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November 1, 2004

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

Re: ***Design Specification for a Wireless Home Phone-operated Assistant***

Dear Dr. Rawicz,

The attached document, *Design Specification for a Wireless Home Phone-operated Assistant (HomePA)*, defines in detail the architectural overviews, the component descriptions, and the implementations of the prototype for our ENSC 340 project.

Our project is to design a phone-operated system that can control multiple home appliances and facilities via wireless communication. This system consists of, a central control unit (CCU) acting as a base transmitter, and multiple client appliance units (CAUs), depending on the amount of electric devices to be controlled. The CCU is connected to the household phone line, receiving and processing a touch-tone command sent by an individual's phone call. The phone command determines the device to be controlled; the CCU will then call the corresponding CAU to operate the device.

The attached document explains the functionality of our HomePA in terms of the design and implementation of its subsystems. By referring to the requirements previously described in the *Functional Specification for a Wireless Home Phone-operated Assistant*, this design specification ensures that the development of our final prototype proceeds smoothly. In addition, we include a user interface specification to facilitate the usability of our HomePA, aiming to provide our customers a friendly user interface.

Our project team, Trax Technologies, is comprised of five enthusiastic and industrious fourth year engineering students. Group members include Sean Hou (CEO), Jack Lin (CFO) and Fred Yu (CTO), David Chen (COO), and Howard Chang (CIO). Each student brings their diverse knowledge and talents to the team. Should you have any questions regarding our design specification, please feel free contact us at traxtech-ensc340@sfu.ca.

Yours sincerely,

Howard Chang

Howard Chang
Chief Information Officer
Trax Technologies Inc.

Enclosure: ***Design Specification for a Wireless Home Phone-operated Assistant***

Trax Technologies Inc.

Design Specification for a Wireless Home Phone-operated Assistant

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Executive Summary

Many people are unable to independently operate and monitor standard home appliances and equipment without the assistance. Some of these people are physically disabled suffering from paralysis, leg amputation, arthritis, and other such debilitating conditions. Although the conventional home control systems are a solution, most people are unable to enjoy the comfort and efficiency that these systems provide. Most individuals cannot afford a versatile remote control system because of the excessive cost involved, along with the extensive and sophisticated installation required. Seniors and younger children may also be challenged by the complexity of familiarizing themselves with conventional system controllers.

Trax Technologies is committed to developing a Wireless Home Phone-operated Assistant (HomePA), which will allow individuals to remotely control and monitor the current operating status of home appliances or facilities via a phone call. This device will provide paraplegics, seniors, and even the general public the convenience of home remote controls.

The design specification describes the design requirements of the overall system of the HomePA, ensuring a smooth transition between functionality and development. The HomePA is comprised of three subsystems: the Central Control Unit (CCU), the Wireless Communication Unit (WCU), and the Client Appliance Unit (CAU). The CCU will be connected to the household phone line and will receive and process a touch-tone command sent by an individual's phone call. When an individual phones his or her own home, after a predetermined number of rings the system will automatically switch to a voice-menu interface run by the CCU. The user will be required to enter an access code, which will lead the user to the voice menu. Here, the user can control the system through a series of touch-tone commands. The control unit will call and control the corresponding CAU through the WCU based on the phone command received directly through the phone line. The CAU consequently controls the designated appliance.

Each subsystem has its own defined design specifications in terms of its architectural overview, component description, and implementation. These specifications represent the requirements that our HomePA prototype should follow. Several user interface specifications have also been prepared to assure a hassle-free and user-friendly product.

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Glossary

AC: Alternating Current

CAU: Client Appliance Unit

CCU: Central Control Unit

DC: Direct Current

D/A: Digital/Analog

DAA: Data Access Arrangement

DPLL: Digital Phase Lock Loop

DTMF: Dual Tone Multi-Frequency

EVB: Evaluation Board

FCC: Federal Communications Commission

IC: Integrated Circuit

IR: Infrared

LED: Light Emitting Diode

PCB: Printed Circuit Board

PDIP: Plastic Dual Inline Packaging

PSTN: Public Switch Telephone Network

SPI Serial Peripheral Interface

WCU: Wireless Communication Unit

1. Introduction

Our product, the HomePA, allows any individual to remotely control and monitor the current operating status of home appliances with nothing more than a few touch-tone key presses via a phone call. This device will provide paraplegics, seniors, and even the general public the convenience of remotely operating and monitoring home appliances and facilities without actually having to be within physical reach of the controls. The intended completion date of our HomePA is December 2004. Upon completion, our final prototype will at least satisfy the minimum requirements proposed for this project.

1.1. Scope

This design specification describes in detail the various system attributes that our HomePA must satisfy by the end of our development. The three functional subsystems of the HomePA consist of the Central Control Unit (CCU), the Wireless Communication Unit (WCU), and the Client Appliance Unit (CAU). The overall system requirements outline several general design specifications, explaining how the functionality of the entire system is implemented. In addition, for each functional subsystem, its architectural overview, component description, and implementation will be examined accordingly. Finally, a section for the user interface specifications of the HomePA is included to ensure that our final product has a friendly user interface.

1.2. Intended Audience

This design specification is intended for both of the field application engineers' and project managers' reference when manufacturing the functional subsystems of our HomePA. This document, in combination with *Functional Specification for a Wireless Home Phone-operated Assistant,* will assist these engineers in building the product according to the specified set of functional and design requirements. Additionally, the project manager will utilize this document to evaluate potential technical difficulties associated with the schematic design of the HomePA, as well as to ensure that each subsystem contributing to the finished prototype is being implemented with the required design specifications.

2. System Overview

The HomePA allows individuals to use any telephone to remotely control and monitor home appliances or open/close doors and windows via wireless communication. The system can be divided into three main functional subsystems: the central control unit, the wireless communication unit, and the client appliance unit(s). Notice that multiple client appliance units may coexist, depending on the number of home appliances or facilities to be controlled and monitored. The system collaboration diagram in Figure 1 illustrates how each subsystem in our HomePA interacts with one another.

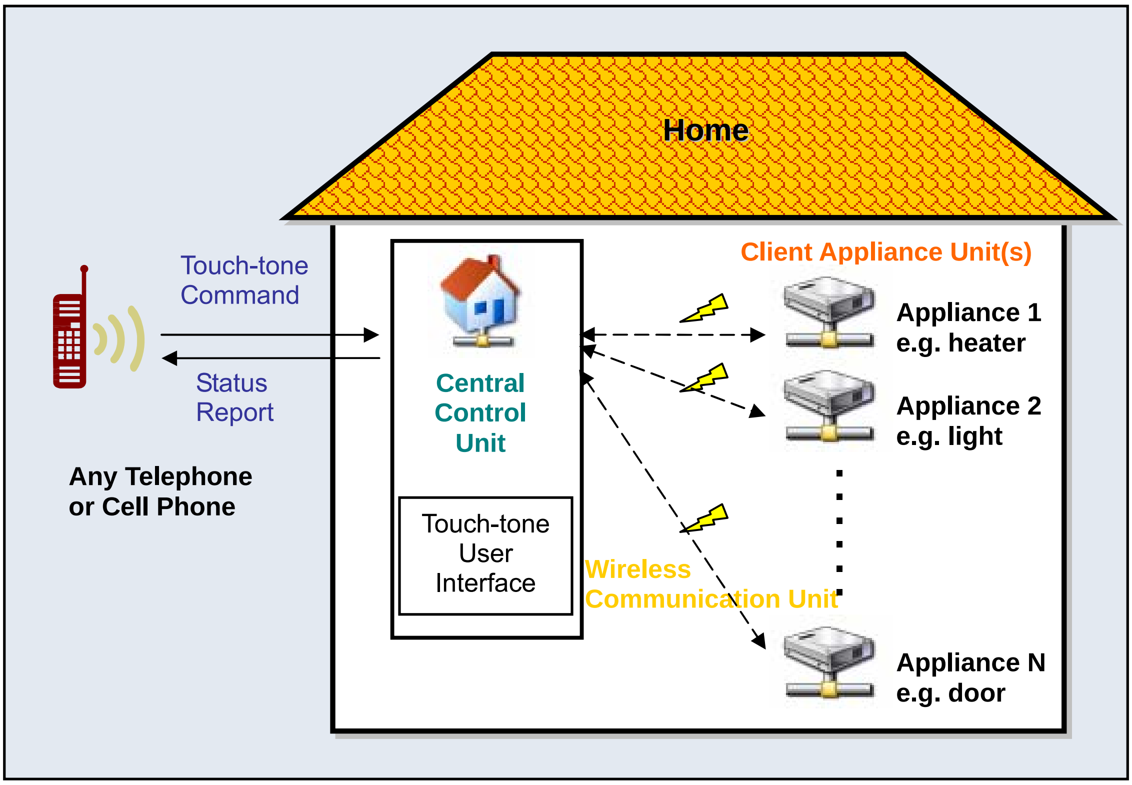

Figure 1: Collaboration Diagram of HomePA

2.1. Central Control Unit (CCU)

The central control unit, connected to a household phone jack, will receive incoming phone calls from a user. It possesses a touch-tone user interface that allows the user to determine the home appliance or facility that he or she would like to control or monitor. The CCU will process the user's key press(es) and then call and command the corresponding client appliance via the wireless communication unit.

2.2. Wireless Communication Unit (WCU)

The wireless communication unit is responsible for calling the designated client appliance unit, which in turn is responsible for actually operating the designated appliance or facility. Also, in the situation that the user requests a status report from a CAU, the WCU forwards the result as an outgoing signal to the CCU.

2.3. Client Appliance Unit (CAU)

The client appliance unit will be attached or integrated to an appliance or home facility that the user would like to control and monitor. Once the CAU has received a command from the WCU, it performs the assigned operation on the appliance/facility – switch on/off or open/close. The CAU can also report back to the CCU the current status of the facility or appliance via the WCU. Multiple client appliance units can be controlled by the same CCU through the wireless network.

3. Central Control Unit

3.1. Architectural Overview

The central control unit, as shown in Figure 2, consists of five individual components, including the microprocessor, the Dual Tone Multi-Frequency (DTMF) transceiver, the Data Access Arrangement (DAA) line interface, the voice playback device, and the Light Emitting Diode (LED) display. Each component is controlled by a single PIC16F877A microprocessor. The CCU is also connected to the wireless communication unit through the microprocessor. Since the CCU needs to be able to receive and transmit audio and touch-tone signals through the Public Switch Telephone Network (PSTN), a telephone line interface or a DAA device is required for interfacing between analog transmission equipment (the DTMF transceiver and voice playback device) and the telephone line (through the Tip and Ring lines). In addition, the DAA device can provide the necessary isolation and surge protection for the CCU from the telephone line. A DTMF transceiver is used to decode and generate touch-tone audio signals which are transmittable through the PSTN. The voice playback device is an audio chip that contains pre-recorded voice messages. These messages can be played back to the user over the telephone. The last integral component is an LED display, which displays the current status of all client appliances currently controlled and monitored by their client appliance units. The following figure is a block diagram of the architectural overview of the CCU.

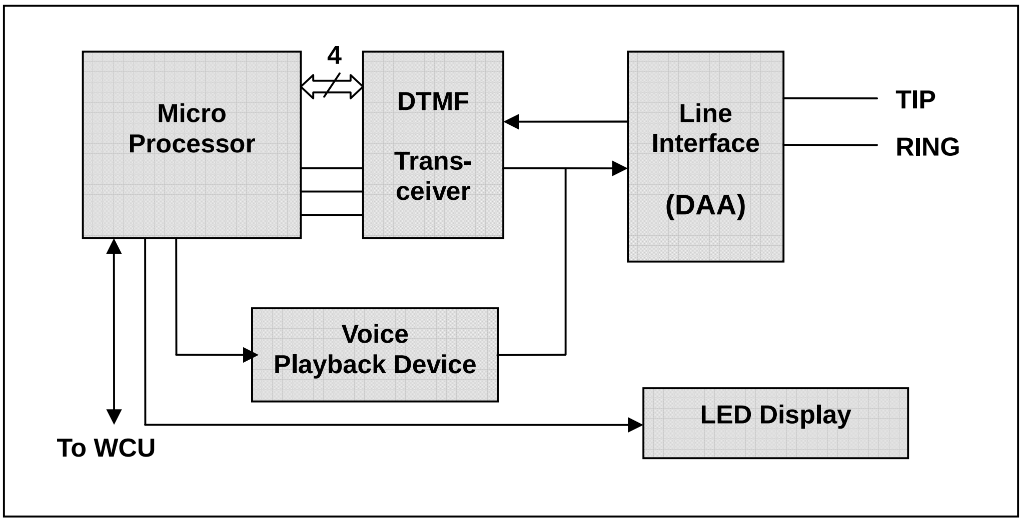

Figure 2: Architectural Overview of Central Control Unit

3.2. DTMF Transceiver

3.2.1. Component Description

The CM8880-PI (Figure 3), manufactured by California Micro Device, is the DTMF transceiver implemented in the central control unit.

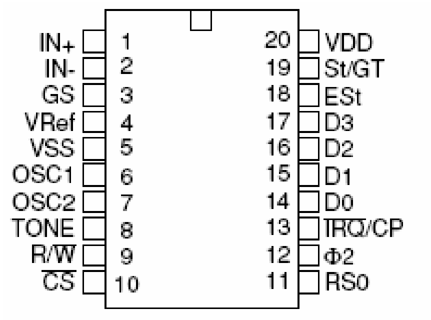

Figure 3: CM8880-PI Pin Configuration

The CM8880-PI is a fully integrated DTMF transceiver with a call progress filter for analyzing call progress tones. This chip communicates through the microprocessor over a 4-bit bus (*D3* to *D0*). In addition, it contains an internal counter that provides a burst mode so that the tone burst can be transmitted with precise timing. The transmitter is capable of generating all 16 pairs of DTMF signals and utilizes a switched-capacitor D/A converter for low distortion and high accuracy DTMF signalling. The following table outlines all 4-bit bus values with corresponding digit values and dual frequencies.

Table 1: Functional Decode/Encode (0 = Logic Low, 1 = Logic High)

FLOW	FHIGH	Digit	D3	D2	D1	D0
697	1209	**1**	0	0	0	1
697	1336	**2**	0	0	1	0
697	1477	**3**	0	0	1	1
770	1209	**4**	0	1	0	0
770	1336	**5**	0	1	0	1
770	1477	**6**	0	1	1	0
852	1209	**7**	0	1	1	1
852	1336	**8**	1	0	0	0
852	1477	**9**	1	0	0	1
941	1209	**0**	1	0	1	0
941	1336	*****	1	0	1	1
941	1477	#	1	1	0	0
697	1633	**A**	1	1	0	1
770	1633	**B**	1	1	1	0
852	1633	**C**	1	1	1	1
941	1633	**D**	0	0	0	0

A list of pin assignment and descriptions for the 20-pin CM8880-PI shown in Figure 3 is provided in Table 2.

