applications. In past times, parties interested in communications over great distances had to educate themselves in electromagnetics (EM) concepts to implement transmission and reception devices. This necessity created a large pool of engineers and technicians well-versed in these concepts for radar design and use. Radar was proven to be an amazing development during the 20th century. However, other technologies are beginning to supplement and in some ways replace radar, for instance the Global Positioning System (GPS) and wireless communications.

Consequently, our main goal is to produce an EM demonstrative device using radar that will be highly interesting, especially for the younger generation. This device will provide the children with the essential exposure and basic ideas behind radar by allowing them to interact with a low-power and safe radar. Early education in these concepts is an important aspect in attracting more attention to these fields in the future. The Massachusetts Institute of Technology Museum attracts hordes of young children ripe for engineering indoctrination. The hands-on nature of the radar project will plant a seed in the minds of the children, a seed which will hopefully grow into the delectable fruit of curiosity in the future.

Background

Radar in its modern conceptualization has existed since World War II, during which it was used to track air targets for military purposes. With time, this technology has extended to uses in communications, weather tracking, sensors, police work, and more. This means that the use of radar is growing among the general population.

Radar makes use of well-known EM phenomena to characterize a target. A transmitting antenna produces a user-defined EM wave which reflects off of surfaces in the beam path. These reflected waves are received and processed to retrieve useful information about the objects in the signal path. Position and its derivative components, velocity and acceleration, can effectively be characterized to varying degrees of accuracy depending on characteristics of the transmitted wave.

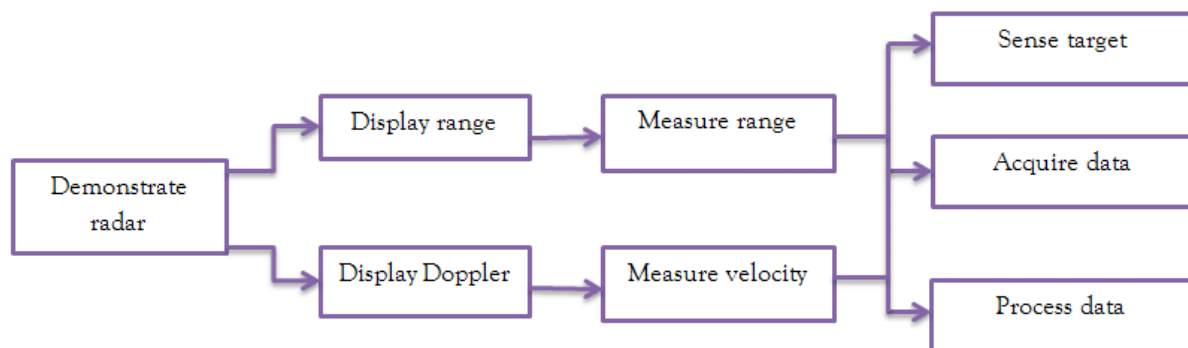
Massachusetts Institute of Technology Lincoln Laboratory (MITLL) developed a kit to demonstrate radar system principles utilizing affordable, off the shelf parts and a simple, easy to understand design. MITLL's kit is designed for use with a laptop as the processing unit. To extract the desired information from the radar output signal, it must undergo a user-facilitated processing sequence, and the data thus cannot be displayed in real time. Our project aims to automate signal interpretation and to display the desired information in real time. The display will appeal to children by incorporating interactive visually-stimulating graphics.

Objectives/Design Specifications

- To spark youth's interest in radar engineering through hands-on and interactive experiments
- To repackaging the improved radar system according to MIT Museum's specification
 - Housed in a stand-alone and movable cart system
 - Approximate one meter in height
 - Other dimensions will depend on the size of the radar system
- To demonstrate a visually stimulating radar effects for children
 - Output video in a "waterfall" configuration to display output information
- To improve of an existing low cost radar system developed for instructional use by adding a data acquisition and processing chain
- To construct an operational prototype capable of producing meaningful radar displays (range vs. time intensity and Doppler vs. time intensity) through real time data processing
 - Processing must eliminate static objects to avoid 'room blindness'
 - Processing type (ranging or speed detection) will be selected with an external switch

The team's basic objective is to produce an educational EM exhibit based on the MITLL radar project kit. Early exposure to scientific concepts is an important factor in a child's future learning interests. The final product, meant for the MIT Museum, will be surrounded by many static objects. These must be filtered out so that children will only see themselves in the output. Output should make intuitive sense with little in the way of interpretation.

