

RGBA Color Mixing with Bluetooth® Low Energy Communication

*Authors: Swathi Sridhar,
Ashutosh Tiwari,
Namrata Dalvi
Microchip Technology Inc.*

INTRODUCTION

This application note provides the description of RGBA (Red, Green, Blue and Amber) LED color mixing using Microchip's PIC16F1579 and the Bluetooth® Low Energy (BLE) communication of Microchip's RN4020 Bluetooth 4.1 low energy module.

The RGBA Badge Demo Board uses several Microchip technologies. The board has four LEDs of red, green, blue and amber color. The brightness of each of these LEDs is controlled through PWM duty cycle. PIC16F1579 features four 16-bit PWMs that are used to drive the LEDs. The 16-bit PWMs allow precise control over the intensity of each color LED and the mixing of the different brightness levels of RGBA create different colors. The mTouch® sensing solution is used to operate two capacitive touch sliders and mTouch CVD Library is used for this purpose. The mTouch CVD Library is available on Microchip Library for Applications (MLA). The on-board RN4020 is used for

getting the PWM values from the Android™ or desktop application using the Bluetooth Low Energy communication.

RUNNING THE RGBA BADGE BOARD

For the initial set-up of the RGBA Badge Board, follow these steps:

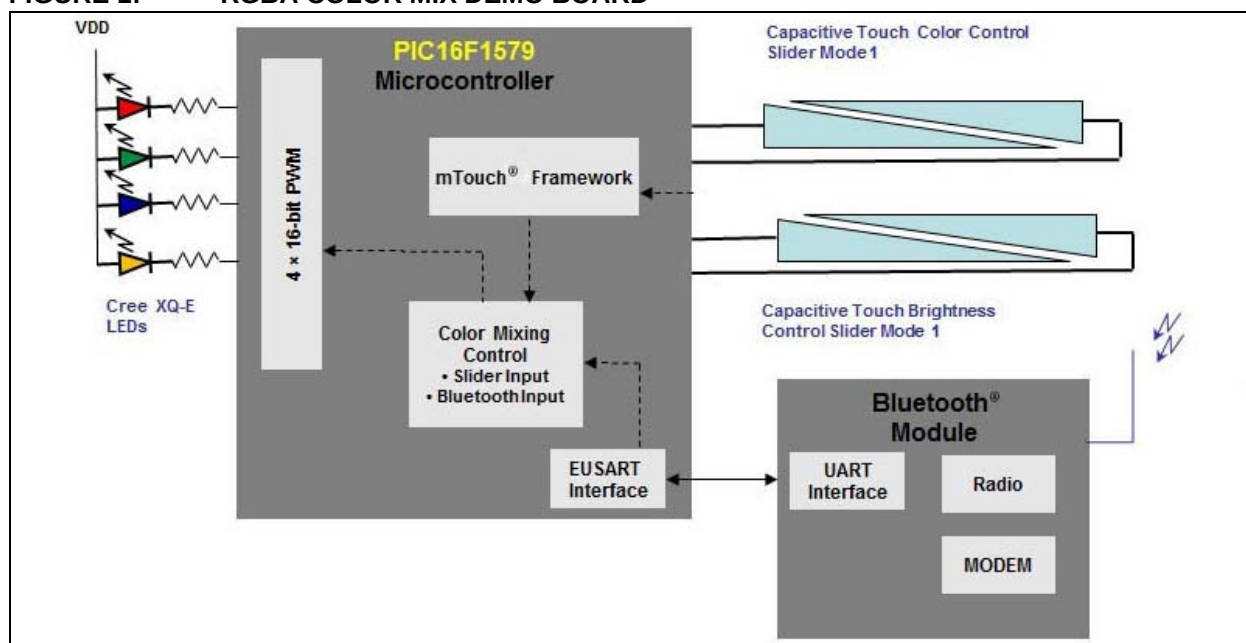
1. The RGBA Badge Board is powered by a 1.5V AAA battery, which is to be placed inside the battery holder.
2. Turn the switch ON. The switch is located on the top right corner of the board.