Table 2: CM8880-PI Pin Assignment Table

Pin Function Table

Name	Description
IN+	Non-inverting op-amp input.
IN-	Inverting op-amp input.
GS	Gain Select. Gives access to output of front end differential amplifier for connection of feedback resistor.
V_{REF}	Reference voltage output. Nominally $V_{DD}/2$ is used to bias inputs at mid-rail (see application circuit).
V_{SS}	Negative power supply input.
OSC1	DTMF clock/oscillator input.
OSC2	Clock output. A 3.5795 MHz crystal connected between OSC1 and OSC2 completes the internal oscillator circuit.
TONE	Dual Tone Multi-Frequency (DTMF) output.
R/$\overline{W}$	Read/write input. Controls the direction of data transfer to and from the microprocessor and the CM8880. TTL compatible.
CS	Chip Select. TTL input (CS = 0 to select the chip).
RSO	Register select input. See register decode table. TTL compatible.
$\Phi 2$	System clock input. May be continuous or strobed only during read or write. TTL compatible.
$\overline{IRQ}$/CP	Interrupt request to microprocessor (open-drain output). Also, when Call Progress (CP) Mode has been selected and Interrupt enabled the IRQ/CP pin will output a rectangular wave signal representative of the input signal applied at the input op-amp. The input signal must be within the bandwidth limits of the Call Progress filter. See Filter 6.
D0-D3	Microprocessor data bus. TTL compatible.
ESt	Early Steering output. Presents a logic high once the digital algorithm has detected a valid tone pair (signal condition). Any momentary loss of signal condition will cause ESt to return to a logic low.
StGT	Steering input/Guard Time output (bidirectional). A voltage greater than V_{TSt} detected at St causes the device to register the detected tone pair and update the output latch. A voltage less than V_{TSt} frees the device to accept a new tone pair. The GT output acts to reset the extenal steering time-constant; its state is a function of ESt and the voltage on St.
V_{DD}	Positive power supply input.

Finally, the CM8880-PI is a dual-in-line package IC chip with a typical dimension of 0.5in by 0.4in. Therefore, both its packaging and its dimension are suitable for our HomePA.

3.2.2. Implementation

Referring to the data sheet provided by California Micro Devices, the CM8880-PI can be connected to a microprocessor using the implementation illustrated by the circuit diagram in Figure 4.

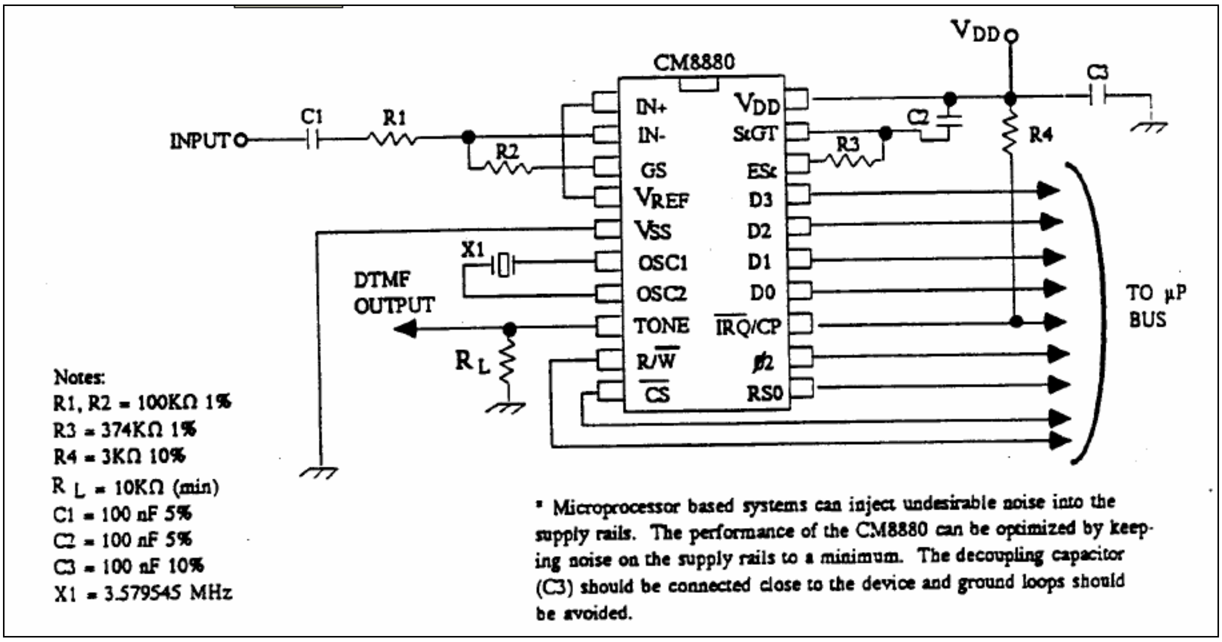

Figure 4: CM8880-PI Single End Input Connection (µP = Microprocessor)

The CM8880-PI is implemented using a single-ended input with provisions made for gain adjustments by connecting a feedback resistor between the Inverting Input pin, *IN-*, and the Gain Select pin, *GS*. Before registering a decoded tone pair in the internal register, the receiver is required to perform a check on the validation of the signal duration. In order to perform this check, a steering circuit is required, which involves the use of an external RC circuit with a time constant driven by the Steering Input pin, *Est*. The dual tone signals are generated by an internal clock, which requires a standard burst crystal having a resonant frequency of 3.579545MHz.

The typical operating supply voltage, V_{DD}, for the configuration in Figure 4 is 5V. In addition, the values of the capacitor and the resistor will follow the suggested values stated in the data sheet to obtain the best results while preventing any damages to the IC chip or any other electronic components.

3.3. Telephone Line Interface

3.3.1. Component Description

For telephone line interfacing, we use the MH88425AD DAA chip by Zarlink Semiconductors. The Zarlink MH88435AD provides a complete interface between audio or data transmission and a telephone line when under DTMF operation. The MH88435AD is approved by the UL1950 and FCC part 15 and 68 standards; therefore, this chip is fully compatible with the PSTN line interface in North America. The pin connection and functional block diagram are shown in Figure 5 and Figure 6, respectively.

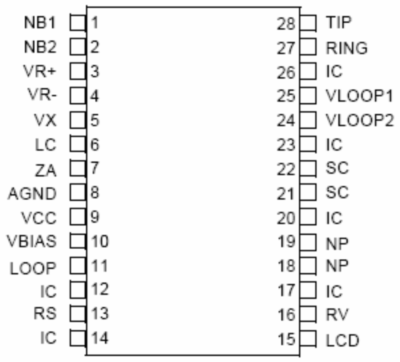

Figure 5: MH88435AD Pin Configuration

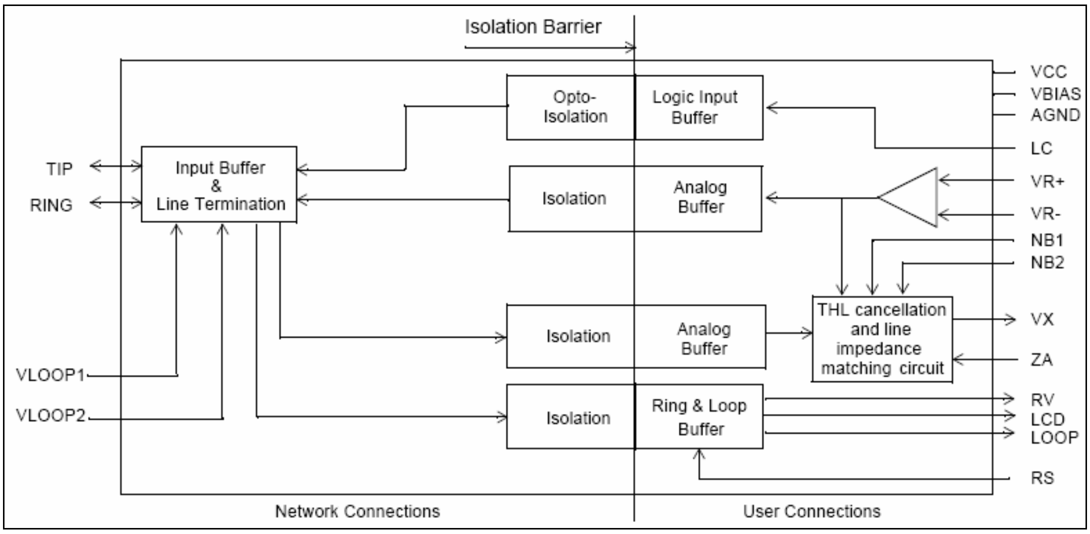

Figure 6: MH88435AD Functional Block Diagram

Moreover, the MH88435AD provides a high voltage isolation barrier and a 2-to-4 wire conversion, while featuring an externally programmable line and network balance impedances. Table 3 outlines the description of each pin.

Table 3: MH88435AD Pin Assignment

Pin Description

Pin #	Name	Description
1	NB1	**Network Balance 1.** External passive components must be connected between this pin and NB2.
2	NB2	**Network Balance 2.** External passive components must be connected between this pin and NB1.
3	VR+	**Differential Receive (Input).** Analog input from modem/fax chip set.
4	VR-	**Differential Receive (Input).** Analog input from modem/fax chip set.
5	VX	**Transmit (Output).** Ground referenced (AGND) output to modem/fax chip set, biased at +2.0V.
6	LC	**Loop Control (Input).** A logic 1 applied to this pin activates internal circuitry which provides a DC termination across Tip and Ring. This pin is also used for dial pulse application.
7	ZA	**Line Impedance.** Connect impedance matching components from this pin to Ground (AGND).
8	AGND	**Analog Ground.** 4-Wire ground. Connect to earth.
9	V_{CC}	**Positive Supply Voltage**. +5V.
10	VBIAS	**Internal Reference Voltage.** +2.0V reference voltage. This pin should be decoupled externally to AGND, typically with a 10µF 6.3V capacitor.
11	LOOP	**Loop (Output).** The output voltage on this pin is proportional to the line voltage across Tip - Ring, scaled down by a factor of 50.
12, 14, 17, 20, 23, 26	IC	**Internal Connection.** No connection should be made to this pin externally.
13	RS	**Ringing Sensitivity.** Connecting a link or resistor between this pin and LOOP (pin 11) will vary the ringing detection sensitivity of the module.
15	LCD	**Loop Condition Detect (Output).** Indicates the status of loop current.
16	RV	**Ringing Voltage Detect (Output).** The RV output indicates the presence of a ringing voltage applied across the Tip and Ring leads.
18, 19	NP	**No Pin.** Isolation barrier, no pin fitted in this position.
21, 22	SC	**Short Circuit.** These two pins should be connected to each other via a 0Ω link.
24	VLOOP2	**Loop Voltage Control Node 2.** Used to set DC termination characteristics.
25	VLOOP1	**Loop Voltage Control Node 1.** Used to set DC termination characteristics.
27	RING	**Ring Lead.** Connects to the “Ring” lead of the telephone line.
28	TIP	**Tip Lead.** Connects to the “Tip” lead of the telephone line.

3.3.2. Implementation

Figure 7 shows the typical implementation for the MH88435AD.

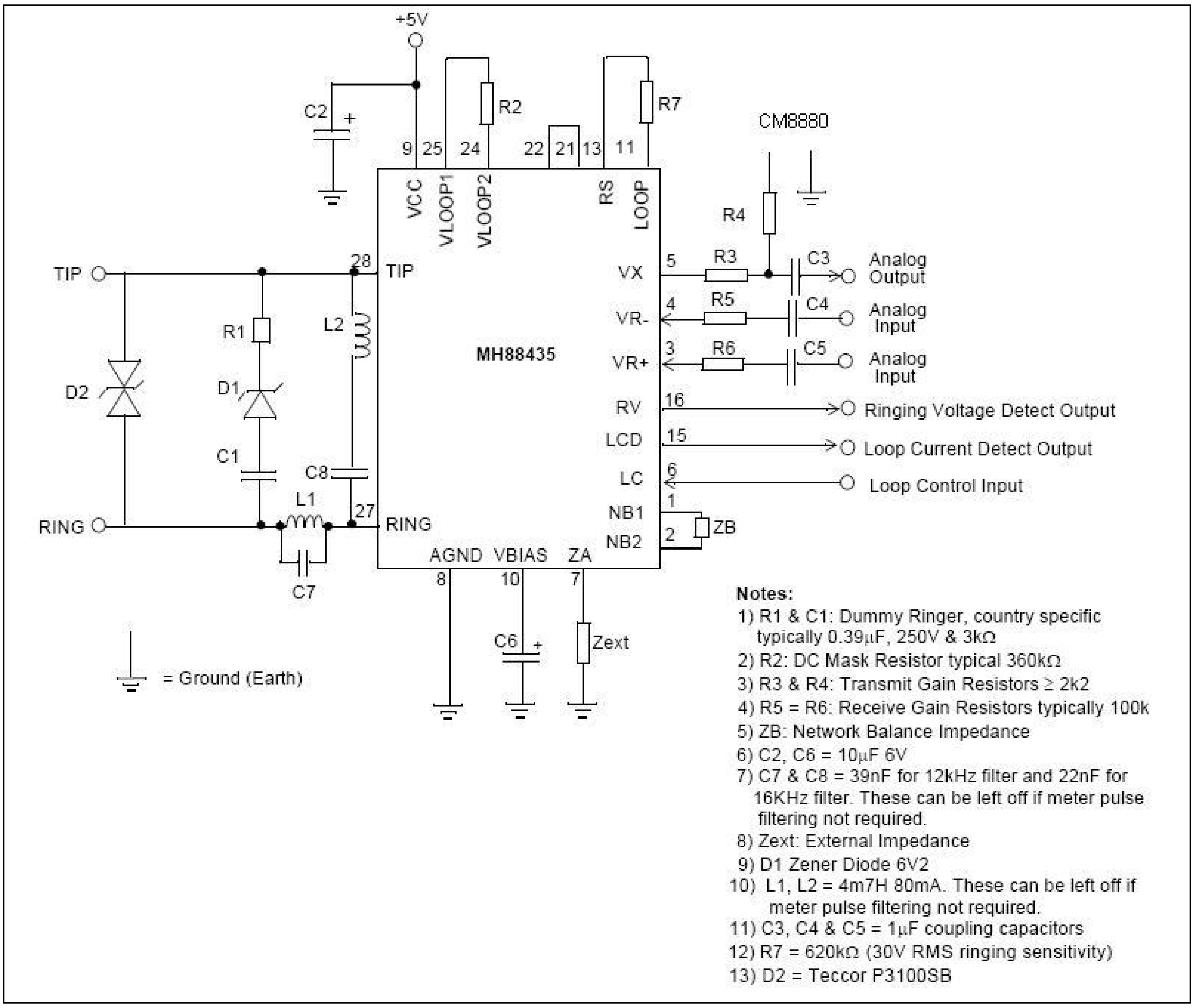

Figure 7: MH88435AD Typical Application Circuit Connection

The analog output of the MH88435AD shown in Figure 7 is connected to the input of the CM8880-PI configuration shown in Figure 4, while the analog input of the MH88435AD is a combination of signals from the CM8880-PI Tone output and the output of the voice playback device, APR6016 (detailed in Section 3.5).