FAST Diagram



Conceptual Design Descriptions

Radar utilizes high frequency carrier signals which are impossible to accurately process with basic hardware. MIT's kit employs a mixer which multiplies a transmission reference signal with the input signal. Multiplication produces a phase difference representation of the signal in the audio frequency band. Frequencies in this range are easily manipulated, as they are widely used in existing designs. Materials and references are abundant.

A possible design solution uses an Arduino microcontroller board for signal processing. Arduino is a hobbyist microcontroller platform with a significant user community, making it a suitable choice for our needs. Ideally, the challenges of the project's processing component will already have been addressed by the members of the community. This allows us to avoid re-inventing the wheel, and to focus on other aspects of the design.

Digitally processing an audio signal requires analog-to-digital conversion (ADC) and additional mathematical computation for signal manipulation. In order to process the signal in real time, these calculations must be performed at a rate quick enough to avoid lag in the graphical output. Fluid graphical output is necessary for the display to be engaging.

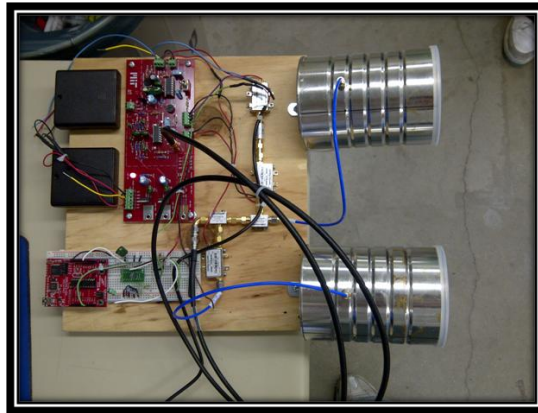
Ranging and speed-detection functions can be integrated into a single mode of operation, called moving-target indication (MTI) radar. MTI utilizes a pulsed transmission and extracts frequency shift and time delay information from the received pulse to determine speed and range, respectively. Although it is theoretically possible, its implementation in the context of our project would likely produce undesirable results and exceeds our budget. MTI suffers from multiple blind frequencies, resulting in poor Doppler visibility. This disadvantage, coupled with the high cost of building such a radar system, significantly reduces the viability of MTI for our purposes.

Our radar will be capable of non-simultaneous ranging and speed detection, greatly simplifying the design and testing process. The user will be able to select the intended mode of operation with a switch. In speed-detection mode, the radar transmits a continuous 2.4 GHz wave with no modulation. The reflected signal is frequency-mixed with the transmitted signal. This produces a sum of sinusoidal outputs whose phases are the phase difference and sum of the transmitted and reflected signals, respectively. A low-pass filter eliminates the high-frequency component of the signal. The speed of the target is determined by a linear relation with the frequency of this output signal. In ranging mode, the 2.4 GHz transmitted signal will be frequency-modulated by a ramp waveform, producing a 'chirp'. The radar system can detect the range of an object by analyzing the spectrum of the reflected signal and then using the individual frequency components of the chirp as a reference against which to compare the reflected signal. Digital signal processing will allow us to determine the target's speed or range in real time and to display it logically and colorfully on an external screen.

Ranking of Conceptual Designs

1. Arduino-based signal processing with non-simultaneous ranging and speed detection.
2. Arduino-based signal processing with simultaneous ranging and speed detection.
3. Moving target indication (MTI) radar with simultaneous ranging and speed detection.
4. Digital signal processing chip (DSP) based radar with simultaneous ranging and speed detection.

After researching our options, we decided to design our processing system around the Arduino platform. Its ease of use and vast user community support make it a very attractive choice for our specialized computational needs. The microprocessor on the Arduino board is a general-purpose chip, allowing the user significant computational versatility.



Layout of the Pre-constructed MITLL kit

The radar pictured above was prepared by a team from the previous semester. The RF circuitry consists of a VCO, attenuator, two amplifiers, a splitter and a frequency mixer. All of the components have approximately 2.4GHz operating frequency and 50Ω impedance. These components are manufactured by Mini-Circuits.



Layout of the Arduino MEGA 2560R3

The Arduino MEGA 2560 R3 is the specific model our project will employ. It will process the radar output signal and communicate the ranging and speed information gained thereby to the PICASO for graphical processing.