There are two different modes of operation of the RGBA Badge Board:

1. Mode 1: HSVW (Hue Saturation Value plus White) and Brightness Sliders mode.
2. Mode 2: Chromaticity Selector using Bluetooth Low Energy mode (BLE).

The RGBA Board initially powers-up in Mode 1, Slider mode. There are two capacitive touch sliders on the board: one for color input and the other for controlling the brightness levels ([Figure 1](#)). For a detailed operation of Mode 1, refer to [Section "Mode 1: HSVW and Brightness Sliders"](#).

FIGURE 1: RGBA COLOR MIX DEMO BOARD



For Mode 2, install the Android application on either a smartphone or desktop.

In Mode 2, the respective PWM values are sent to the board from an Android application or from a Windows® application via Bluetooth. The application features the CIE 1931 XY chromaticity chart. The exact PWM values of the selected color and brightness levels are computed and sent over Bluetooth. The RN4020 module on the board receives the PWM values. The RGBA badge firmware then uses the received PWM duty cycle values required to display the selected color. When the user chooses to exit Mode 2, the board will continue to operate in Mode 1. The user can always choose to connect from the application at any point of time and thus exit Mode 1. For a detailed operation of Mode 2, refer to [Section “Mode 2: Chromaticity Selector Using Bluetooth Low Energy”](#).

LED Lighting

The light produced by the LEDs varies due to several factors. The brightness, measured in lumens, will vary for LEDs of different types, and between LEDs of the same type. For color LEDs, the specific color, measured by the chromaticity values, will differ from one LED to another.

During research for this application note, small samples of CREE LEDs were measured to develop a brightness and chromaticity profile. The values were then used as typical values in the hardware design and in the software's chromaticity calculations. This process is called color tuning.

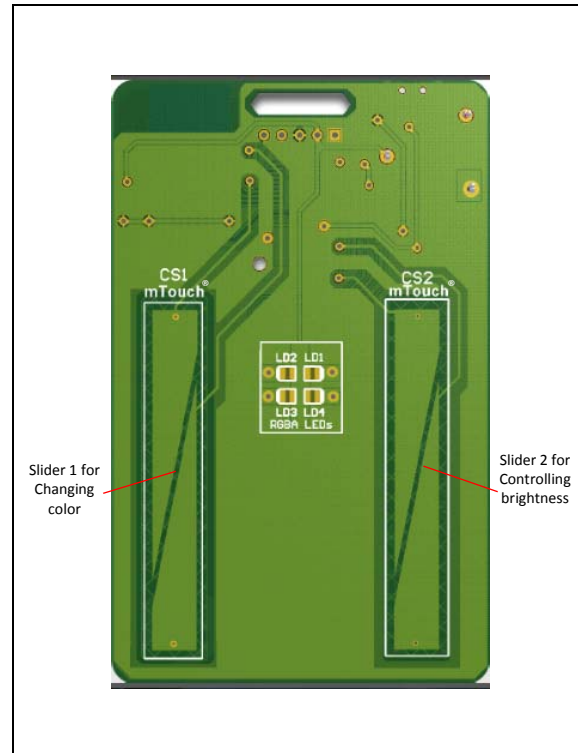
The resistor values were fixed so that each color produced the same number of lumens. The LED series resistors are:

- Red – 820Ω
- Blue – 400Ω
- Green – 500Ω
- Amber – 500Ω

Mode 1: HSVW and Brightness Sliders

There are two capacitive touch sliders on the board: one for color input and the other for controlling the brightness levels ([Figure 2](#)).

FIGURE 2: SLIDERS ON RGBA DEMO BOARD



If the mTouch slider on the left is touched while operating in Slider mode, the color selected on the slider is output on the LEDs. The selected color is displayed until another input is received. The brightness of a particular color can be controlled with the slider switch on the right. The mTouch Framework v2.3 has been used for decoding input values received from the sliders.

For further details about the HSVW Slider, refer to application note *AN1562 High Resolution RGB Color Mixing* (DS00001562).