The *TIP* and *RING* leads in Figure 7 correspond to the two telephone line connections, which connect to a standard RJ11 telephone jack. The electronic components connected between the *TIP* and *RING* pins act as a protection circuit. For better protection results, we will also include additional TR600-165 Resettable Fuses, connected as shown by the circuit diagram in Figure 8.

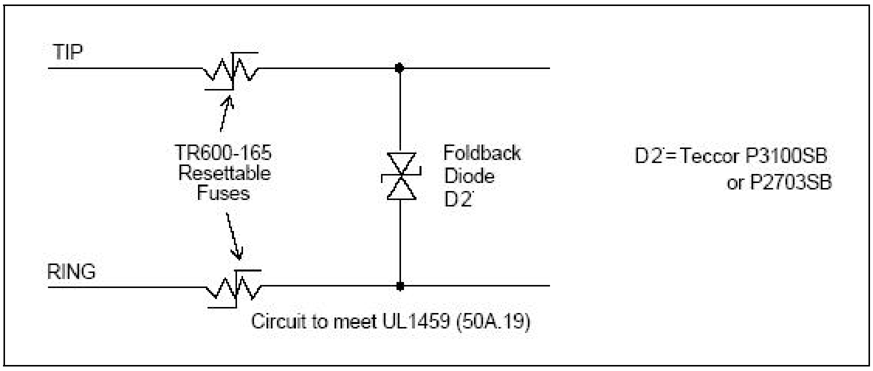

Figure 8: MH88435AD Protection Circuit with Additional Fuses

3.4. Microprocessor

3.4.1. Component Description

The central control unit microprocessor will utilize Microchip's PIC16F877A, which comes in a 40-pin PDIP package. This microprocessor is chosen because of its power, versatility and ease in programmability. The execution time for an instruction only takes approximately 200ns. The pin diagram of the microcontroller is shown in the following figure.

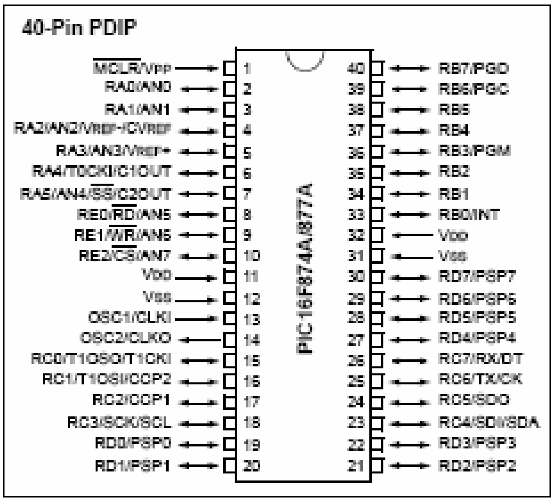

Figure 9: Pin Diagram of PIC16F877A Microprocessor

The PIC16F877A microprocessor has 40 pins; 33 of them can be configured to act as I/O pins. Such a large number of I/O pins will be beneficial for the implementation of the CCU of our HomePA. Not only will the PIC16F877A microprocessor be utilized to communicate with the voice playback device, the DTMF transceiver, and the wireless communication unit in the CCU, it will also be used to control multiple client appliance units.

The PIC16F877A is powered by a DC supply of 5V, while an external oscillator required to operate the microprocessor clock is set to 20MHz. Assembly programs can be loaded on to the microprocessor via the ICD1 EVB or the PICSTART Plus development application.

3.4.2. Implementation

The PIC16F877A microprocessor needs two voltages, V_{DD} and V_{SS}. V_{DD} is to be connected to +5V DC, whereas V_{SS} will be connected to ground. In addition, pin 13 and 14 in Figure 9 are the oscillator input and output, which should be connected to the crystal oscillators. Pin 1 is reserved as a master clear; thus, this pin is not available as an I/O. Finally, the remaining 33 pins are used for I/O interfacing. The block diagram is shown in Figure 10.

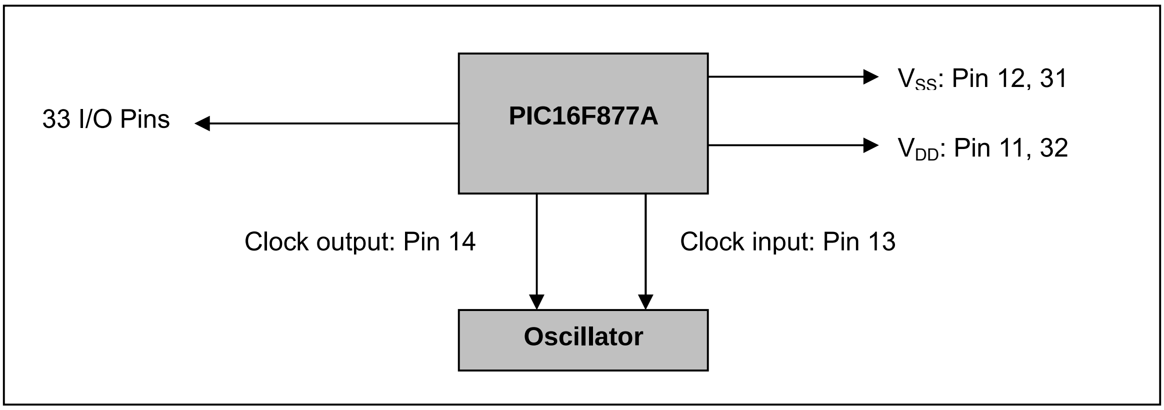

Figure 10: Basic Microcontroller Implementation Diagram

The 33 I/O pins are to be program controlled; therefore, the pin assignment will be different for the central control unit and individual home appliance applications.

3.5. Voice Playback Device

3.5.1. Component Description

APLUS Integrated Circuits Inc.'s APR6016 is a voice playback device that features high quality audio playback of a pre-recorded audio message stored in the on-chip internal memory. Up to 16 minutes of audio and 30Kbits of digital data can be stored, as this device supports dual mode storage of analog and/or digital data. In addition, the APR6016 can use either the four built-in sampling clock frequencies or an external sampling clock, depending on user's preference on quality and duration levels when recording an audio signal.

The APR6016 has an industry standard Serial Peripheral Interface (SPI), which allows any commercial microprocessor (in our application, Microchip's PIC16F877A) to manage message playback. This device also consumes small amounts of power; its playback operating current is approximately 15mA and its standby current is at most 1µA.

Due to the fact the APR6016 uses a proprietary analog multi-level storage technology implemented in an advanced non-volatile Flash memory process, no battery backup is required and audio signals can be reproduced without distortion. The following table presents some important technical specifications of the device's operation.

Table 4: APR6016 Technical Specifications

Power Supply Voltage	3.0V
Operating Voltage	3.0V
Operating Temperature	0 – 70°C
Built-in Sampling Rates	4.0, 5.3, 6.4, 8.0 kHz

Figure 11 displays the layout of the pins on the voice playback device. Figure 12 presents a block diagram of the device's internal circuitry.

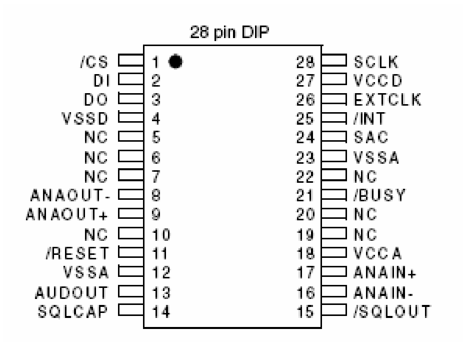

Figure 11: APR6016 Pin-out Diagram

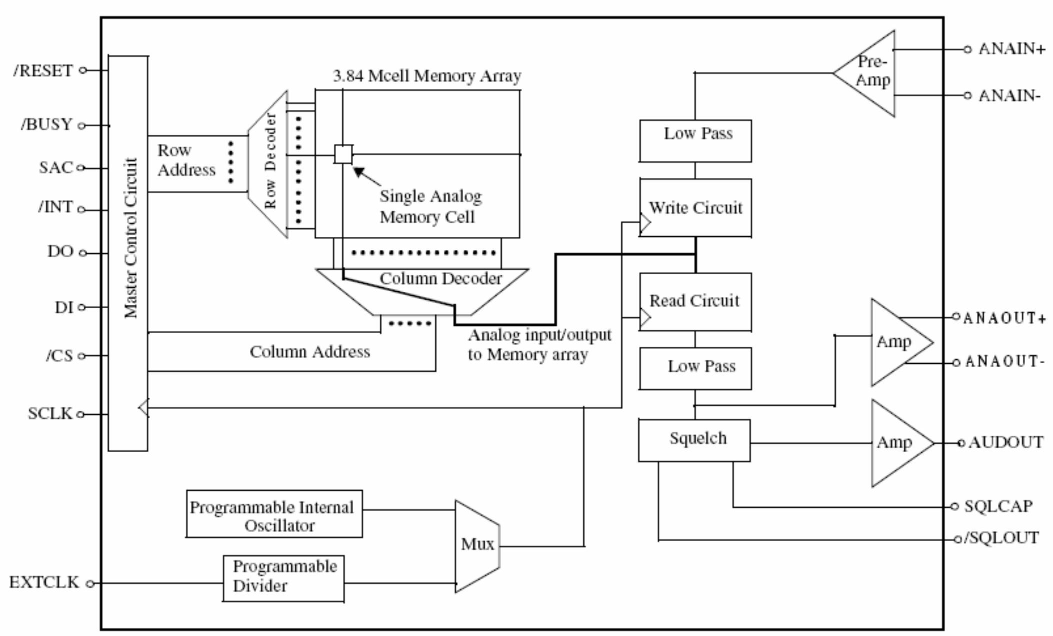

Figure 12: APR6016 Block Diagram (Internal Circuitry)

3.5.2. Implementation

As mentioned in Section 3.4, the telephone line interface of the CCU transmits audio signals by the audio playback device. The APR6016 chip needs to contain some pre-recorded audio messages on its supplementary demo board as shown in Figure 13. The demo board is connected to a 3V DC power. Since we want to maximize the recording time, we select a sampling rate of 4.0kHz (the minimum built-in sampling rate) by setting switches 3 and 4 on SW4 to ON and OFF positions, respectively. An audio message is recorded through the LINE-IN input, which accepts any analog audio signal; up to 16 minutes of audio can be recorded based on the chosen sampling rate.

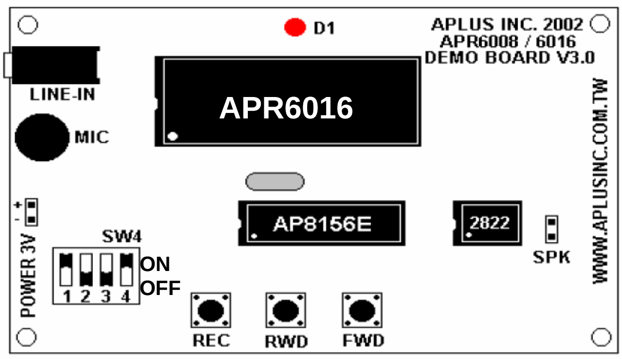

Figure 13: APR6016 IC Demo Board Layout

Once the one-time recording operation has been carried out, the APR6016 chip is to be migrated to the actual circuit of the CCU. A partial circuit diagram of the circuitry surrounding the APR6016 is illustrated in Figure 14. The chip is to be powered by a 3V DC supply, which is connected to *VCCD* (pin 27) and *VCCA* (pin 18) with a 0.1μF bypass capacitor in parallel for each pin as compensation. *VSSA* and *VSSD*, known as the respective analog and digital grounds, are to be connected to the common circuit ground.

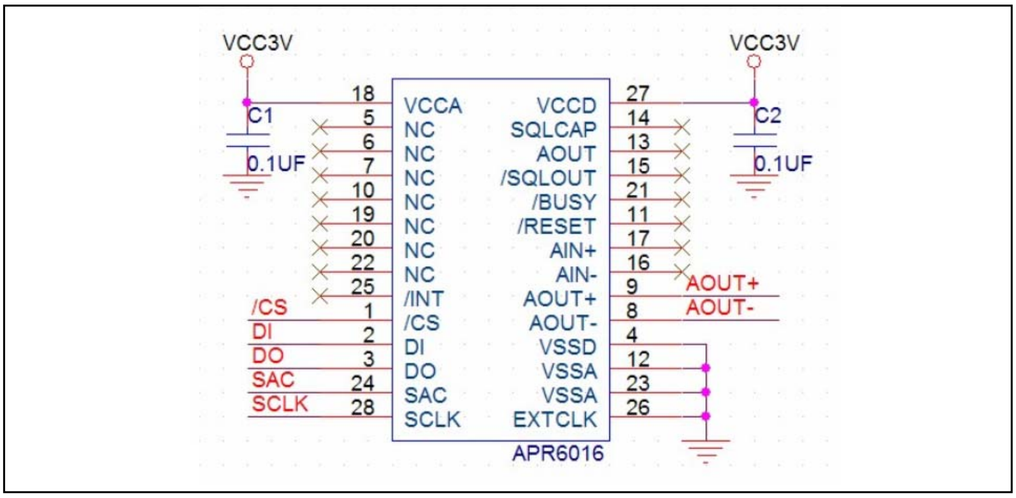

Figure 14: Partial Circuit Diagram near APR6016

Since the APR6016 is to be controlled by the PIC16F877A microprocessor via the SPI interface, the microprocessor acts as the SPI master while the APR6016 acts as the SPI slave. When the master generates and feeds a clock into the SPI clock input, *SCLK*, and selects the slave device via the chip select input, */CS*, data may be transferred in either direction simultaneously. Data communication between the recording device and the microprocessor is performed through the data input and output pin, *DI* and *DO*, respectively, which are connected to two bidirectional I/O ports on the microprocessor through the SPI bus. Data is clocked into the APR6016 through the *DI* pin upon the rising edge of the SPI clock, and it clocked out through the *DO* pin on the falling edge. The signal fed into the */CS* pin selects the APR6016 as the currently active slave on the SPI interface when it is active low. In addition, the active low signal from the sector address control output, *SAC*, is to be connected to another I/O port of the microprocessor when the voice playback device is nearing the end of the current segment. Finally, both of the positive and negative audio outputs, known as *AOUT+* and *AOUT-*, are to be fed to the respective positive and negative inputs of the MH88435 line interface for voice playback of pre-recorded messages.

3.6. LED Display

3.6.1. Component Description

In our application, we will have several LED indicators to show the status of all the client appliances currently being controlled or monitored by the HomePA. Red P428-ND LEDs and green P432-ND LEDs are chosen for display due to their relatively low costs.

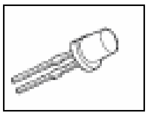

Figure 15: LED Diagram

3.6.2. Implementation

LED lights are used to indicate the status of the home appliances, i.e. whether or not the door is locked or unlocked; whether or not the window is open or close. For example, when the door is locked, the red LED will be on. When the door is unlocked, the green LED light is on. The block diagram can be illustrated in Figure 16.