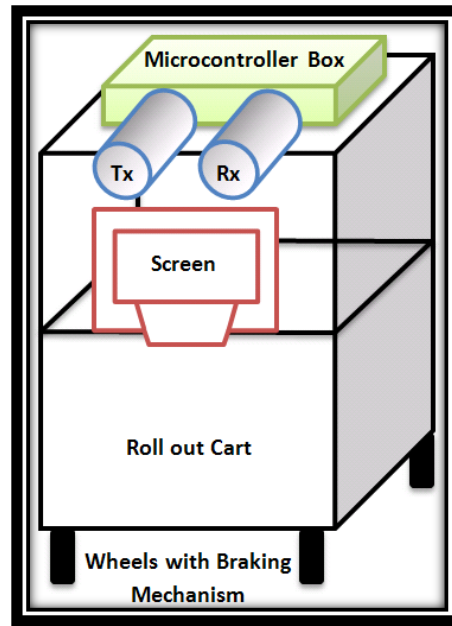


Layout of PICASO GFX2 Graphics Processor

PICASO GFX2 graphics processor will be used for image processing to display the range and velocity versus time. Upper-level graphics functions make the GFX2 easy to use, and its VGA output is

compatible with most modern displays. The GFX2 outputs 256 colors which, when compared to similar GPUs, is a wide range.

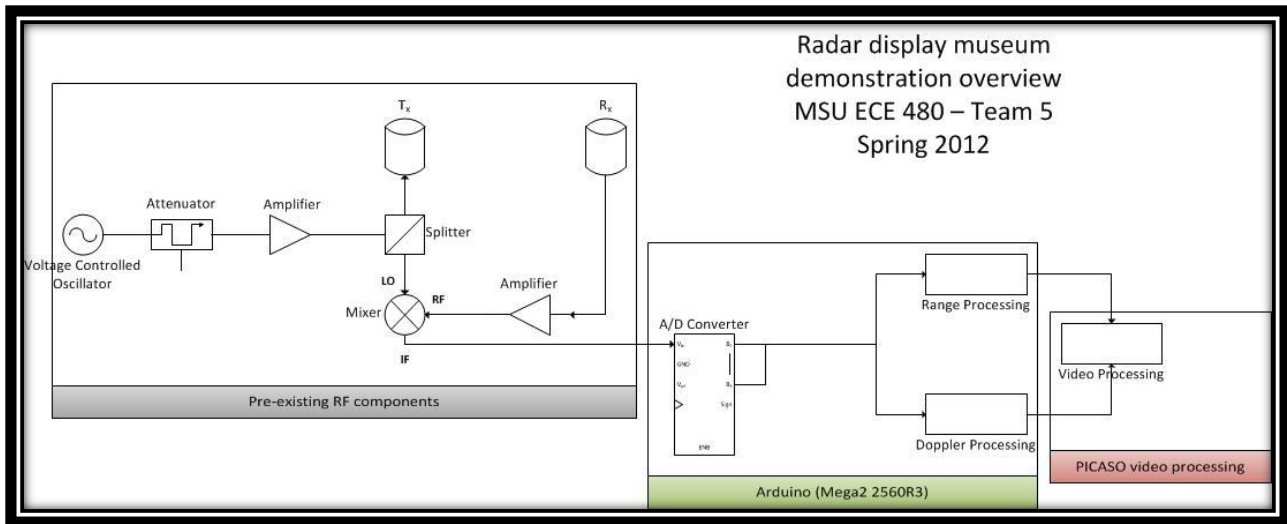
Proposed Design solution



End product prototype

After considering all designs specifications given and goals that we had set, our radar system will be assembled in a similar manner shown in the figure above. We will have 3 major components which are the “can-tennas”, microcontroller box and an output screen. Further modifications will be done in terms of the placement of the components on the dimensions of the roll out cart, output screen and the enclosed box.

The “can-tennas” will be placed at approximately 1m height which is the average height of a 6 year old. All of the microcontrollers used will be enclosed in a box for protection and covered with a Plexiglas to display the controllers. The controllers will also be labeled in order for the children to identify them. The output screen will be placed on a shelf below the “can-tennas” at an appropriate height. Each of the three units will be modular allowing various placements to aid in the maintenance of the radar system in the MIT Museum.