Mode 2: Chromaticity Selector Using Bluetooth Low Energy

The chromaticity selector application GUI consists of the CIE 1931 xy chromaticity chart ([Figure 3](#)). CIE 1931 color space shows a wide range of colors in terms of chromaticity (x) and luminance (y). The color and brightness levels of red, green and blue LEDs mapped onto the CIE color space defines a triangle that encompasses all possible shades that can be generated by the output of three devices; this is known as the color gamut.

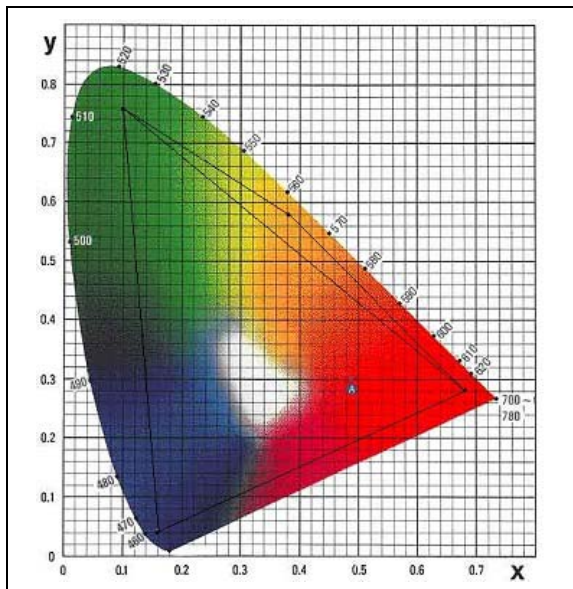
To produce a particular color in the gamut, the PWM intensity to be set for the individual LEDs is obtained by applying the formula in [Equation 1](#).

EQUATION 1: PWM INTENSITY SETTING

$$\underbrace{\begin{bmatrix} Y_R \\ Y_G \\ Y_B \end{bmatrix}}_{\text{PWM Intensity}} = \underbrace{\begin{bmatrix} \frac{x_R}{y_R} & \frac{x_G}{y_G} & \frac{x_B}{y_B} \\ 1 & 1 & 1 \\ \frac{1-x_R-y_R}{y_R} & \frac{1-x_G-y_G}{y_G} & \frac{1-x_B-y_B}{y_B} \end{bmatrix}^{-1}}_{\text{x, y coordinates specific to LED}} \times \underbrace{\begin{bmatrix} \frac{x}{y} \\ 1 \\ \frac{1-x-y}{y} \end{bmatrix}}_{\text{Color Mix}}$$

To obtain a better range of colors, an amber LED has been added. The x,y data for the amber LED is mapped onto the CIE 1931 xy color space. This defines another triangle between the red, amber and green coordinates. If we mix red, amber and green in different proportions we will obtain the colors within the color gamut in [Figure 3](#). The PWM intensity for this range of colors is calculated using the same formula in [Equation 1](#). The CIE 1931 chromaticity chart with the two triangles is shown in [Figure 3](#).

FIGURE 3: CIE 1931 COLOR SPACE WITH RGBA LED COLOR GAMUT



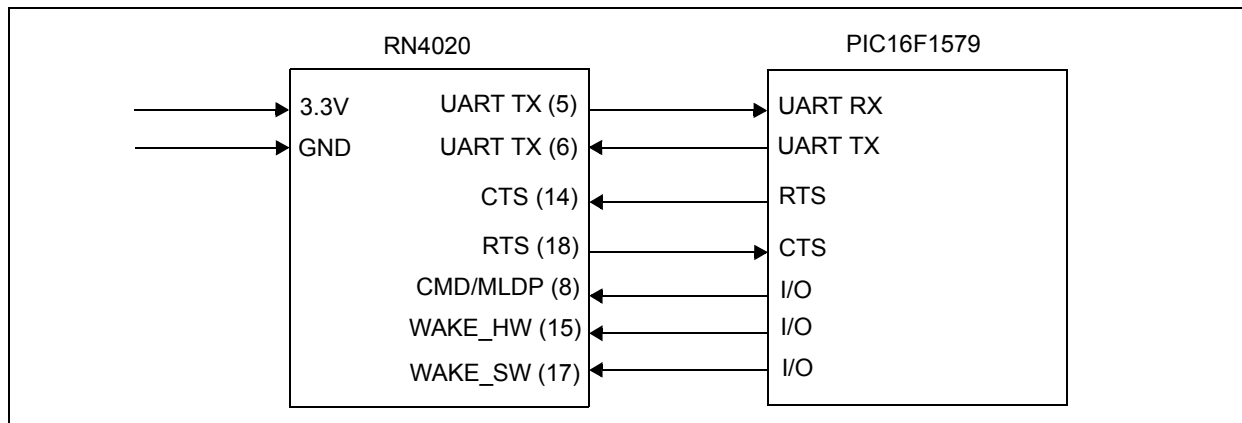
The PC GUI and the Android application used in this mode implement this color mixing algorithm to calculate the duty cycle values necessary to produce the desired color. The process is explained in detail in the [Application Software](#) section.