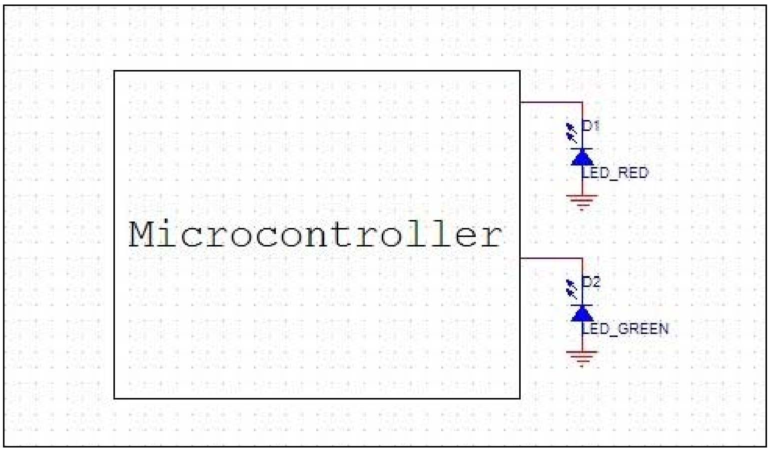

Figure 16: Block Diagram for LEDs

When the microcontroller detects that the door is locked, it will send out a voltage high to the red LED, and send out a voltage low to the green LED. On the other hand, when the microcontroller detects that the door is unlocked, it will turn off the red LED by sending a voltage low signal and turn on the green LED by sending it a voltage high. This mechanism will be accomplished using a software implementation.

3.7. Power Supply

The central control unit is to be powered by an external adaptor capable of supplying 6V DC from the household AC power outlet. Power requirements for the different individual components in the CCU are summarized in the following table.

Table 5: Voltage Requirements of Each Component in Central Control Unit

Component	Part Number	Required Voltage
Microprocessor	PIC16F877A	5.0V
DTMF Transceiver	CM8880-PI	5.0V
Voice Playback Device	APR6016	3.0V
Line Interface (DAA)	MH88435AD	5.0V

An adaptor output of 6V DC is desirable, as three components inside the CCU require an operating voltage of 5.0V and one requires 3.0V. The power supply voltage of 6.0V will be scaled down using various resistors to produce the required voltage for each internal component.

For the microprocessor, the DTMF transceiver, and the line interface (DAA), we use 1MΩ and 5MΩ resistors and connect each of the components in parallel to the 5MΩ resistor to divide the voltage to 5.0V. For the voice playback device, we use two 3MΩ resistors and connect the components in parallel with the 3MΩ resistor near the ground to divide the voltage to 3.0V.

The following circuit diagram shows the internal voltage dividers for the CCU.

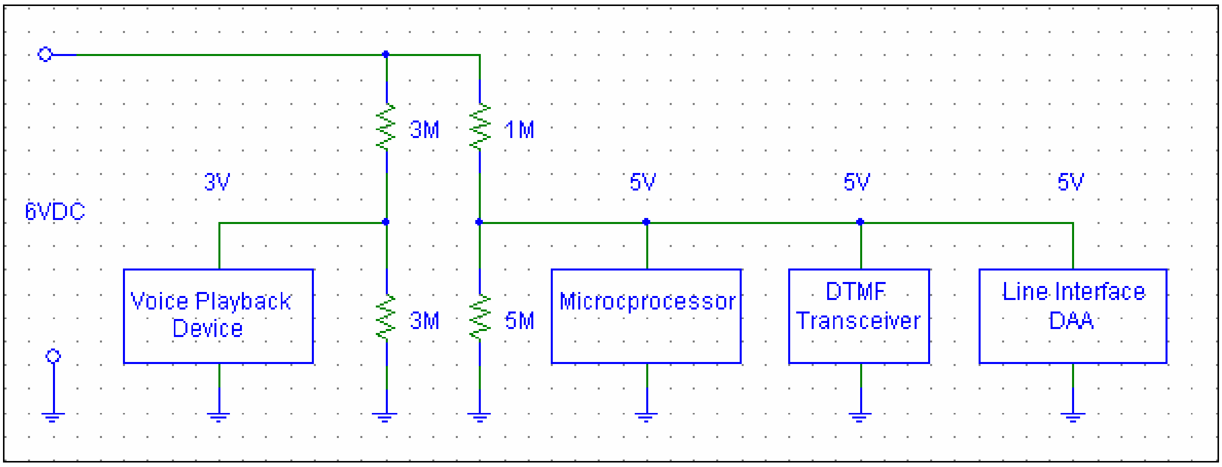

Figure 17: Internal Voltage Divider Circuitry of Central Control Unit

4. Wireless Communication Unit

4.1. Architecture Overview

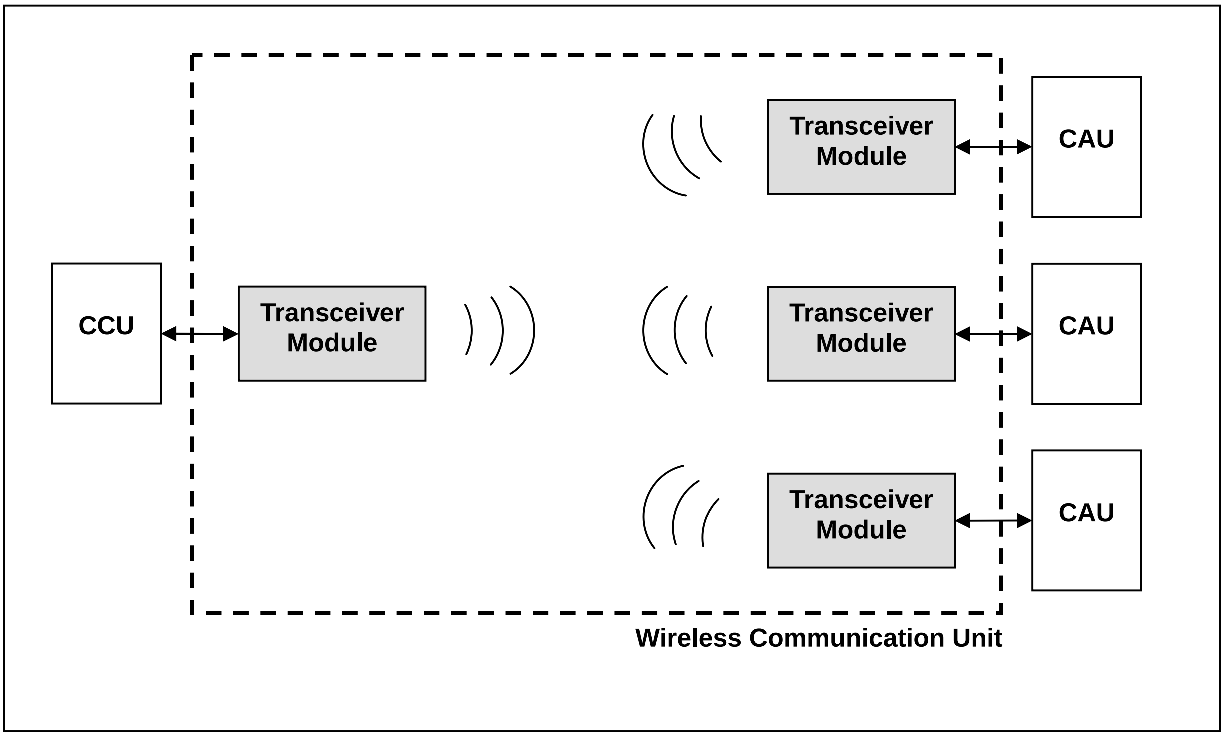

Figure 18: Block Diagram of Wireless Communication Unit

4.2. Component Description

The data communication between the central control unit and the client appliance unit(s) must be bidirectional, in order to meet the system function specifications listed as follows:

1. The CCU can send control codes wirelessly through the WCU to the CAU.
2. The CAU must be able to report the current status of the appliance, which the user wishes to control and monitor, back to the CCU.

In order to meet the aforementioned requirements, transceivers are used in constructing the WCU. Each of the transceiver modules shown in Figure 18 is identical and provides the same functionality. Each transceiver must be able to modulate and transmit wirelessly a stream of data, in the form of either control or status codes. On top of that, each must be able to receive and demodulate the signals broadcasted in its operational frequency band.

4.3. Implementation

The data communication involves transmitting and receiving streams of control and status codes in between the central control unit and client appliance unit; hence, high speed communication is desirable but not necessary. Because a simple wireless communication device is sufficient, we chose the RTF-Data-Saw 4800 bps AM Transceiver Module, made by Abacom Technologies, to implement the WCU.

An RTF AM Transceiver consists of a transmitter and a receiver and is suitable for half-duplex bidirectional transmission. Namely, the transmitter component can function independently from the receiver component. This feature results in low power consumption, because the transmitter component can be powered off during the receiving operation and vice versa. Both the transmitter and receiver can be powered independently by a 5V supply voltage and requires only one I/O pin per pair. The figure below shows the system block diagram of the transceiver module.

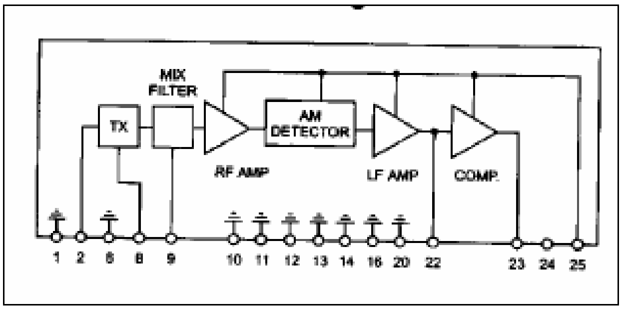

Figure 19: Block Diagram of the RTF AM Transceiver

The following diagram shows the physical circuit to be implemented as our module.

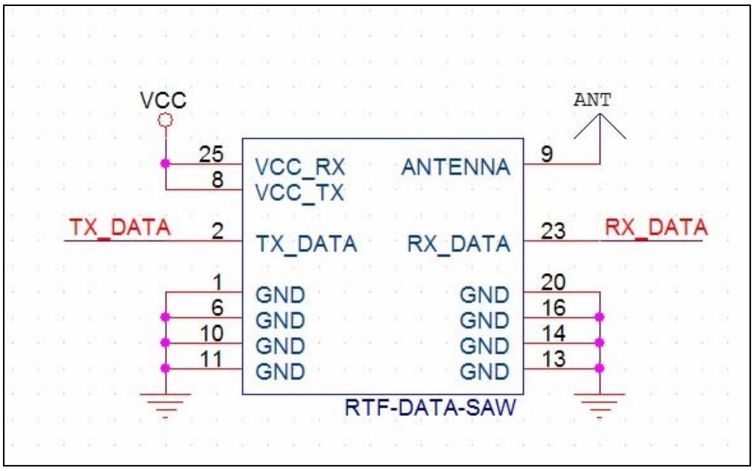

Figure 20: Connection Diagram of Wireless Communication Module

The *VCC* is 5V as specified in the data sheet, and the antenna will be constructed by attaching a quarter wavelength of wire to the *ANTENNA* pin. The signals *RX_DATA* and *TX_DATA* represent data being received and transmitted, respectively. These signals will be the input and output to the microcontrollers in the CCU and CAU.

4.4. Transmission Methodology

The data is transmitted in a packet of 9 bits. The first bit is the start bit (logic '0'), followed by 7 bits of data, and terminating with a stop bit (logic '1'). The transmission between the transceivers requires a special bi-phase coding called Manchester Encoding.

4.4.1. Manchester Encoding

The Manchester Encoding possesses the following rules:

1. In Manchester Encoding, a logic '0' in data is represented by a '0' to '1' transition (rising edge) at the centre of each data bit.
2. In Manchester Encoding, a logic '1' in data is represented by a '1' to '0' transition (falling edge) at the centre of each data bit.

The encoding can be implemented using an exclusive-OR operation between the data and a clock frequency at twice the bit rate. The following diagram shows process of producing a stream of Manchester encoded data.

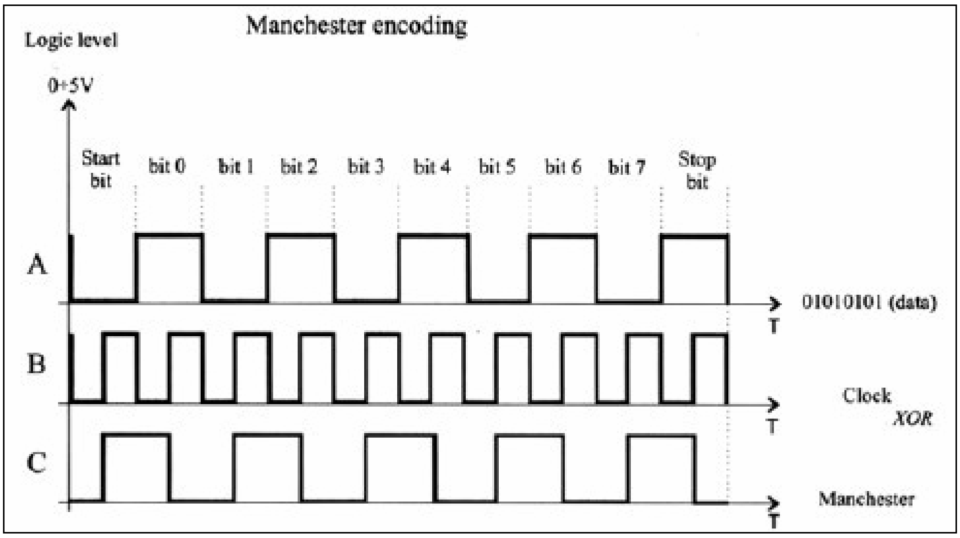

Figure 21: Manchester Encoding of a Stream of Data

From Figure 21, we see that transitions occur at the centre of every data bit. Section 4.4.2 will discuss the synchronization between the transmitter and receiver.

4.4.2. Digital Phase Lock Loop (DPLL)

DPLL is a technique used to extract the data transmission rate. If the received encoded data is sampled at a very high frequency, the sampled start bit may look like:

000000000000000111111111111111

However, if the transmitter and the receiver are not synchronized, the sampled start bit may look as follows:

000011111111111111100000000000

The example above shows the restoration of data with a misalignment of four sampling clock cycles. Therefore, the misalignment can be adjusted by shifting the stored value by four sample bits. This technique demonstrated is called the digital phase lock loop.

5. Client Appliance Unit

5.1. Architectural Overview

The client appliance unit consists of a sensor, an actuator and a microprocessor. There are four types of client appliance units in our prototype: light, door, window and heater. The architecture of each type of client appliance resembles the block diagram as shown below.

