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December 19, 2002

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 340 Post Mortem of MicroTracker

Dear Dr. Rawicz:

Attached is the *Post Mortem of MicroTracker*, which outlines the current status of our prototype and the difficulties we encountered during the design and implementation phases. Our objective is to create a handheld tracking device capable of locating tags attached to objects or people.

The attached document discusses the deviations between the current prototype and the original functional and design specifications. Also provided in this document are the budget and the timeline for the design and implementation phases. Furthermore, we will discuss the project management strategies we used, as well as the contributions and personal experiences obtained in doing this project.

MicroTrak Inc. consists of five enthusiastic and dedicated, fourth-year engineering students: Lawrence Li, President and Chief Executive Officer; James Dykes, Chief Financial Officer; Victor Leung, Chief Operations Officer; Herman Lo, Chief Technology Officer; and Bernard Ng, Chief Hardware Engineer. If you have any questions, feel free to contact us at (604) 525-9185 or via email at 340-group@sfu.ca.

Sincerely,

Lawrence Li

Lawrence Li
President and CEO,
MicroTrak Inc.

Enclosure: *Post Mortem of MicroTracker*
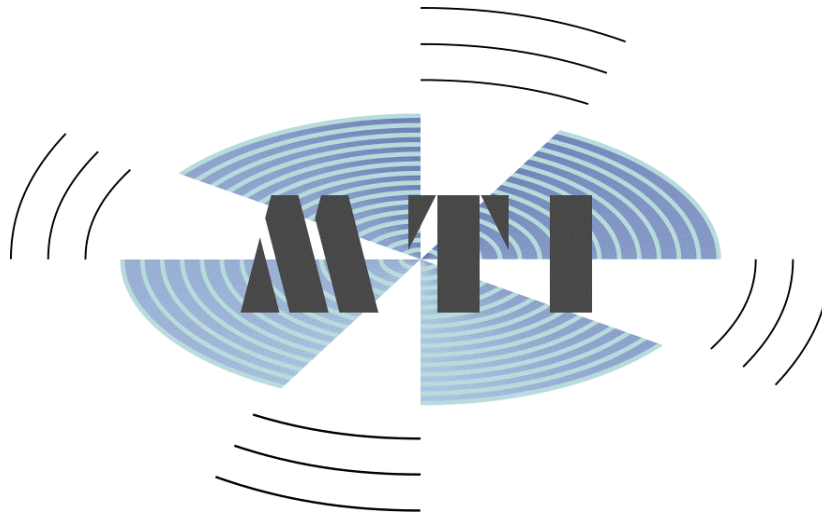
Post Mortem of MicroTracker

Project Team: **James Dykes**
                      Victor Leung
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                      Herman Lo
                      Bernard Ng

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                      340-group@sfu.ca

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1 Introduction

For the past three months, our group has worked together to create MicroTracker: A handheld wireless tracking device capable of locating missing items and people. The design of MicroTracker focuses on locating the tag based on relative signal strength, which varies with distance.

MicroTracker can be used for many applications such as locating lost items and alarming of left-behind items. In the following sections, a system overview will be provided along with a discussion on the difficulties encountered and the design changes made. In addition, the personal aspect of the project, namely the experience and knowledge gained, will be discussed.

2 System Overview

MicroTracker consists of a handheld tracker and multiple tags, as illustrated in Figure 1.

Figure 1. MicroTracker System Diagram

MicroTracker is designed to track tagged objects, to alert users when the tracker and the target tags are a user-defined distance apart, and to alarm users of the onset of the tag's SOS signal.

A powered-on tag will continuously transmit a signal to the tracker. By turning on the tracker and tuning to the target tag's channel, the tag can be located using the range indicator.

With the alarm on, users will be notified when the tracker and the tag are a user-defined apart. This function is achieved by comparing the tag's transmitted signal strength against a voltage reference as set by the users. Users also have the option of being alarmed when the tracker and the tag are too close together. This function again is achieved using signal strength comparisons. Furthermore, when the emergency button on the tag is pressed the buzzer and the emergency LED on the tracker will activate, regardless of whether the alarm is on or off.

An audio microphone circuit optionally monitors the surrounding sounds on the tag, which can be heard on the tracker through an audio jack.

3   Current State of the Project

At the time of this writing, we have built a prototype that can perform all the phase 1 functions listed in the *"Functional Specification of MicroTracker."* In addition, a surrounding sound monitoring function was added. Since MicroTracker consists of two components - tags and a tracker- each will be discussed in Sections 3.1 and 0 respectively.

3.1 Tag

3.1.1 Tag Functional Deviations

Unless otherwise specified, the functional requirements listed in the *"Functional Specifications of MicroTracker"* are fulfilled. Sections 3.1.1.1 to 3.1.1.3 discuss the critical requirements.

3.1.1.1 Physical

Due to lack of layout experience, we built the tag using a double-sided single layer PCB. Without packaging, the tag size is 70mm X 50mm X 40mm, which implies the size requirement will not be fulfilled with the packaging. However, adding 2mm to each side of the tag should not affect the usability of the tag.

The weight of a tag without packaging is 80grams. After packaging, the weight requirement of 100grams should be fulfilled. Furthermore, instead of using pushbuttons, switches were used.