High-level diagram of the design setup

The voltage controlled oscillator (VCO) is set to produce a constant 2.4 GHz signal by supplying its input with roughly 2 V. An IC function generator is used to produce a triangle wave which, when combined with the dc offset, modulates the VCO output, producing a frequency-modulate continuous wave (FMCW) signal. The signal is then attenuated by half (-3 dB) in order to get the maximum bandwidth from the low noise amplifier (LNA). After amplification, the signal is split between the transmission “can-tenna” and the mixer’s local oscillator (LO) port for downconversion with the radio frequency (RF) signal received from the second “can-tenna”. The output from the mixer is fed into the Arduino’s ADC port for sampling.

Risk and Concerns Analysis

Federal regulation of the EM spectrum limits the strength and bandwidth of any EM signal produced. In many radar applications, power emission constraints can be a concern. High-powered radars can emit harmful radiation and interfere with local systems operating in the same frequency band as the radar. Our proposed radar design will emit approximately 10 mW below the 2.48 GHz range, well below the ISM band power limitation of 1 W and below more strictly regulated frequency bands.

Due to time constraints, we must procure the processing hardware as soon as possible so that we can become acclimated to it. The negative experiences of past teams demonstrate the importance of an acclimation period. Theoretically ideas can be done in a day, but in practice more time is needed to insure a proper solution. This is a basic consideration in all human endeavors but with the invariability of academic scheduling it is of primary concern.

Long term maintenance is an important consideration in any design. Ideally day to day operation of the display should involve no more than flipping the on switch. This should eliminate any need for a startup procedure or other interaction on the part of museum workers. Also, access to the internal components should be easy in case part replacement is needed. The access panel will be within reach of all components and will be under lock and key for safety reasons.

Our final product will be mounted on a roll-out cart thus ensuring the structural integrity of the cart for repeated use is an important consideration. In order to protect both the radar system and users, we will implement a braking mechanism for the wheels to prevent unintended movement of the cart. In addition, sharp edges along the edge of the cart will be rounded as much as possible to protect against possible falls or other accidents.

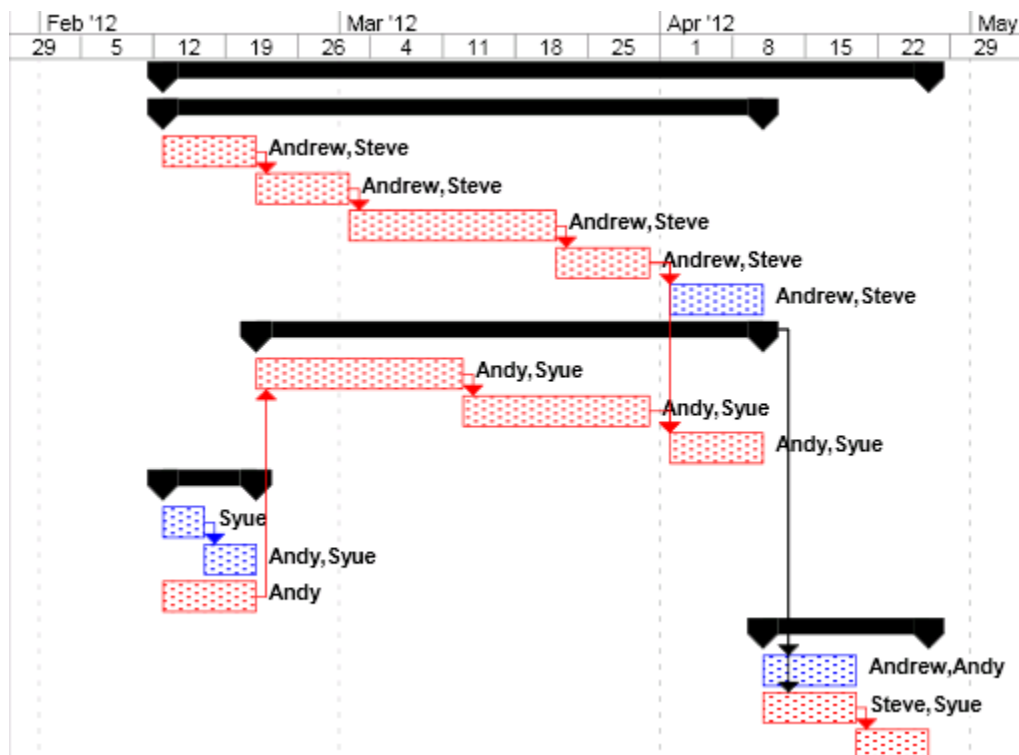
Project Management Plan

- Andrew – Signal processing and communications programming
- Andy – Graphics programming & structure design/fabrication
- Steve – Algorithmic analysis and programming
- Syue – Graphics programming & structure design/fabrication