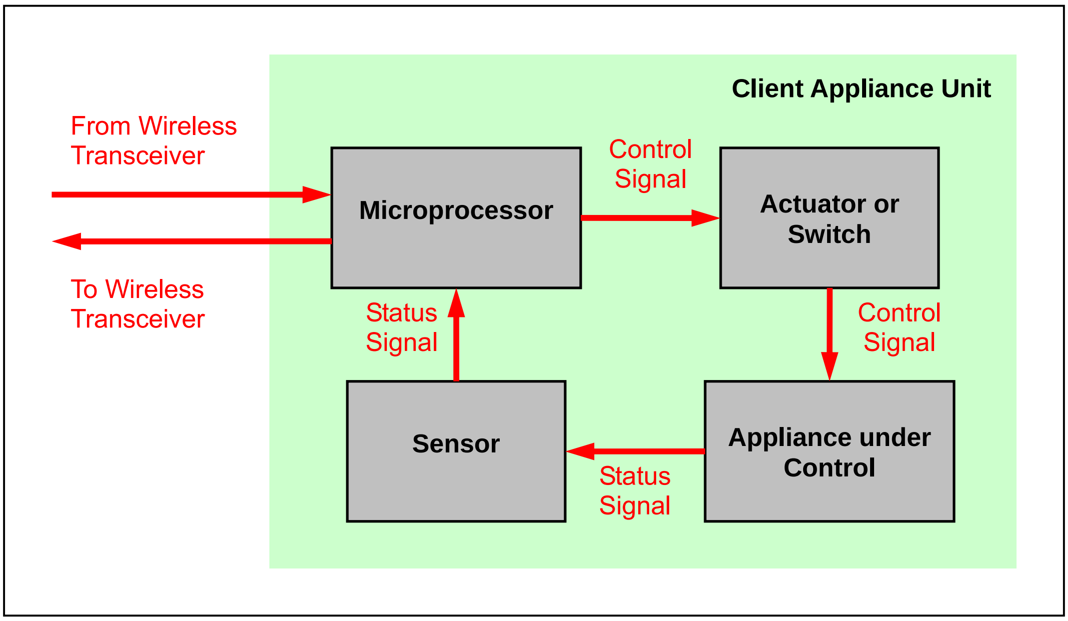

Figure 22: Block Diagram for Client Appliance Unit

A user command generated by the telephone end is sent through the wireless transceiver to the CAU microprocessor. The wireless transceiver then identifies the user's control command, checks the current status of the sensor, and then makes necessary changes to its actuator or switch. Then, after the completion of the required task, the CAU microprocessor notifies the user by sending a message back to the CCU via the wireless transceiver.

5.2. Power Supply

The microprocessors and circuits used in the client appliance units are to be powered by three AA-type (R6PU 1.5V) dry cells in series, contributing to a total DC voltage of 4.5V. Each CAU has its individual battery box where alkali or rechargeable batteries can be installed as alternatives if the user wishes to lengthen the operating duration of the batteries.

5.3. Light Unit

5.3.1. Component Description

The component parts for the prototype light unit include:

- a household light bulb under test
- AC power cords
- a homemade switch
- two iron pins
- two electromagnets
- a PIC16F877A microprocessor
- a contact sensor circuit

5.3.1.1. Light Bulb and AC Power Cord

The light unit is capable of controlling all kinds of household light bulbs. For testing and demonstration purposes, a light bulb with power rating of 120V, 60W is implemented in our prototype model.

The AC power cords are used to connect the light bulb to the 120V, 60Hz AC power outlet. The power cords form a continuous current path to turn on the light bulb when the homemade switch is on. The power cords form a discontinuous current path to turn off the light bulb when the homemade switch is off.

In building our prototype, we choose to implement an AC-powered light bulb because it more accurately models the typical light bulb found in homes. Alternatively, we can also use a small battery-powered light bulb in our implementation.

5.3.1.2. Homemade Switch, Permanent Magnets and Electromagnets

The homemade switch, shown in Figure 23, is constructed using three wooden blocks: a base, a panel and a pivot. The pivot block is fixed to the base block while providing a pivot point to the panel block. As a result, the two ends of the panel block, which are denoted as the ON end and the OFF end, can swing up and down about the pivot point.

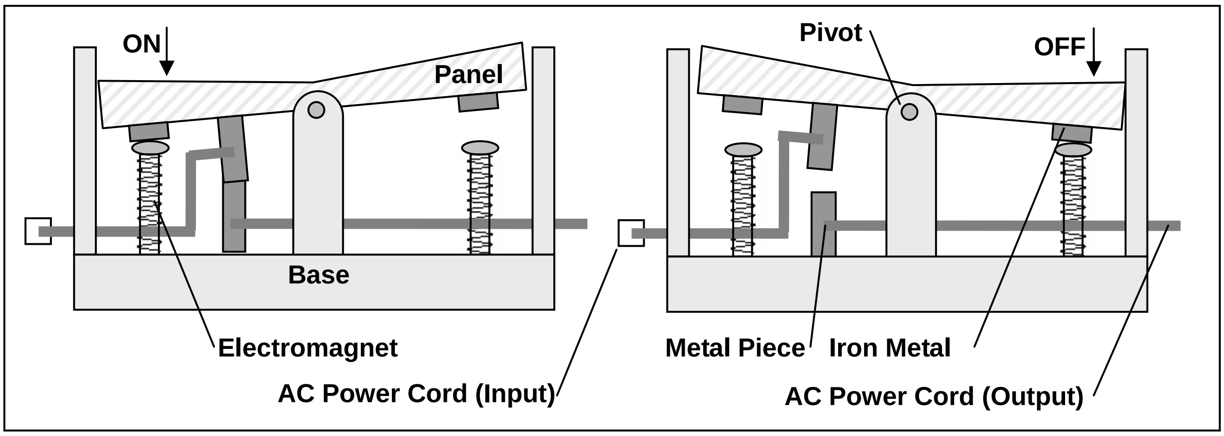

Figure 23: Schematic of Homemade Switch

In order to allow user to switch on and off the light bulb manually, one metal piece hangs down from the panel block while a second metal piece sticks out from the base block to act as a set of contact sensors (Figure 23). The two metal pieces are placed in a way that they will be in contact when the ON end of the panel block is lowered, simulating the "switch on" state. Since the two pieces are in contact with each other, the current path from the AC power line to the light bulb becomes continuous and the light bulb is switched on. On the other hand, the two metal pieces are isolated when the OFF end of the panel block is lowered, simulating the "switch off" state. Since the two pieces are no longer in contact, the current path from the AC power line to the light bulb is broken, and the light bulb is switched off.

Additionally, to allow the light bulb to be controlled electronically by the microprocessor, two metal pieces and two electromagnets are added to the homemade switch (Figure 23). The electromagnets are made by winding coated copper wire around metal cores, creating solenoids. A metal protrusion hangs down from each end of the pivot block, while an electromagnet sticks out from each end of the base block. The electromagnets are also connected to the control output pins of the microprocessor.

During the "switch on" state, the electromagnet on the ON end receives an output "HIGH" from the microprocessor and conducts. As a result, the conducted electromagnet attracts the iron metal directly above it and pulls down the ON end of the panel block. The lowering of the ON end of the panel block enables the continuous current path and thus switches on the light bulb. On the other hand, during the "switch off" state, the electromagnet on the OFF end receives an output "HIGH" from the microprocessor and conducts. Then, the conducted electromagnet attracts the iron metal on the OFF side and pulls down the OFF end of the panel block. The lowering of the OFF end of the panel block disables the current path and thus switches off the light bulb.

Finally, the dimension of the homemade switch is roughly: 15cm by 10cm in base and 8cm in height.

5.3.1.3. Microprocessor and Contact Sensor Circuit

The PIC16F877A microprocessor is used to provide electrical control and receive status information of the light bulb. The basic setup of the microprocessor is discussed previously in Figure 10. In addition, two output pins from the microprocessor are connected to the two electromagnets in order to select the proper electromagnet to conduct.

Then, in order to monitor the status of the homemade switch, an input pin of the microprocessor is connected to the iron metal on the ON side. Then, the following circuit is constructed to determine whether the electromagnet and the iron metal are in contact with each other. Since the iron metal on the ON side touches the electromagnet underneath whenever the switch is ON, Figure 24 acts as a contact sensor for determining if the light bulb is switched on.

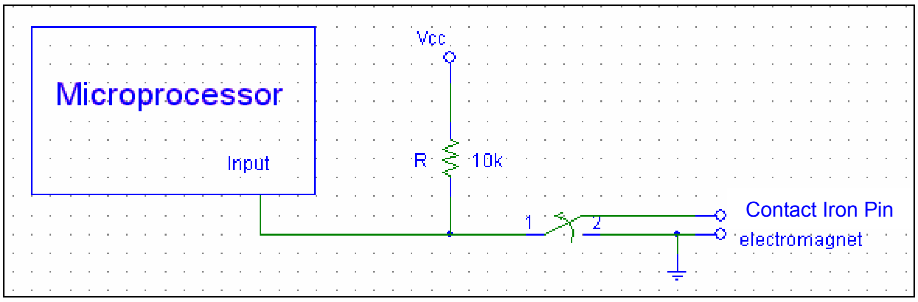

Figure 24: Schematic of Contact Sensor Circuit

As illustrated in Figure 24, when the contact piece and the electromagnet are not touching, the path between node 1 and 2 is open, and the microprocessor input is kept HIGH (equal to Vcc). When the contact piece and the electromagnet are touching, the path between node 1 and 2 is closed, and the microprocessor input is pulled LOW by the ground at the electromagnet end. The 10 kΩ pull-high resistor is used to limit the current to the milliamp range while the input voltage is pulled LOW.

The above sensor circuit is a simple method for detecting if the light bulb is on. Alternatively, a photodiode can be used for detecting the status of the light bulb. However, the accuracy of the photodiode circuit will be easily affected by the amount of surrounding ambient light present. Also, in order to reduce the component count, the implementation in Figure 24 is chosen.

5.3.2. Implementation

The overall block diagram of the light unit is illustrated in Figure 25. Figure 25 is a modified version of the generic block diagram shown in Figure 22.

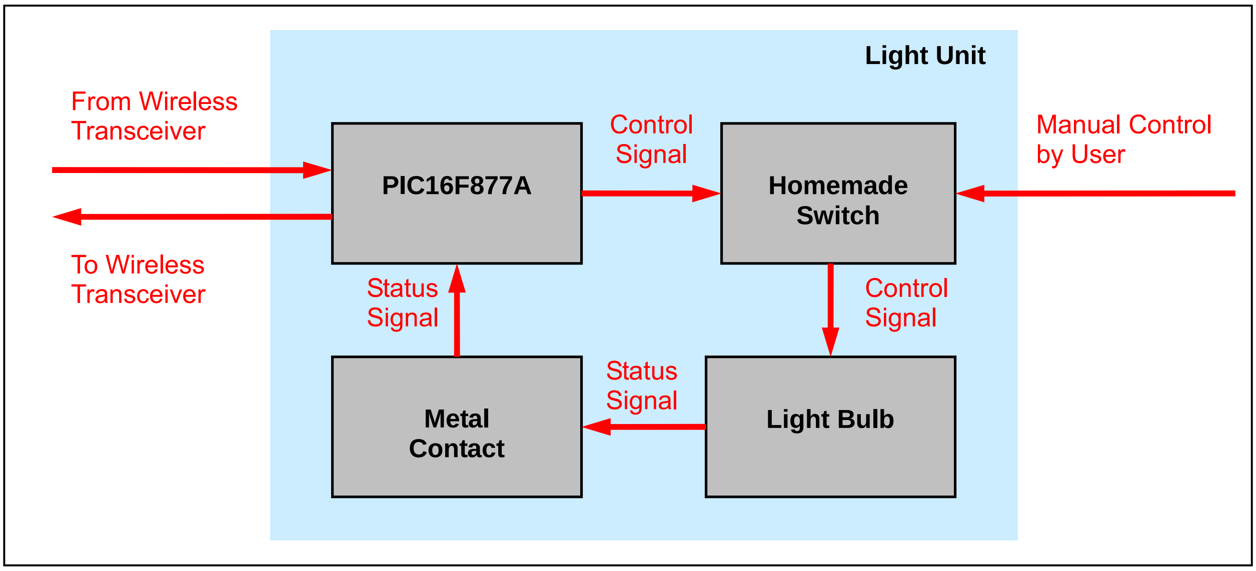

Figure 25: Block Diagram for a Light Unit

Next, Figure 26 is the overall design of the light unit. The light bulb is connected to the AC power outlet via the AC power cords. When the homemade switch is turned ON either by manually pressing the ON side of the panel block or electronically conducting the electromagnet on the ON side, the two iron metal pieces are brought into contact. As a result, the current path becomes continuous, and the light bulb is switched on. When the homemade switch is turned OFF either by manually pressing the OFF side of the panel block or electronically conducting the electromagnet on the OFF side, the two iron metal pieces are isolated. As a result, the current path becomes discontinuous, and the light bulb is switched off.

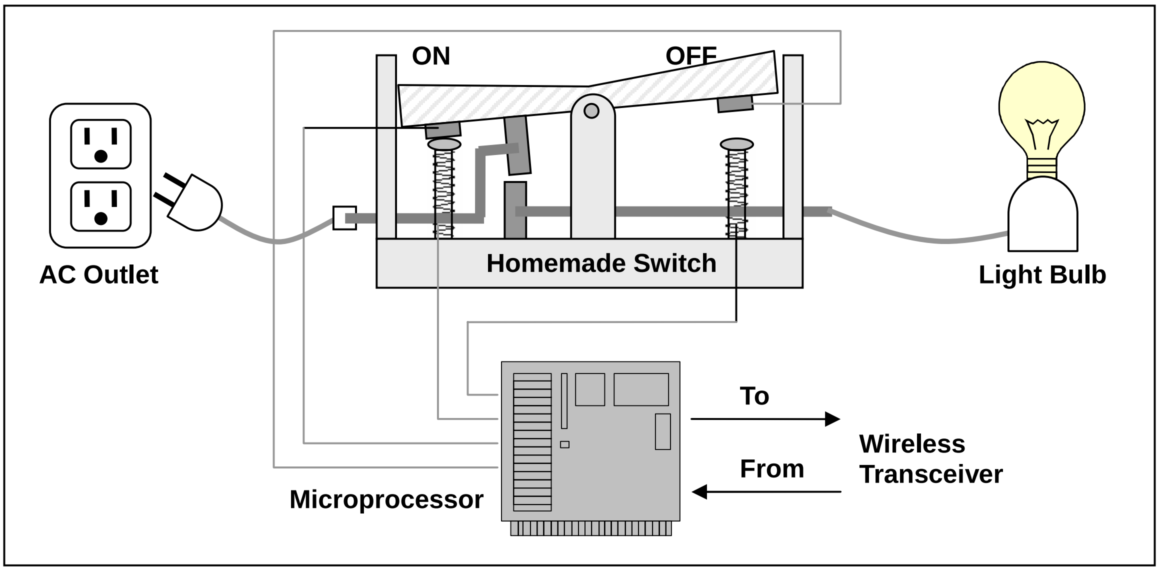

Figure 26: Schematic of Light Unit

5.4. Door Lock Unit

5.4.1. Component Description

The component parts for the prototype door lock unit include:

- a wooden door lock
- a standard gear
- a bevel gear
- a DC motor
- a rack gear
- a PIC16F87 microprocessor
- a contact sensor circuit

5.4.1.1. Wooden Door Lock

The wooden door lock is made of a rectangular wooden bar that slides inside two metal holders as shown in Figure 27. The two metal holders are nailed onto a piece of wooden board which simulates the actual door.