3.1.1.2 Electrical

When all devices on the tag are on, the maximum current and power consumed are 21mA and 105mW, respectively; thus, the current and power consumption requirements are fulfilled. However, since the tag is continuously on, further reducing the power consumption is essential.

3.1.1.3 Antenna

We used the "ant" helical antenna from Linx instead of the "Splatch" planar antenna. The tag's transmission range is increased from 400 feet to 600 feet in open area due to the change of antenna. The drawing of the "ant" antenna with dimensions is shown in Figure 2.
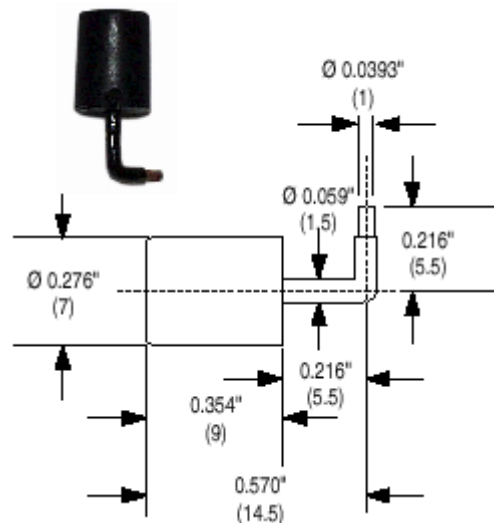

Figure 2. "Ant" Helical Antenna

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According to Figure 2, the new antenna is smaller than the old antenna, thus saving space on the tag. However, the new antenna is more vulnerable to detuning from surrounding sources of interference.

Table 1 shows the old and new antenna specifications.

Table 1. Old and New Antenna Specifications

Requirement No.	Features	Old Antenna Values	New Antenna Values	Units
[R 1]	Physical Dimensions (length x width x thickness)	1.102 x 0.54 x 0.062	0.57 x 0.0276 x 0.0276	Inch
[R 2]	Electrical Length	¼ λ	¼ λ	-
[R 3]	Center Frequency	916	916	MHz
[R 4]	Useable Bandwidth	40	30	MHz
[R 5]	Characteristic Impedance	50	50	Ohm
[R 6]	VSWR	<1.7	1.2685 – 1.8423	-
[R 7]	Loss	-1	-1	dB

3.1.2 Tag Design Deviations

Unless otherwise specified, the design of the tag is the same as stated in the *"Design Specifications of MicroTracker."* Sections 3.1.2.1 to 3.1.2.2 discuss the critical design modifications.

3.1.2.1 Tag Power Indicator

Upon realizing that the original design of the tag power indicator circuit would only output the constant voltage drop of an LED, we redesign the circuit such that 9V was supplied to the LED whose output would then be voltage divided. However, to ensure that the circuit would operate correctly we decided to characterize the output of the voltage regulator and confirm the operation of our design. Figure 3 illustrates the obtained characteristics for the voltage regulator and other node voltages in the tag power indicator circuit.
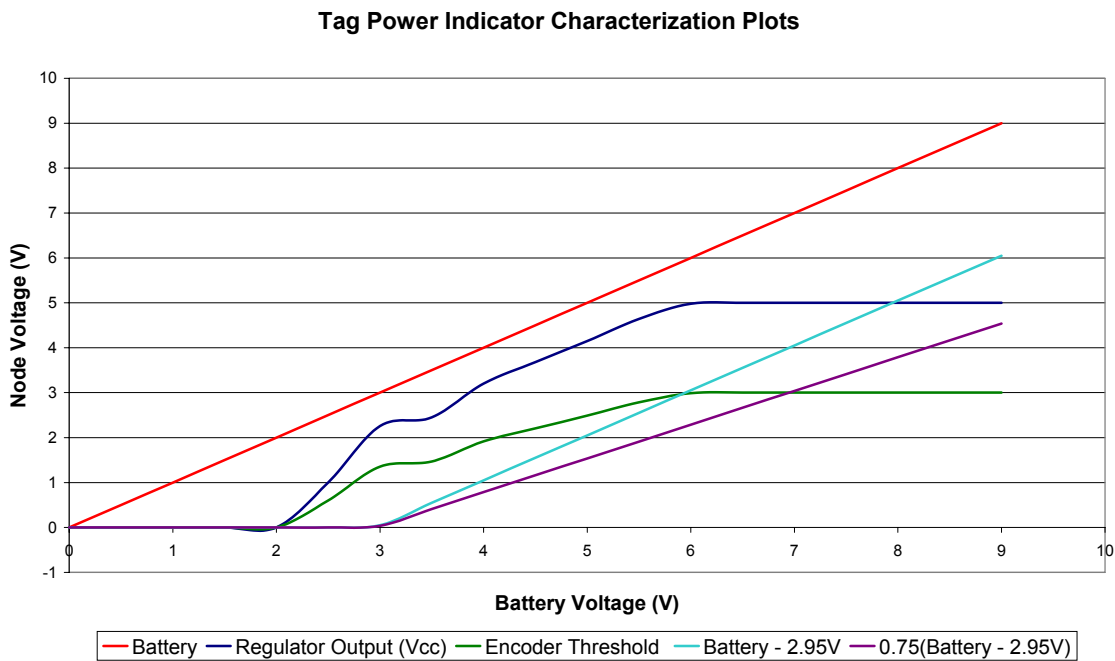
Tag Power Indicator Characterization Plots