Design plans have been structured such that tasks are always available and consensus can be reached about key project components before relevant processes are designed. We begin with primary set up to insure that future use of the radar kit is consistent. Then, as a group, we decide upon serial communication standards and insure everyone has a firm understanding of the underlying DSP principles. After this the group divides into tasks detailed in the Gantt chart below.

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Interactive Radar	54 days	Mon 2/13/12	Thu 4/26/12		Andrew,Andy, Steve,Syue
Arduino Processing	42 days	Mon 2/13/12	Tue 4/10/12		
A/D conversion	7 days	Mon 2/13/12	Tue 2/21/12		Andrew,Steve
FFT	7 days	Wed 2/22/12	Thu 3/1/12	3	Andrew,Steve
Noise Reduction	14 days	Fri 3/2/12	Wed 3/21/12	4	Andrew,Steve
Peak Detection	7 days	Thu 3/22/12	Fri 3/30/12	5	Andrew,Steve
Serial Communcation	7 days	Mon 4/2/12	Tue 4/10/12	6	Andrew,Steve
Graphics Processing	35 days	Wed 2/22/12	Tue 4/10/12		
Visual Design	14 days	Wed 2/22/12	Mon 3/12/12	15	Andy,Syue
Input Interpretation	14 days	Tue 3/13/12	Fri 3/30/12	9	Andy,Syue
Serial Communication	7 days	Mon 4/2/12	Tue 4/10/12	6,10	Andy,Syue
Analog Design/ Preperation	7 days	Mon 2/13/12	Tue 2/21/12		
Replace Pots with Resistors	4 days	Mon 2/13/12	Thu 2/16/12		Syue
Audio Band Filter?(if needed)	3 days	Fri 2/17/12	Tue 2/21/12	13	Andy,Syue
Power Supply	7 days	Mon 2/13/12	Tue 2/21/12		Andy
Cart Design/Fabrication	12 days	Wed 4/11/12	Thu 4/26/12		
Design structure and housing	7 days	Wed 4/11/12	Thu 4/19/12	8	Andrew,Andy
Plan power/wire routing	7 days	Wed 4/11/12	Thu 4/19/12	8	Steve,Syue
Final Touches/ Aesthetics	5 days	Fri 4/20/12	Thu 4/26/12	18	

Timeline for Gantt chart



Gantt chart for design process

Feasibility Matrix

Engineering Criteria	Importance	Possible Solutions		
		Arduino and PICASO Based Processing	Laptop	Digital Signal Processing Chip
Portable	8	9	9	9
Graphical Data Communication	9	3	9	1
Low Power Consumption	3	9	3	9
Real Time Processing	10	9	9	9
Ease of use	10	9	9	3
Maintenance	7	9	3	9
Total		369	363	291

Feasibility	Importance	Possible Solutions		
		Arduino and PICASO Based Processing	Laptop	Digital Signal Processing Chip
Cost	8	9	1	3
Time	10	9	3	1
Safety	7	9	3	9
Visual Output	5	3	9	3
Total		240	104	112

Budget

\$250.00 for microcontroller and associated costs (attachments, evaluation board, etc.)

- \$55.00 for PICASO Graphics Controller
- \$55.00 for Arduino Mega

\$100 for movable cart and associated costs (wood, screws, wheels, etc.)

- \$31.90 for a movable AV cart as a basis

\$150 for additional unforeseen costs

References

Arduino Mega 2560. (n.d.). In *Arduino*. Retrieved January 21, 2012, from <http://arduino.cc/en/Main/ArduinoBoardMega2560>

Day, D. A. (n.d.). Radar. In *U.S. Centennial of Flight Commission*. Retrieved February 2, 2012, from http://www.centennialofflight.gov/essay/Evolution_of_Technology/radar/Tech39.htm

Skolnik, M. I. (1962). *Introduction to Radar Systems*. USA: McGraw-Hill Book Company Inc.