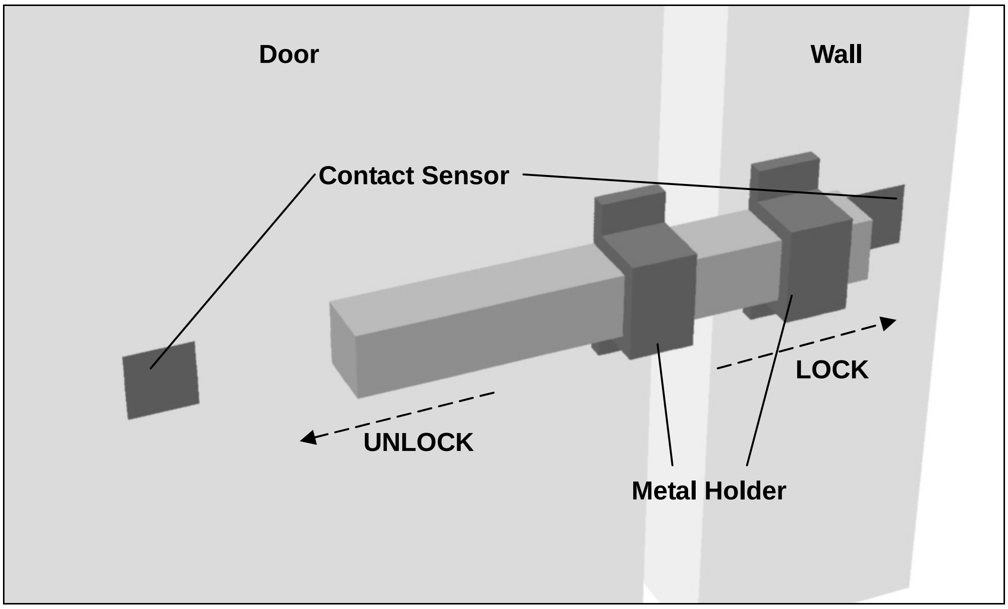

Figure 27: Schematic of Wooden Door Lock

5.4.1.2. DC Motor and Gear

The DC motor we selected for moving the wooden bar is the RE-260RA-18130 Mabuchi brush motor. The operating conditions for the motor are listed in Table 6.

Table 6: DC Motor Operating Conditions

Parameter	Value
Operating Voltage Range	1.5 to 4.5V
No Load Speed	7100 turns/min
No Load Current	0.16A
Maximum Speed	6000 turns/min
Maximum Current	0.88A
Maximum Torque	2.58mN-m
Stall Torque	16.7mN-m
Stall Current	4.80A

Attached to the rotating axle of the DC motor is a standard gear, connected to a bevel gear which is followed by a rack gear. The gear system converts rotational motion generated by the motor into translational motion. As well, the gear system increases the torque applied by the motor while decreases the speed at which the bar moves. The door lock slides towards left or right depending on the rotational direction of the motor. Since the speed at which the bar moves is not a concern in our design, no precise gear ratio is calculated. To simplify part selection, only available gear sizes are used to build the gear system. The gear system is shown in Figure 28.

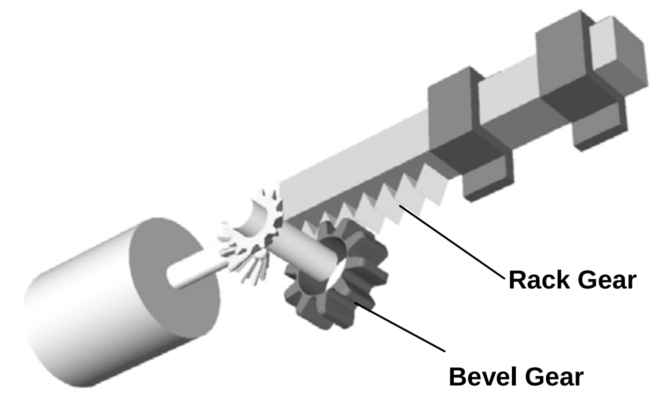

Figure 28: Schematic of Gear System

5.4.1.3. Microprocessor and Contact Sensor Circuit

The PIC16F877A microprocessor is used to drive the motor and receive status information of the door lock. The basic set up of the microprocessor is discussed previously, as shown in Figure 10. In addition, two output pins from the microprocessor are used to provide voltage inputs to the positive terminal of the motor.

The DC motor has a positive and a negative terminal. In our particular application, the negative terminal is grounded. When a positive voltage is applied to the positive terminal, the motor turns in the clockwise direction, looking toward the axle. On the other hand, when a negative voltage is applied to the motor, the motor turns in the counter clockwise direction, looking toward the axle. In our design, we use one output pin from the microprocessor to supply positive voltage to the motor. In addition, we use a second output pin to supply negative voltage by adding a unity gain inverting amplifier.

The maximum current at the output pin of the PIC16F877A microprocessor is approximately 25mA. In order to realize the optimal performance of the motor, we need to significantly increase the current level in the output pin to a value close to the maximum allowable current of the motor, 0.36A. To produce a high current level, we adapt the Darlington configuration to build a voltage follower.

The schematic for the Darlington configuration along with the inverting amplifier is shown in Figure 29.

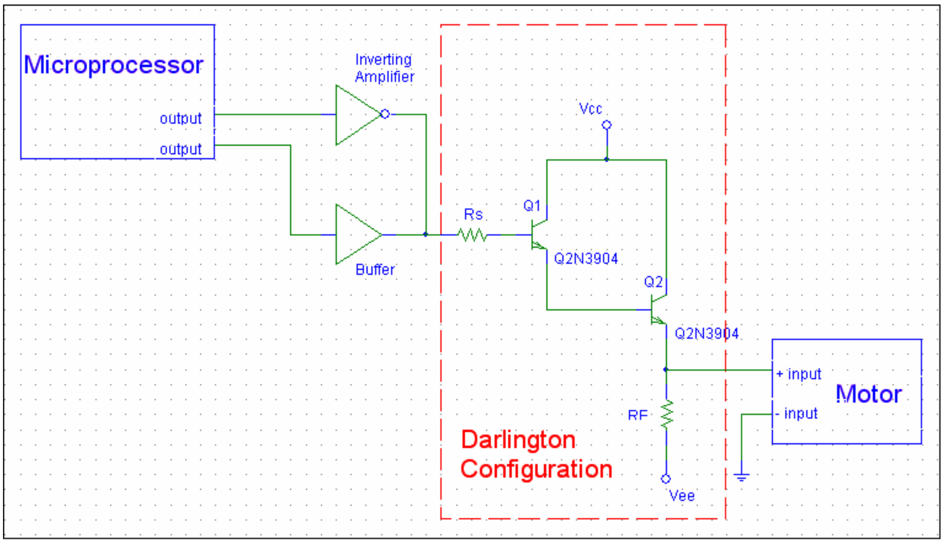

Figure 29: Schematic of Voltage Follower Using Darlington Configuration

Finally, to check the status of the door lock, one set of contact metals is attached to each end of the wooden door lock, which are denoted as the UNLOCK end and the LOCK end. In each set, one piece of metal is attached to the back side of the door lock and one piece of metal is attached to surface of the door. One input of the microprocessor is then connected to each set of contact metals. Then, Figure 30 is the circuit that determines if the contact metals are in contact.

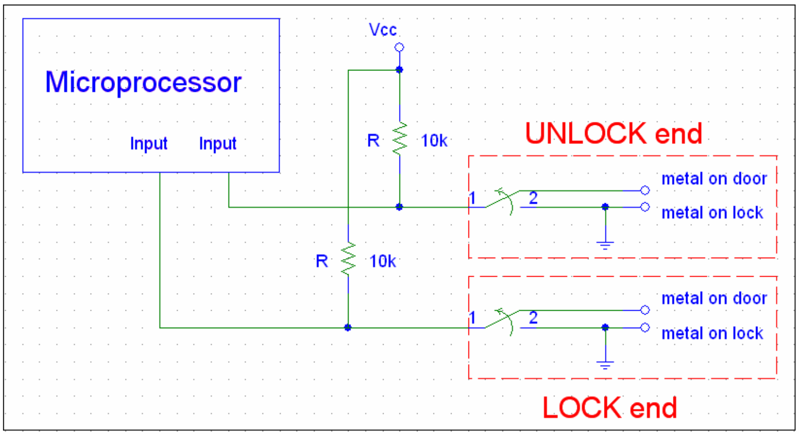

Figure 30: Schematic of Contact Sensor Circuit

The contact metals are used to indicate whether the "unlock" or the "lock" operation has been completed. If during the unlock operation and the set of contact metals at the UNLOCK end is touching, the microprocessor identifies that the door lock has reached the end of its path, and the microprocessor stops sending positive voltage to rotate the motor. If during the lock operation and the set of contact metals at the LOCK end is touching, the microprocessor identifies that the door lock has reached the end of its path, and the microprocessor stops sending negative voltage to rotate the motor.

5.4.2. Implementation

The overall block diagram of the door lock unit is illustrated in Figure 31, which is a modified version of the generic block diagram shown in Figure 22.

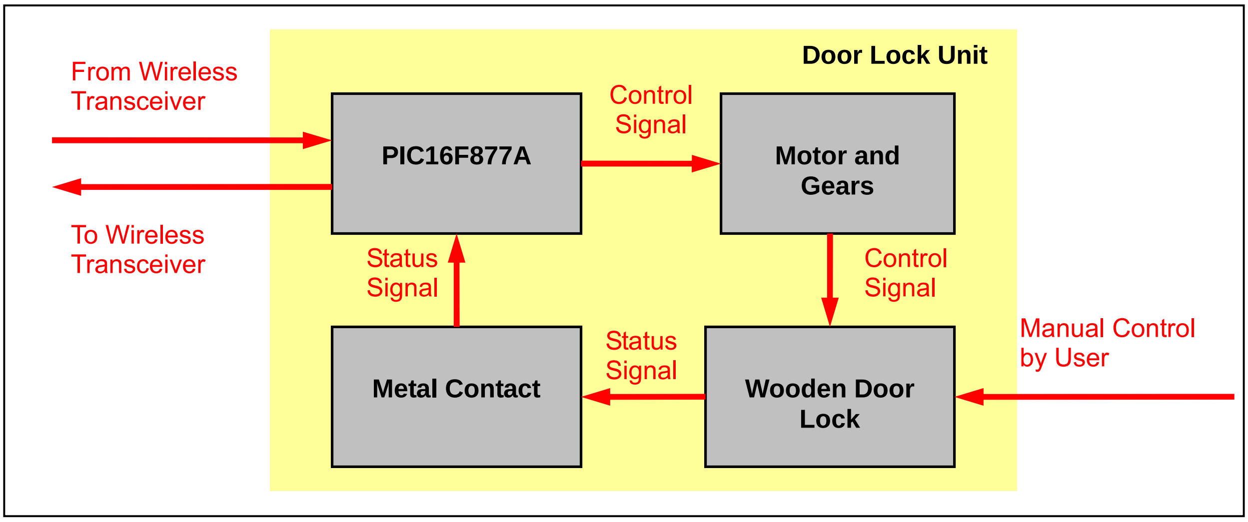

Figure 31: Block Diagram for Door Lock Unit

Figure 32 shows the overall design for the door lock unit. To unlock the door, the microprocessor sends a positive voltage to the positive terminal of the motor to rotate the motor in the clockwise direction. Next, the gear system slides the door lock to the left, unlock direction. Then, when the contact metal sensors at the UNLOCK end are touching, the microprocessor detects that the lock has reached the end and stops the motor rotation. In contrast, the microprocessor sends a negative voltage to slide the door lock to the lock direction. Then, the microprocessor stops the motor when the contact sensors at the LOCK end are in contact.

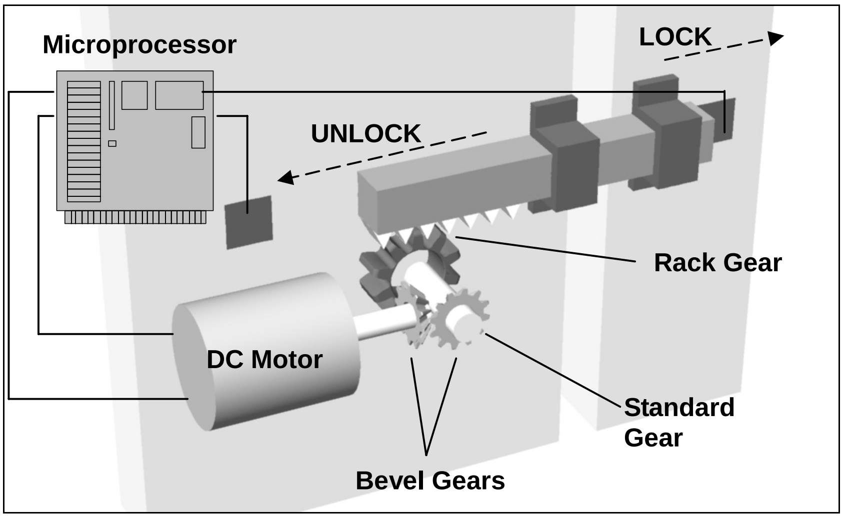

Figure 32: Schematic of Door Lock Unit

5.5. Window Unit

5.5.1. Component Description

The component parts for the prototype window unit include:

- two transparent plastic boards
- a standard gear
- a bevel gear
- a dc motor
- a rack gear
- a infrared sensor (emitter and receiver)
- a PIC16F87 microprocessor
- a contact sensor circuit

5.5.1.1. Plastic Boards, Motor and Gear

The plastic boards are used to model a sliding window. The standard gear, bevel gear and the rack gear are used to improve the torque of the dc motor, convert rotational motion to translational motion and reduce the rotational speed of the DC motor. The DC motor we selected is the RE-280RA-2865 Mabuchi brush motor. The operating conditions of the motors are indicated in Table 6 in Section 5.4.1.

The motor and the gear system work jointly to slide the plastic board left and right. The design for this portion is similar to the sliding door lock as described in Section 5.4.1.1 and 5.4.2.2.

5.5.1.2. Infrared Sensor

An infrared emitter and an infrared receiver are located at two ends of an open window in such a ways that when the window is in the process of closing, the receiver is in the line of sight of the emitter. The infrared sensor is implemented as a safety feature to stop the window from closing when an obstacle is present in the closing path of the window. The placement of the infrared emitter and receiver is illustrated in Figure 33.