Figure 3. Tag Power Indicator Characterization Plots

As illustrated in Figure 3, the encoder threshold for logic "1" drops significantly when the battery voltage drops below 6V. This drop is due to the decrease in the output voltage of the voltage regulator. However, due to the decrease in the encoder threshold, using an LED (1.55V) would cause the battery curve to shift down by 1.55V and the voltage divider would reduce the curve's slope. Given the input to the encoder had to be below VCC when the battery voltage was 9V, the output of the LED and voltage divider circuit would always intersect the encoder threshold twice and causing the encoder to interpret a "1" when the battery voltage is between 2.5 and 3V. To solve this problem, we were required to shift the battery curve further down before reducing its slope. Adding two diodes after the LED provided a more than sufficient voltage drop. Thus, the characteristic of the 0.75(Battery – 2.95V) curve is achieved by using an LED and 2 diodes to shift down the battery curve, and a voltage divider to reduce the curve's slope.

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Figure 4 illustrates the old and new design.

| Old Design | New Design |

Figure 4. Old and New Design of Tag PWR Indicator

Using the new design, a power low reminder will be sent to the tracker when the battery voltage drops below 7V.

3.1.2.2 Microphone

We implemented a microphone on the tag to monitor the surrounding sound at the tag's location. This option allows for baby monitoring and other applications. Figure 5 shows the schematic of the microphone circuit.
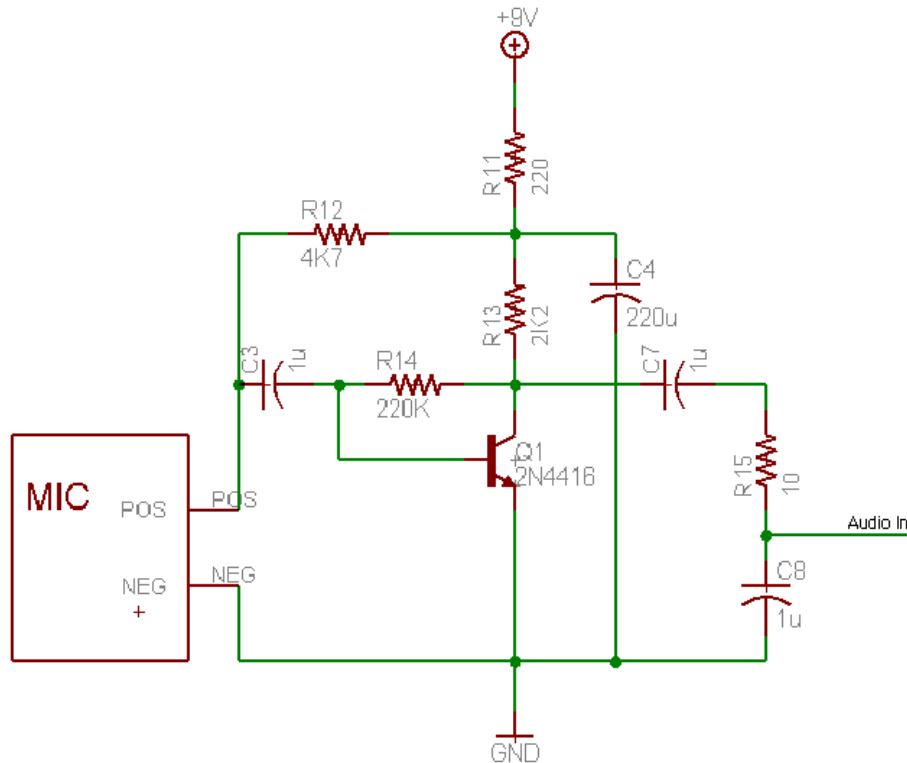
Figure 5. Microphone Circuit

R11-C4 is a low pass filter to eliminate noise from the 9V battery. C3 is for removing the DC voltage from the Q1 base input. R12 is for providing current to the microphone's small internal amplifier for proper operation. R13-R14 sets the transistor amplifier's gain to 100, which equals to R14/R13. C7 removes any DC offset from the amplifier output. R15-C8 at the output is a low pass filter with a cutoff frequency of 100KHz to reduce high frequency noise.

3.2 Tracker

3.2.1 Tracker Functional Deviations

Unless otherwise specified, the functional requirements listed in the *"Functional Specifications of MicroTracker"* are fulfilled. Sections 3.2.1.1 and 3.2.1.2 discuss the critical requirements.

3.2.1.1 Physical

Due to lack of layout experience, we built the tracker using a double-sided single layer. Without packaging, the tracker size is 100mm X 70mm X 35mm, so the size requirement was not fulfilled. However, the tracker can still fit into most pocket sizes.

The weight of a tag without packaging is 120grams. After packaging, the weight requirement of 150grams should be fulfilled. Furthermore, instead of using pushbuttons, switches were used.

3.2.1.2 Electrical

When all devices on the tracker are on, the maximum current and power consumed are 50mA and 250mW, respectively; thus, the current consumption requirement was not fulfilled but the power consumption was.