For details about color theory and XYZ color space, refer to *AN1562 High Resolution RGB Color Mixing* (DS00001562).

The chromaticity selector application sends the PWM values over Bluetooth. The RGBA Badge Board is equipped with a RN4020 Bluetooth low energy module for BLE communication. The RN4020 BLE module will be able to communicate with mobile phones and PCs featuring Bluetooth v4.0 transceivers. RN4020 is primarily used for receiving duty cycle values from master devices that run the chromaticity selector application.

The pin-to-pin configuration between the PIC16F1579 microcontroller and the RN4020 BLE module is shown in [Figure 4](#).

FIGURE 4: PIC16F1579 TO BLE MODULE INTERFACE DIAGRAM



The UART interface supports ASCII commands to control or configure the RN4020 module. The configuration of the RN4020 module, the various commands used and the firmware implementation is detailed in the [Firmware](#) section.

Note: There are two types of Bluetooth devices: Bluetooth classic and Bluetooth Low Energy (BLE). A BLE device can only communicate with another BLE device or Bluetooth smart-ready, (i.e., dual-mode device). Hence, if RN4020 is used with a RGBA Board, the master host device must be BLE or Bluetooth smart-ready, (i.e., dual-mode device), in order to be able to communicate with the RN4020 module.

FIRMWARE

The two major components of the RGBA LED color mixing firmware are the capacitive touch implementation and the BLE communication.

Capacitive Touch Implementation

The two sliders on this board are implemented using mTouch Framework. The mTouch CVD Library is available on Microchip Libraries for Applications (MLA). The capacitive touch software process can be divided into three distinct phases:

1. Acquisition – Using a voltage-based measurement technique like CVD to obtain a sample from the capacitive touch sensor.
2. Filtering – Manipulating the incoming sensor samples to increase the effective signal-to-noise ratio (SNR) of the system by attenuating the noise.
3. Decoding – Determining whether a sensor is pressed or released based on the current value of the sensor samples and the previous behavior of the sensor.

For more information on mTouch CVD Library for Slider implementation, refer to [mTouch Framework documentation](#).

BLE Communication

The RN4020 module complies with the Bluetooth core specification v4.1. The RN4020 module is controlled by the user through input/output lines and a UART interface. The UART supports ASCII commands to control or configure the RN4020 module for any specific requirement based on the application. The module supports the user-defined private profile/service which can fit a user's application.

The UART configuration is as follows:

- Baud rate: 115200
 - Data Bits: 8
 - Parity: None
 - Stop Bits: None
- User-Defined Profile
- Peripheral
- Service Universally Unique Identifier (UUID)
- Characteristics

For this demo board, the following commands are issued to configure the RN4020 module for the application:

1. Pull WAKE_SW high to enter Command mode
2. Set the following parameters:
 - Baud rate: 115200
 - Data Bits: 8
 - Parity: None
 - Stop Bits: 1
3. SF,1 //Factory Reset
4. SS,00000000 // User Defined Profile
5. SR, 00000001 // set device as Peripheral
6. PS, <128-bit UUID> //Define a private service with 128 bit UUID
7. PC, <128-bit UUID>,<characteristic property>,<maximum data in bytes> // Add private characteristic to the current private service