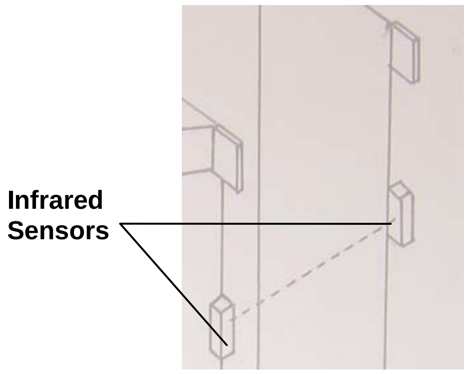

Figure 33: Schematic for Infrared Sensor Placed on Window Unit

The infrared emitter we selected is SFH4502. It features the following operating conditions:

Table 7: Infrared Emitter Operating Conditions

Parameter	Value
Forward Current	100mA
Operating Temperature Range	-40 to 100°C
Power Dissipation	180mW
Wavelength at Peak Emission	950nm

The infrared receiver we selected is QSD122. Some operating conditions for the infrared receiver are shown as follows:

Table 8: Infrared Receiver Operating Conditions

Parameter	Value
Forward Current	100mA
Operating Temperature Range	-40 to 100°C
Power Dissipation	100mW
On State Collector Current	6.00mA (min)
Peak Sensitivity Wavelength	880nm
Reception Angle	±12°

According to Table 8, the infrared receiver can detect wavelengths around 880nm. Meanwhile, from Table 7, the infrared emitter is capable of sending out signals that have wavelengths around 950nm which is close to 880nm.

A picture of SFH4502 infrared emitter is shown in Figure 34, and a schematic of QSD124 infrared receiver is shown in Figure 35.

Figure 34: SFH4502 Infrared Emitter

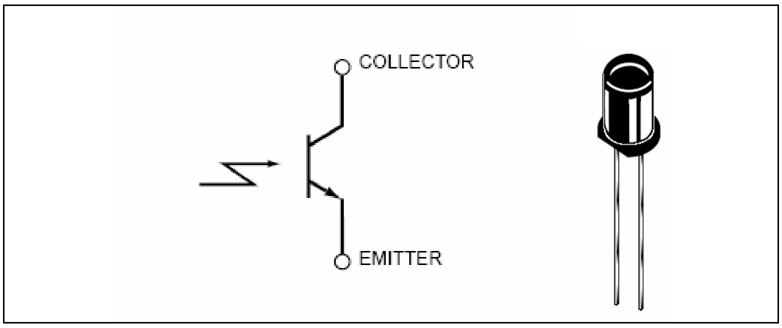

Figure 35: QSD124 Infrared Receiver

While the window is closing, the microprocessor output pin feeds a current to the infrared emitter. As a result, an IR signal is sent from the emitter. If, at this time, no obstacle is present in the closing path of the window, the infrared receiver will successfully detect the IR signal. If the IR signal is blocked from reaching the infrared receiver, an obstacle must be present and the window stops the closing action.

An IR sensor is chosen to implement the safety check feature over other types of sensors because an IR sensor is cost effective and generates low power signal which is not harmful to the human body.

5.5.1.3. Microprocessor and Contact Sensor Circuit

Again, the PIC16F877A microprocessor and the contact sensor circuit are implemented using the same design as the Door Lock Unit, which is described in Section 5.4.1.3. For the contact sensor circuit, two sets of metals are placed on the window. When the sliding window is completely open, one set of contact metals is touching. On the other hand, when the sliding window is completely close, a second set of contact metals is touching. This is illustrated in Figure 36.

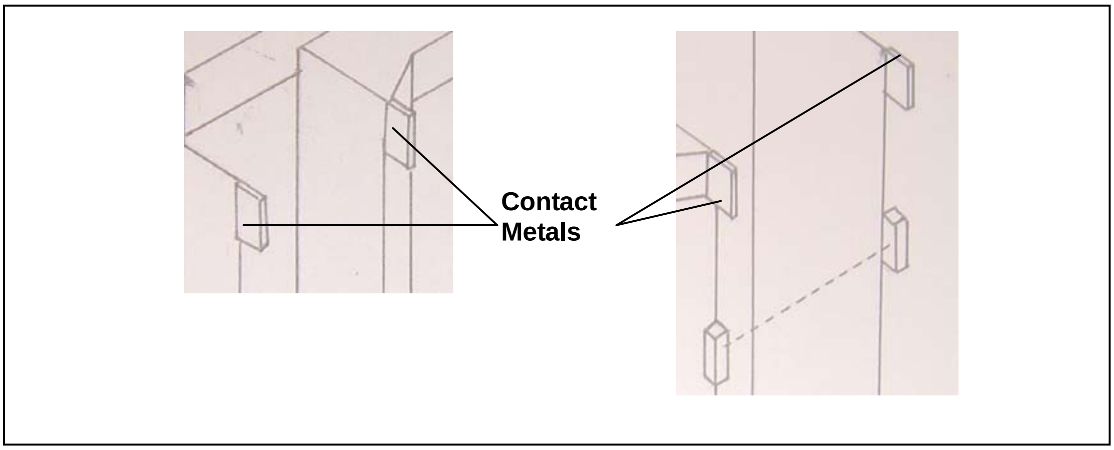

Figure 36: Installation of Contact Metals on Window Unit

5.5.2. Implementation

The overall block diagram of the window unit is illustrated in Figure 37, which is a modified version of the generic block diagram shown in Figure 22.

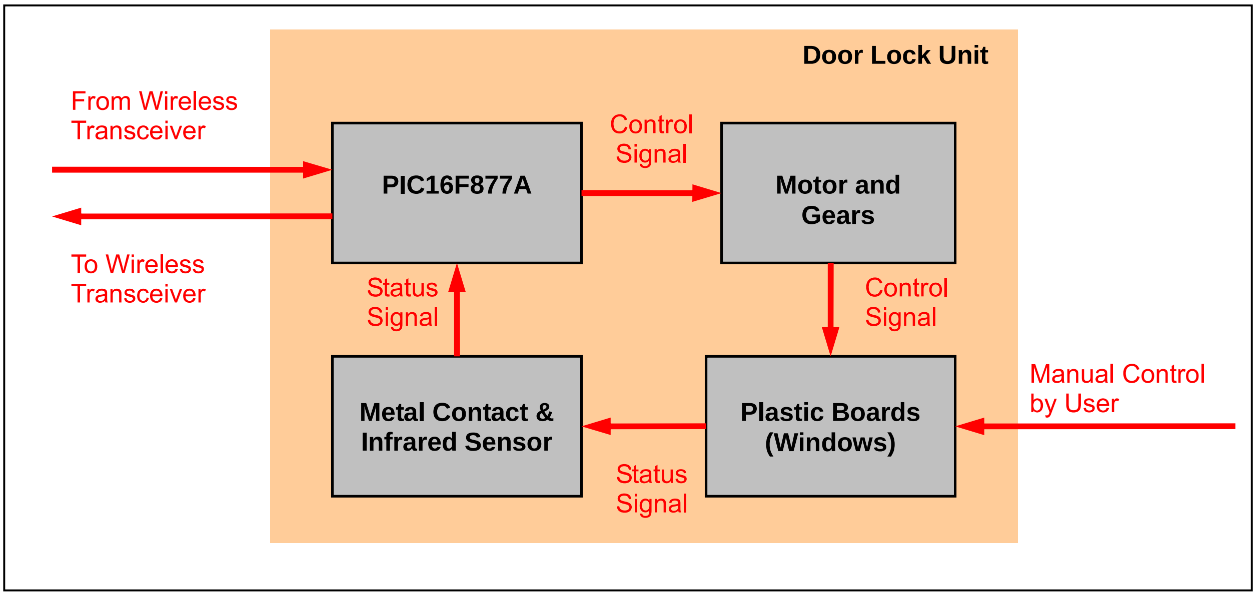

Figure 37: Block Diagram for Door Lock Unit

Figure 38 shows the overall design for the window unit. The microprocessor sends a positive voltage to the positive terminal of the motor which rotates the motor in the clockwise direction. The gear system then slides the window to the left, which is the open direction. In contrast, the microprocessor sends a negative voltage to slide the window to the right, closing the window.

As well, two sensor circuits work jointly with the microprocessor to achieve advanced control. The first sensor circuit consists of two sets of contact metals. One set is in contact when the door is completely opened and another set is in contact when the door is completely close, so the microprocessor stops the rotating motor in either case. The second sensor circuit consists of an infrared emitter and an infrared receiver. The infrared emitter sends out an IR signal to the infrared receiver as the window begins the closing action. If the emitted IR signal is not received, an obstacle must be present in the closing path of the window, then the microprocessor forces the moving window to stop closing.

The dimension of the whole window unit is roughly: 40 cm by 15 cm in base and 30 cm in height.

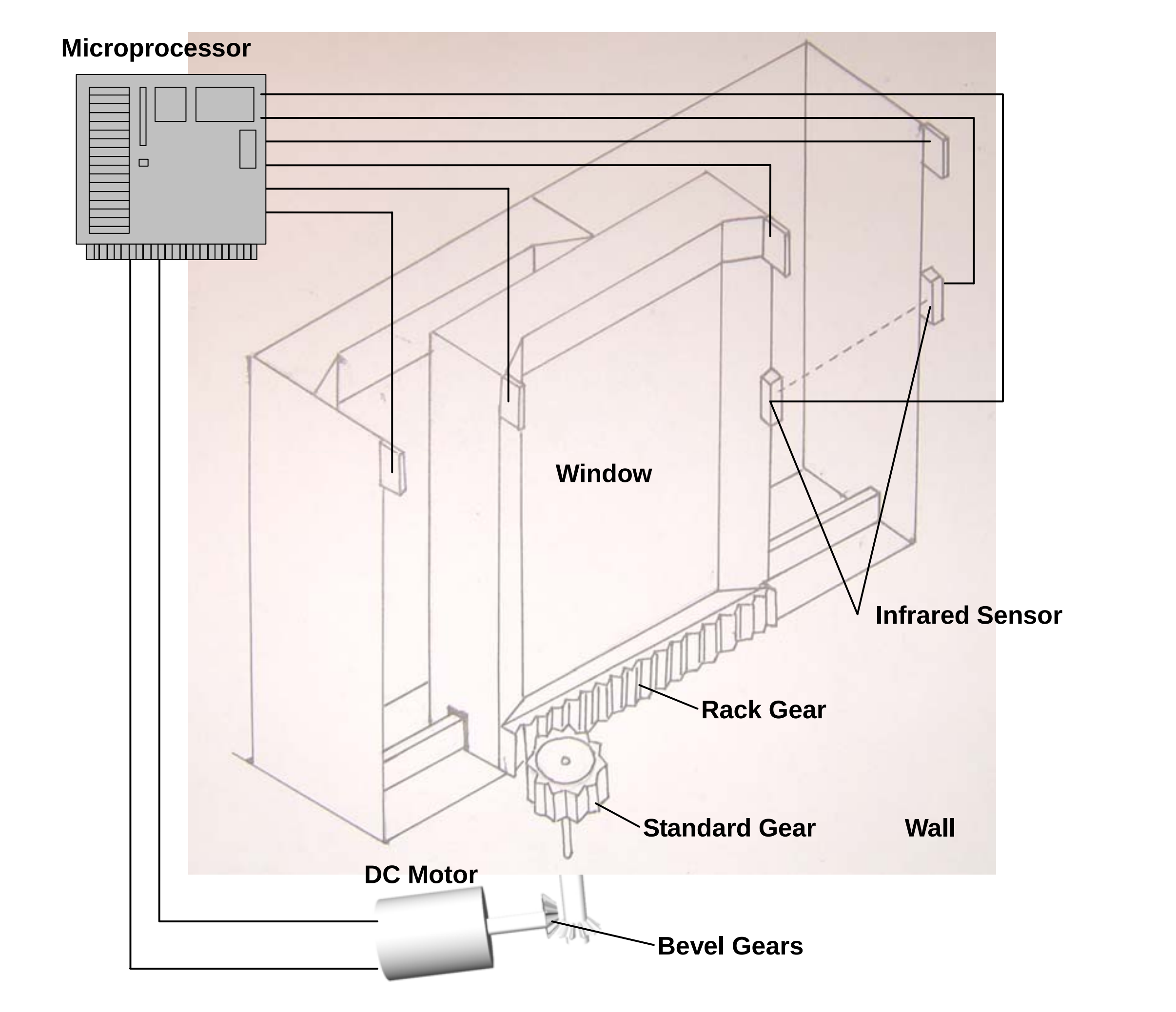

Figure 38: Schematic of Window Unit

5.6. Heater Unit

5.6.1. Component Description

The component parts for the prototype heater unit include:

- a heater controller knob
- a gear train
- a belt
- pulleys (one small and one big)
- a DC motor
- a temperature sensor
- a PIC16F87 microprocessor

5.6.1.1. Heater Controller Knob and Temperature Sensor

In our heater implementation, we choose the heater controller with a simple turning knob. The heater controller knob is shown in Figure 39.

Figure 39: Picture of Heater Controller Knob

The temperature sensor we select is the KT210 Silicon Temperature Sensor. The operating conditions given in the data sheets are as follows:

Table 9: Temperature Sensor Operating Conditions

Parameter	Value
Forward Current	100mA
Minimum R_{25}	970Ω
Maximum R_{25}	1030Ω
Maximum Operating Voltage	25V
Operating Temperature Range	-50 to 150°C

The temperature sensor has a positive temperature coefficient. As a result, the output voltage of the temperature increases proportionally with the increasing temperature. A diagram showing the temperature sensor is given below.

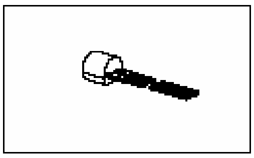

Figure 40: Picture of the Temperature Sensor

5.6.1.2. Motor, Belt and Gear Train

The DC motor we selected for sliding the heater unit is the RE-260RA-18130 Mabuchi brush motor. The operating conditions for the motor are listed in Table 10.

Table 10: DC Motor Operating Conditions

Parameter	Value
Operating Voltage Range	1.5 to 4.5V
No Load Speed	6900 turns/min
No Load Current	0.095A
Maximum Speed	5470 turns/min
Maximum Current	0.36A
Maximum Torque	0.97mN-m
Stall Torque	4.70mN-m
Stall Current	1.40A

A series of gears is attached to the axle of the DC motor to increase the output torque and reduce the output angular speed. A small pulley is also attached to the last gear and is used to drive a big pulley attached to the controller knob. Finally, the two pulleys are connected by a belt to unify their motion.

The motor, gear train, and pulley work together to turn the heater controller knob. Small increments in the turning of the heater controller knob will be achieved by using a large gear ratio.

Alternatively, stepper motor can be used to produce small incremental turning of the heater controller knob. The proposed scheme using a DC step motor and a gear train with a large gear ratio is chosen because it is cheaper and easier to implement than the stepper motor.

5.6.1.3. Microprocessor

The PIC16F877A microprocessor is used to drive the motor and sample the temperature sensor. The basic setup of the microprocessor is discussed previously, as shown in Figure 10. In addition, an analog input pin from the microprocessor is connected to the temperature sensor's voltage output. Meanwhile, the temperature sensor signal ground is connected to the signal ground of the microprocessor. The circuit connection between the temperature sensor and the microprocessor is shown in Figure 41.