3.2.2 Tracker Design Deviations

Unless otherwise specified, the design of the tracker is the same as stated in the *"Design Specifications of MicroTracker."* Sections 3.2.2.1 and 3.2.2.2 discuss the critical design modifications.

3.2.2.1 Range Indicator

Figure 6 illustrates the old and new design of the range indicator.
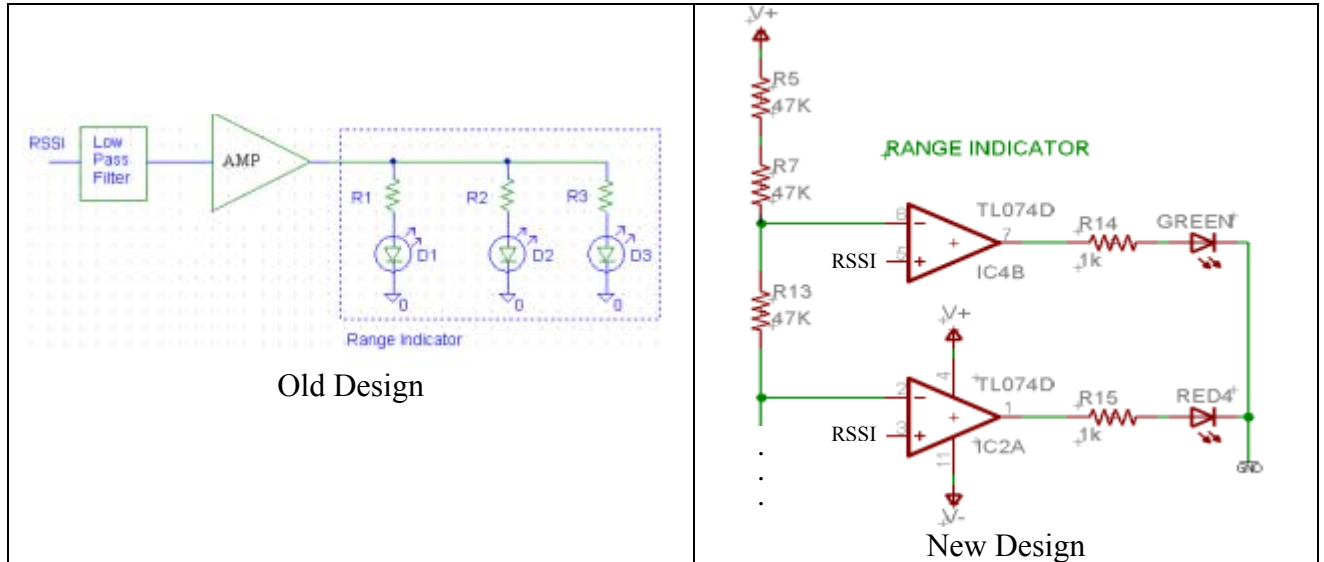

Old Design

New Design

Figure 6. Old and New Range Indicator Designs

After testing the old design, we realized that when D3 is on, D1 will likely burnout due to the current drawn. Therefore, to limit the current through the LEDs, we placed an opamp between the filter and the resistor to ensure the voltage across the resistor and diode will not exceed 5V. Also, the other reason for changing to the new design is that the brightness of the LEDs does not provide a sufficient indication of distance. Therefore, in the new design, an on/off mechanism is used. This mechanism is implemented by configuring the opamps as comparators. In addition, we used 5 LEDs to improve resolution.

3.2.2.2 Audio Output

As an added feature, which was not discussed in the *Functional Specification*, the tracker and tag combination can now be used as a baby monitor. A microphone circuit has been placed on the tag. Also, an audio amplifier and audio connector circuit have been added on the tracker. When used in conjunction with speakers or headphones, the tracker allows users to monitor the target tag's surroundings. However, using this option requires shutting down the digital data transmission used for the tag's power indicator and the SOS, since both digital and analog data share the same signal line to the transmitter. On the other hand, the tracking function remains unaffected. Figure 7 shows the headphone jack circuit.

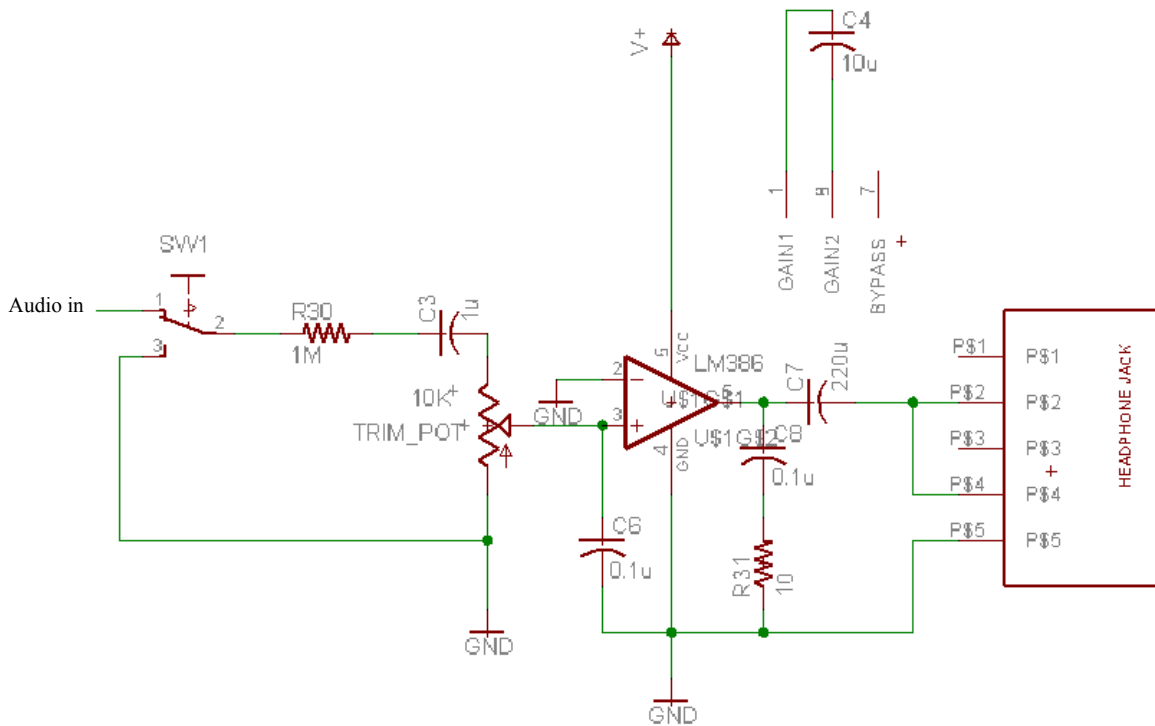**Figure 7. Headphone Jack**

The 10K trimpot is for adjusting the audio volume. The R30-C3 network is for attenuating and AC-coupling the Audio input signal into the gain stage. The LM386 is configured to have a gain of 200 by connecting C4 across the GAIN1 and GAIN2 terminals of the LM386. The R31-C8 branch is for low pass filtering, while C7 is for removing the internal DC offset of the LM386.

4 Budget

As at December 16, 2002, we have incurred the costs listed in Table 2.

Table 2. Proposed Budget and Costs

Item	Estimated Cost	Actual Cost
Printed Circuit Boards	$350	$318.94
Transceivers	$100	$563.02
Antennas	$100	$8.61
Operational Amplifiers	$25	$0.00
Passive Components	$25	$37.25
Vibrating Motor	$15	N/A
Buzzer or Mini-Speaker	$15	$25.00
LEDs	$10	$10
Miscellaneous	$160	$100.82
Total Budget	**$800**	**$1063.64**

Our budget is over our estimated costs since we failed to include the RF evaluation package cost of $563.02. At the time of our proposal, we did not plan on purchasing an evaluation package. However, since none of us were familiar with RF design at the time, we decided to purchase an evaluation board for more reliable and stable testing. In addition, we were able to acquire all our operational amplifiers as samples, thus saving $25 from our original estimated cost. Also, the expense for passive components is over the estimated cost since switches are actually very expensive and we required more switches than expected. Lastly, the miscellaneous cost of $100.82 is due to extra shipping costs.

5 Timeline

Figure 8 shows the comparison of the new and old timelines.
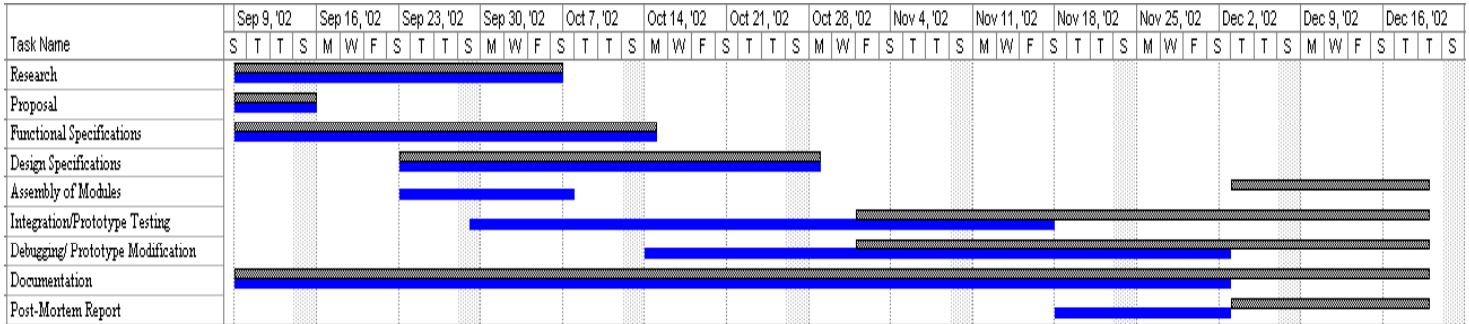

Figure 8. New/Old Timelines Comparison

Due to exams and overwhelming workloads, we incurred significant delays in assembling (start date delayed to December 2), integrating and testing (start date delayed to November 1), as well as debugging and modifying the initial design (start date delayed to November 1). In addition, the finish date for documentation is extended to December 19 and the post-mortem start date was pushed to December 2. The timelines for research, proposal, functional specifications, and design specifications are unaffected since the workloads have yet to increase to unacceptable degrees during that period.