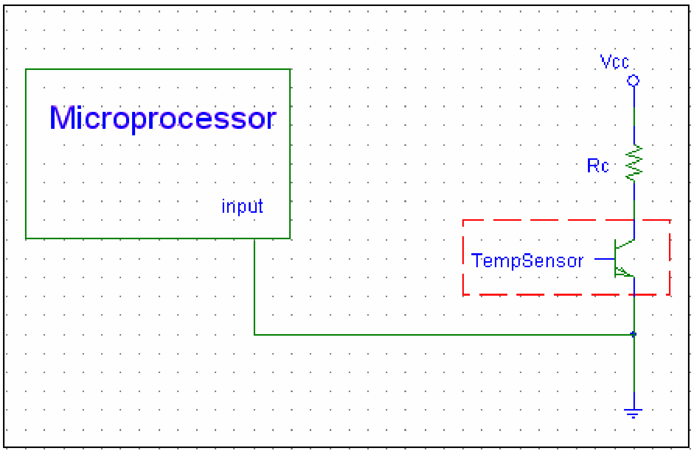

Figure 41: Schematic of Temperature Sensor Circuit

5.6.2. Implementation

The overall block diagram of the heater unit is illustrated in Figure 42, which is a modified version of the generic block diagram shown in Figure 22.

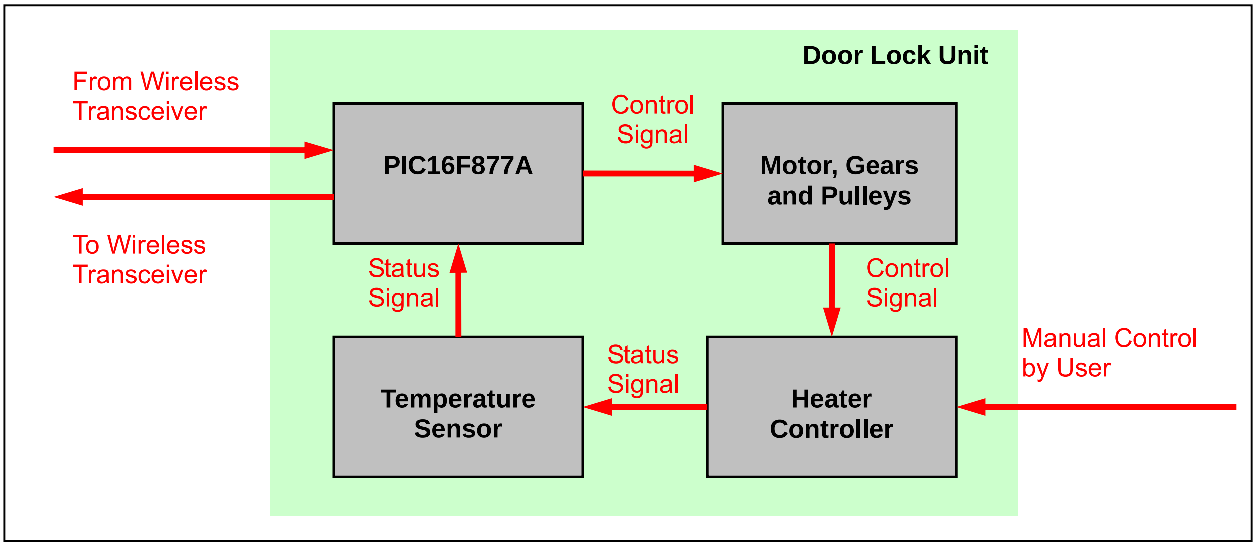

Figure 42: Block Diagram for Heater Unit

When the user wants to achieve a desired temperature, the motor rotates to drive the gear train and the pulley system in order to turn the heater controller knob in the direction toward the desired temperature. The degree rotated is very minimal, ideally less than 1°C. Then, the microprocessor waits for the room temperature to settle after the change before comparing the sensor temperature with the desired temperature. If the desired temperature is not yet reached, the microprocessor moves the motor accordingly to turn the knob toward the desired temperature. Then, the microprocessor waits again for the room temperature to settle before making further changes. This process iterates until the desired temperature is finally achieved.

Figure 43 shows the schematic diagram of the heater unit.

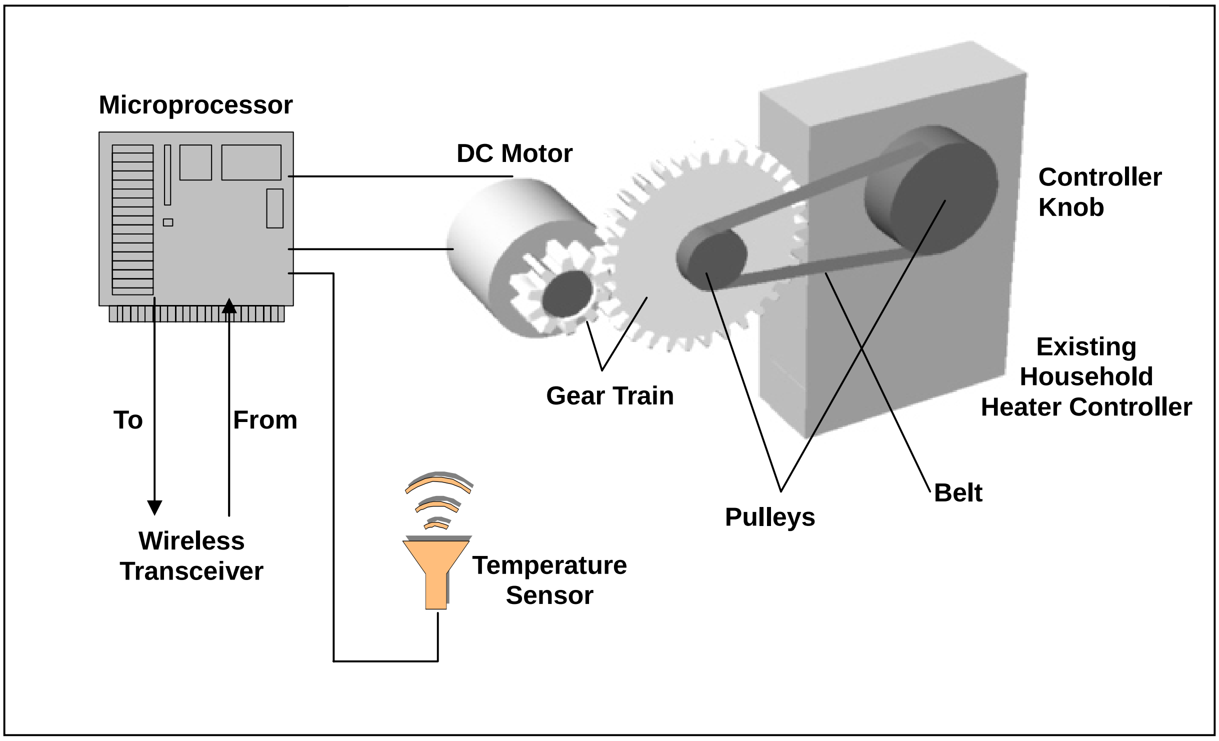

Figure 43: Schematic of Heater Unit

6. User Interface Specifications

The user interface will be implemented using a touch-tone system which allows the user to listen to an audio menu and control the unit through a touch-tone telephone. The HomePA will be activated if the user presses '1' while the phone is ringing. Otherwise, the HomePA will not be activated and the phone will operate normally (i.e. continue ringing, forwarded to answering machine etc.). The flow chart in Figure 44 demonstrates the user interface once the HomePA is activated.

The main menu consists of the following selections:

Table 11: Description of Main Menu Selection

Selection	Description	Operation
1	Check all status	Report all status for every CAU
2	Door	Unlock / Lock / Report status
3	Window	Open / Close / Report status
4	Heater	Input temperature / Report temperature
5	Light Switch	On / Off / Report status

Finally, the HomePA will be terminated at any time once the user hangs up the phone.

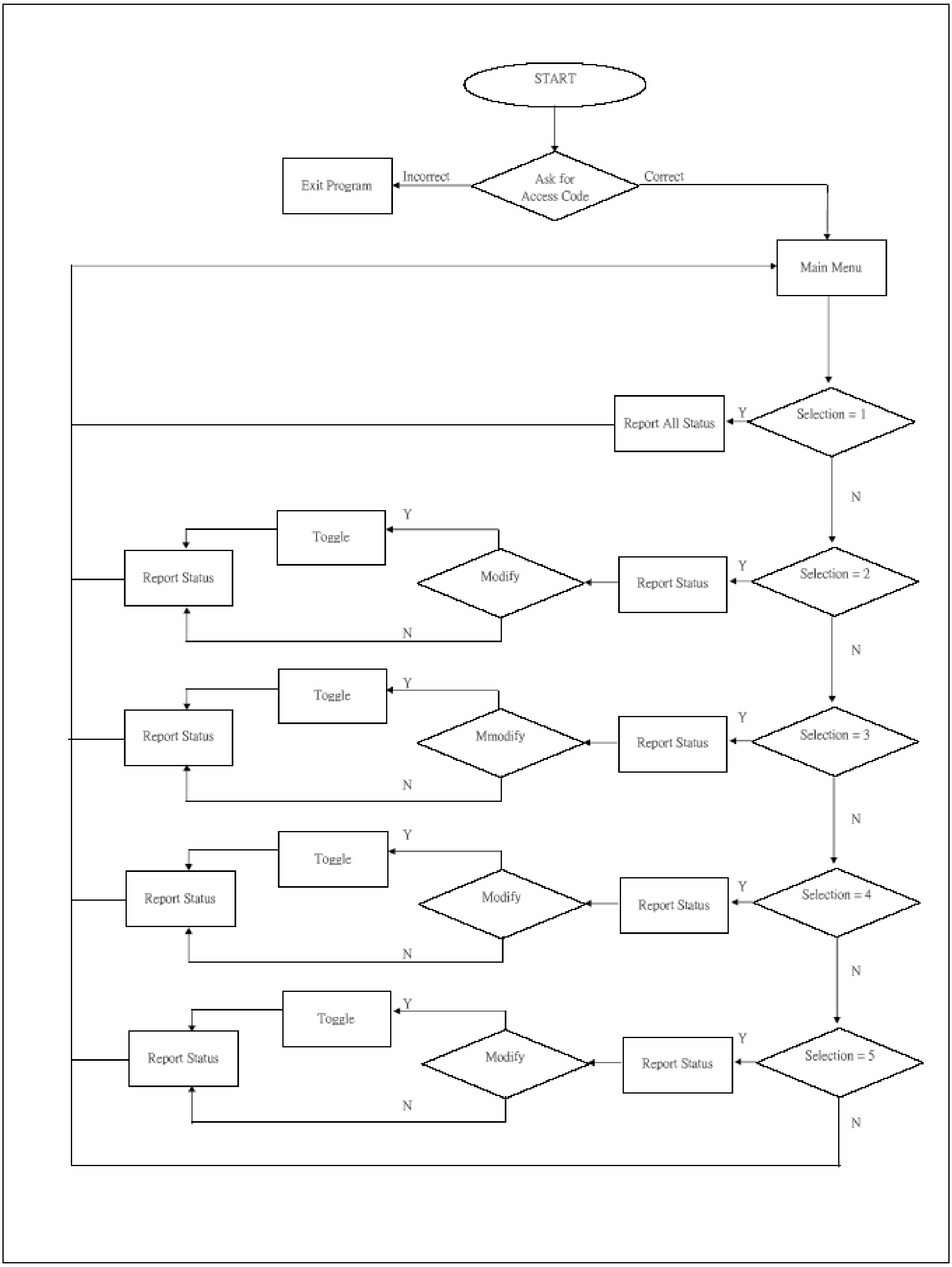

Figure 44: User Interface Flow Chart

7. Conclusion

The design specifications imposed on each subsystem of the HomePA, the central control unit, the wireless communication unit, and the client appliance units, clearly describe how each of these subsystems is implemented and constructed. This document outlines the architectural layout, components, implementation procedures, and user interface specifications that must be incorporated for the HomePA to be an effective home control and monitoring device that brings convenience to elder citizens, minors, and some physically disabled people.

Through these vigorous design specifications, we are confident that our prototype version of the HomePA system will at least satisfy the minimum requirements as outlined in the *Functional Specification for a Wireless Home Phone-operated Assistant*. In order to ensure that all of the functional subsystems of our HomePA actually achieve their desired performance, we will fully simulate our completed prototype according to the test plans stated in our functional specification. Such a discreet approach reflects our thoroughly-defined requirements for each component and the overall system. Trax Technologies use these design specifications as a solid foundation for the development of its Wireless HomePA.

8. Reference

CM8880-PI. DTMF Transceiver. California Micro Devices.

Digi-Key Corporation. <http://dkc1.digikey.com/ca/digihome.html>. 2004

Fairhurst, Gorry. Digital Phase Lock Loop (DPLL). Department of Engineering. University of Aberdeen. <http://www.erg.abdn.ac.uk/users/gorry/course/phy-pages/dpll.html>. October 1, 2001.

Fairhurst, Gorry. Manchester Encoding. Department of Engineering. University of Aberdeen. < http://www.erg.abdn.ac.uk/users/gorry/course/phy-pages/man.html>. September 1, 2001.

KT 210 Silicon Temperature Sensor. Infineon Technologies. <http://rocky.digikey.com/WebLib/Infineon/Web%20Data/KT_KTY%20Series.pdf>.

LN253RP Red LED/LN353GP Green LED. Digi-Key Corporation. <http://rocky.digikey.com/WebLib/Panasonic/Web%20data/LN253RP.pdf>. 2004.

MH88435-P Data Access Arrangement. <http://assets.zarlink.com/DS/zarlink_MH88435_OCT_01.pdf>. 2001.

Microchip Technology. Products > Microcontrollers. <http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1335&dDocName=en010242>. 2004.

Mobile Device Discussing Forum. A True Digital Home!. <http://www.mobile01.com/newsdetail.php?id=1350>. September 16, 2004.

QSD 124 Plastic Silicon Infrared Phototransistor. Fairchild Semiconductor. <http://www.fairchildsemi.com/ds/QS/QSD122.pdf>. July 20, 2001.

SFH 4502 High-Speed Infrared Emitter. Opto Semiconductors. <http://rocky.digikey.com/WebLib/Osram/Web%20Data/SFH4501_2_3.pdf>.2001

RE-260RA Metal-brush Motor. Mabuchi Motor Co. Ltd. <http://www.mabuchi-motor.co.jp/english/cat_files/re_260ra.pdf>.

RE-280SA Metal-brush Motor. Mabuchi Motor Co. Ltd. <http://www.mabuchi-motor.co.jp/english/cat_files/re_280rasa.pdf>.

RTF-DATA-SAW 4800bps AM Transceiver Modules. ABACOM Technologies. <http://www.abacom-tech.com>. 2004.