6 Management Strategy

6.1 Group Dynamics

Since every group member has over 15 credits of course load and some of us have different courses, time was a major issue, especially during exam time. Therefore, we ensured that every group member knows all parts of the project, so that when a group member is busy, the others can continue working on the project.

Another problem we had was group members showing up late. One solution was to offset the meeting to about an hour earlier; therefore, even if a group member is late relative to the declared time, he is actually early. However, since all members know all parts of the project, ones who came early can continue with their work.

Our group consists of members with very different skills, so besides learning from the project, we learned new things from each other.

6.2 Design and Development

Theoretical design and actual circuit are two different things. Initially, we thought our design would work without many problems. However, we noticed many unexpected problems after placing our design onto breadboard. Thus, we should have tested our design earlier. Fortunately, the design problems could be fixed without changing the overall system design.

Two other aspects whose difficulties we underestimated are the layout and packaging. We spent only several days on the layout; thus, the size requirements for the tag and tracker were not fulfilled. We should have considered layout during the design stage. Also, layout and packaging are closely related. Since the layout was not properly done, soldering and packaging became extremely difficult. Furthermore, the antenna was rewired to a location away from the transmitter to reduce the interference from the crystal oscillator.

As noted, our budget is over the estimated value. Since we failed to realize that shipping costs are very expensive, we did not plan thoroughly which parts to buy before ordering. Thus, we should order as many parts as possible at a time from one company to avoid the high shipping costs.

7 Future plans

The current design of MicroTracker is merely for proof of concept. The following suggestions for design changes and improvements can prepare our product for commercialisation in the future.

7.1 RFID for Tag Identification

The disadvantages of identifying tags by carrier frequencies are that interference between adjacent frequency channels cannot be avoided and the number of allowable frequency channels is limited.

With RFID technology, each tag is identified by a digital ID code, which greatly increases the number of different tag ID's. However, an anti-collision algorithm, such as time division multiplexing, is required to track multiple RFID tags at the same time. Therefore, a microprocessor must be added to the tracker for programming the anti-collision algorithm as well as interpreting digital ID codes and other tag specific information.

Spread spectrum technology can be used for RFID communication's method since only one unique frequency at any time is needed. The concept of spread spectrum is that the carrier frequency is constantly and randomly changing within a frequency range; therefore, channel interference is significantly reduced.

Advantages
- Much more available tag ID's
- Only require one frequency channel → lower RF hardware costs
- Less vulnerable to channel interference compared to frequency channel ID (with spread spectrum technology)

Disadvantages
- More difficult to implement (anti-collision and tag data interpretation)
- Require Microprocessor → higher cost, more board space required, harder to layout
- Less reliable due to potential bugs in software
- Higher power consumption from additional microprocessor
- Limited response time

7.2 Auto-activation of Tag by Proximity or Vibration

A passive proximity sensor such as a pair of mutually inductive coils (one on the tag and one on the tracker) can be used to automatically activate the tag when the tag and tracker are a certain distance apart. Alternately, a vibration sensor on the tag can be used to automatically activate the tag when the tag undergoes significant shock.

Advantages
- Lower power consumption (only turn on the tag when required)
- Auto-activation of the tag when user is unaware of the left-behind item

Disadvantages
- More costs for passive proximity sensor or vibration sensor

7.3 Tag's Transmitter and Audio Monitor Activated by Tracker

The tag is required to be a transceiver for this option. The tag will have a power-down mode in which the tag's transmitter is off, while the tag's receiver is waiting for the tracker's activation signal to turn on the tag's transmitter. The tag can also be remotely put into power-down mode from the tracker.

When the audio monitor is activated, the digital signals such as the power indicator and SOS signals cannot be transmitted from the tag. Therefore, an option of remotely activating or deactivating the audio monitor from the tracker will be useful.

Advantages
- More control over tags
- Lower power consumption (deactivate tag when not in use)
- Anti-collision algorithm is not required since the tracker can deactivate all non-target tags and activate only the target tag; however, longer processing time will be required to switch between different target tags and deactivate them
- Digital and audio transmission is remotely selectable on tracker

Disadvantages
- Require transceiver → more costs, less reliable

7.4 Simplify Design for Commercialization

Simplifying the design and reducing the functionality to fit the basic needs of typical users can decrease the manufacturing cost and price of our product; thus, directly improving the marketability. The current design can be simplified down to a page-alarm system in which the tracker transmits a tag specific RFID signal to activate a buzzer on the tag to help the user find the tagged object. Another way to simplify the design is to have only the range indicator option, which is enough to help the user find the tagged objects.

Advantages
- Simpler Design → Smaller Size, Cheaper, Easier to use → Easier to market to general public (lower-end to middle-end users)

Disadvantage
- Fewer Functions
- Harder to find the objects

7.5 Dual Power Solution (Solar + Rechargeable Battery)

A set of solar batteries can be used to provide complementary power when the device is on and recharging the rechargeable battery when the device is off.

Advantage
- Power Conservation

Disadvantage
- Require solar panels and solar circuits → More costs

7.6 LCD Display on Tracker

The LCD display can be used to show the numerical relative distance instead of using the 5-LED range indicator, to assign and list specific names for each tag, and to display user menus for selection of various options on the tracker.

Advantages
- Improved range indication resolution
- More user friendly
- Reduced size since large switches and LEDs can be replaced with a LCD and two or three buttons

Disadvantages
- Require LCD Display and Microprocessor → more costs, more power

7.7 Changeable Tag Mounts

Changeable tag mounts provide users with flexibility on how and where to mount the tag.

Advantages
- Reduces users' search time for mounts
- More flexibility on how and where to mount the tag

Disadvantage
- More costs (optional to user)

7.8 Use Multi-layer PCB with Smaller Components and IC chip

The current prototype tag and tracker are created using double-sided single layer PCB's. Implementing the design on multi-layer PCB's with smaller components can further reduce the sizes of the tag and tracker. Implementing some of the design on an IC chip can also significantly decrease the tag and tracker sizes.

Advantage

- Reduced Size

Disadvantages
- More costs in manufacturing
- Harder to layout

7.9 Use Smaller Battery and Lower Voltage

We are currently using a 9V battery for our prototype. A smaller battery with lower voltage can be used to save space.

Advantage
- Save space

Disadvantages
- Shorter battery life

8 Contributions and Personal Experience

Lawrence Li

During this semester, I finally had the chance to apply the knowledge that I had gained over the last 4 years as an engineer. In nearly all my courses, the tasks at hand would only encompass a small part of the design process. In addition, this project encouraged a more in depth team work as the time restraints and work load demands that the organisation of human resources must be carefully managed at all times.

From this project, I gained a deeper understanding of RF communication, an area that I have almost no practical work experience in. I found that although a lot of courses allowed me to fully understand the theory of operation of an electronic device, seldom did I truly understand the use of these devices as a part of our design.

Using my experiences from coop, I was able to contribute to the final integration of the entire design into a single PCB. In this I found that although components were available, many are not available in the size or the price that we required. Furthermore, any miscommunication between myself and the PCB designer would have meant serious errors on the final PCB layout. Fortunately, the number of mistakes was limited and none posed a risk to the final success of the project.

Herman Lo

I have gained more experience in this project than any other projects I have done in the past. My communication skills are improved immensely through working closely with the rest of the team. I learned to interact with people with diversified personalities in harmony and to always keep an open mind for other teammates' opinions. I realized that listening is one of the most important criteria for managerial success.

I learned that work distribution is also very important in the success of a project. The work has to be spread not only evenly but also according to personal strengths. Productivity of the team is directly dependent on how well work is distributed among team members.

In addition, I realized the most important aspect in engineering is simplicity. Having the most complex design can only make a project more vulnerable to failure. Our product is designed in the simplest way we can think of to avoid unnecessary complications.

Lastly, I gained vast knowledge and experience in RF communications as well as hardware and electronic designs through designing and implementing the product, which will be beneficial to my technical career.

Victor Leung

This project gave me a chance to practice and improve my skills in research, PCB layout and presentation preparation. The PCB layout was more complicated than what I have previously done and I believe the experience would help me tackle even more challenging ones in the future.

Most importantly, working in this big of a group made me re-evaluate my skills. It is very different to complete a task in a small group compared to a bigger group such as this one. Everyone must agree on what, where, when, why, how and how well the task is done. Due to varying schedules and courses, co-ordination was much more difficult than expected. But our commitment to the project and good interpersonal skills allowed us to distribute the tasks to the satisfaction of everyone.

Overall, I learned quite a bit from this project. Both the technical and interpersonal skills acquired here will help me greatly in my future career.

James Dykes

Through this project, I was given a chance to practice my skills in simple circuit design and debugging, and creating circuit schematics using Eagle. In addition, I also learned about the difficulties in part selection and the advantages in proper documentation.

Due to my expertise in document formatting, a natural extension of my role in the group was to critique the work of my colleagues. Having previously worked with some group members before made this task easier by knowing how to praise and encourage the ideas of those members.

Despite a rather tedious timetable, working on this project was a valuable experience for me, and gave me a better understanding of group dynamics, product development, and most importantly, time management.

Bernard Ng

This project exposes me to simple circuit design, which I intend to pursuit for my future career. Through this project, besides further enhancing my soldering skills, I am finally given a chance to apply my circuit knowledge. I was also introduced to some RF concepts and was greatly involved with the documentation, which would prove very useful to my future career.

Working under a group of five was a lot harder than expected. We have to ensure everyone's ideas are heard and the workload is shared properly. Also, due to different class schedules, some group members were not available during certain time period. Fortunately, we ensured every group member knows all parts of the project, so if a group member is busy, the others can fill in the gap.

Overall, working on the project was a great experience. I gained both technical knowledge and interpersonal skills. In fact, I have probably learned more from my group members than from researching.

9 Conclusion

From this project, we have gained a lot of technical and interpersonal skills. Creating a working product under limited time is very difficult. From initial concept to a working prototype, we encountered many obstacles. After many sleepless nights, with parts running out and designs not working, we felt as if being trapped in a black hole. With members becoming frustrated and wires falling off, our group was beginning to break apart. Praying for a miracle, we joined our wisdom with courage in our hearts, the initial design stage was finally surpassed. On the serious side, we have all improved our time management skills and gained a lot of technical knowledge in RF communications, electronics, hardware design, and PCB layout. PCB turned out to be way harder than expected. We should have definitely spent more time on the PCB layout. Also, due to different class schedules, we learned to work independently and aid each other in busy times. Many modifications could be made to our prototype for commercialization. Provided with money, time, and interested customers, we should be able to successfully market our product and begin our promising business careers.

> *Ambitious Dreams are hard to achieve.*
> *But with a great team, we just have to believe.*
> *No mountain too high, no sea too deep.*
> *Finishing this project was a great relief.*

Appendix A. Schematics

Please zoom in for details of tracker and tag schematics in Figure A1 and A2 respectively.

Figure A1. Tracker Schematic

Figure A2. Tag Schematic

Appendix B. PCB Layouts

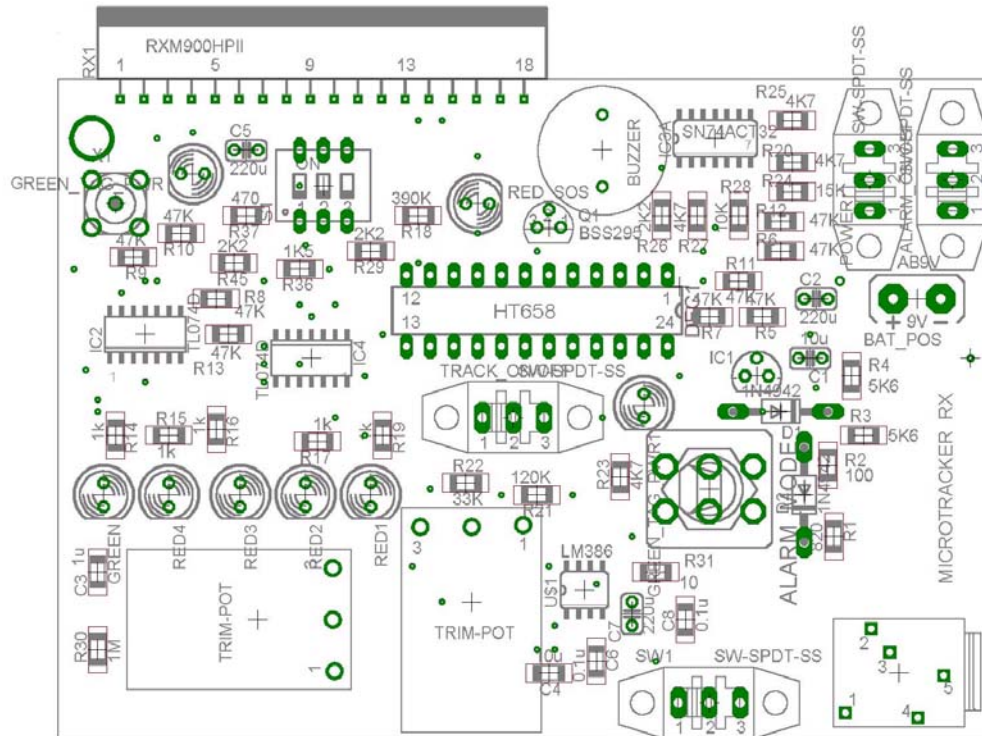Please zoom in for details of tracker and tag layouts in Figure B1 and B2 respectively.
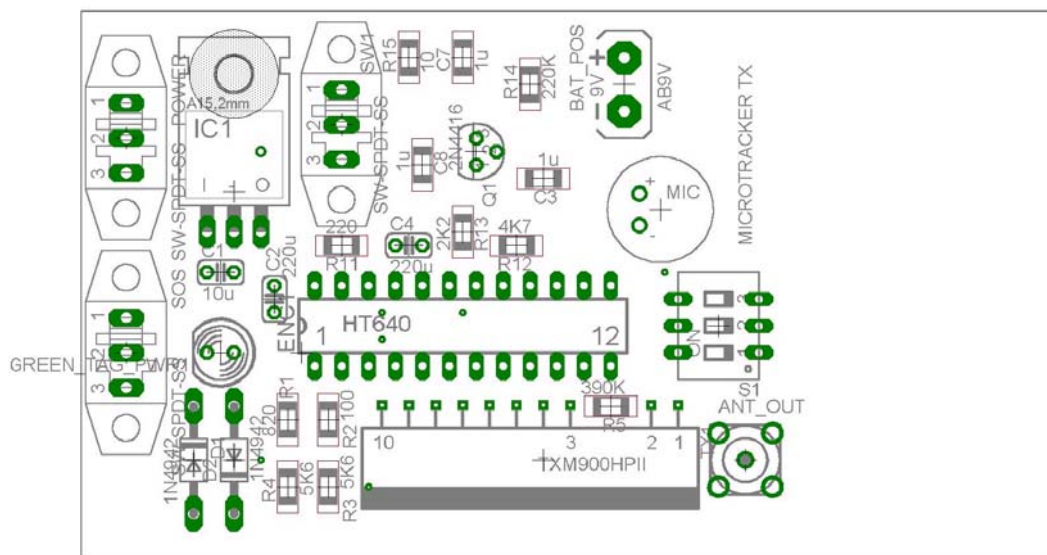

Figure B1. Tracker Layout

Figure B2. Tag Layout