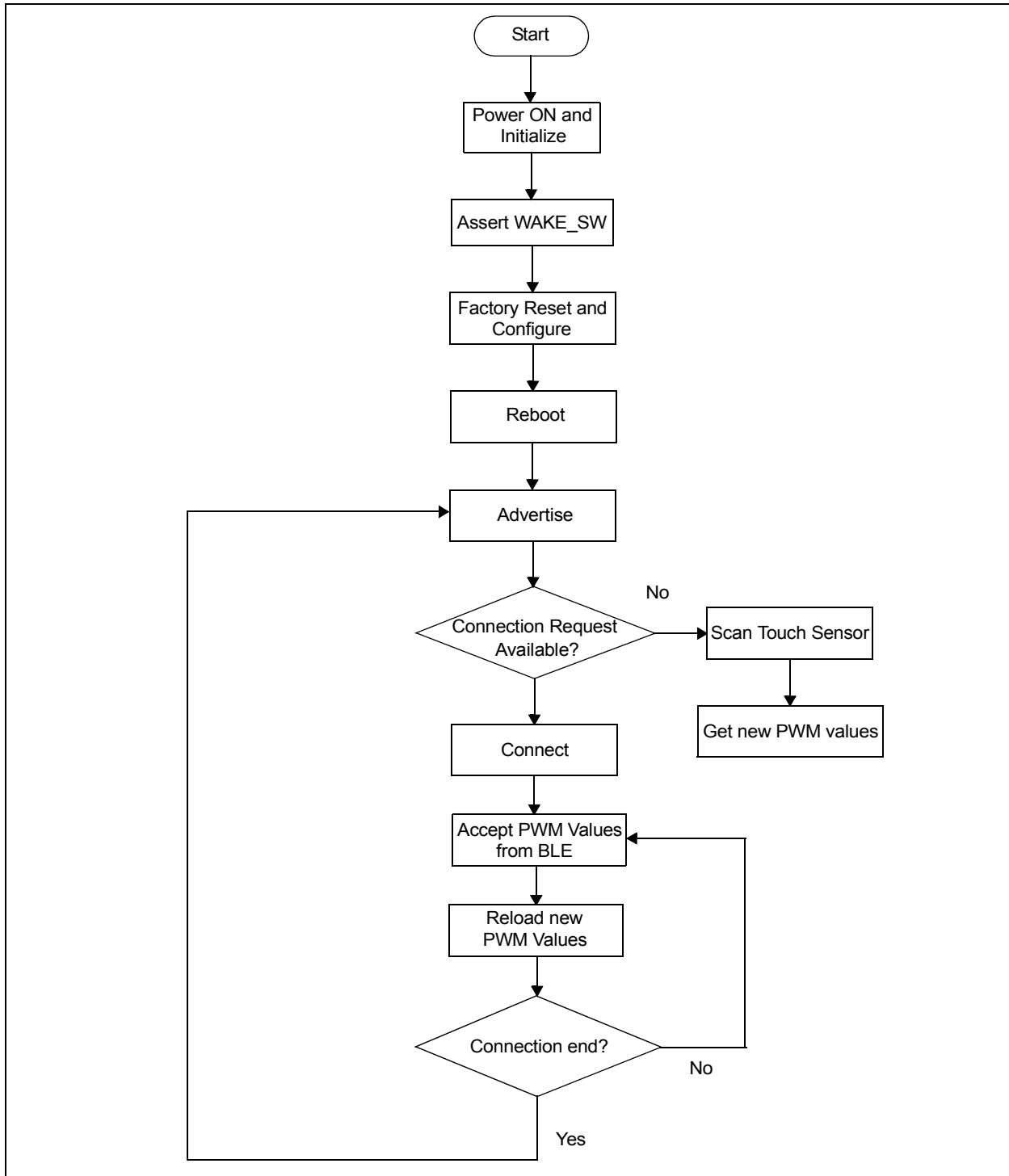
8. R,1 //Reboot RN4020 to make changes effective
9. Once the Reboot is done, the Advertise command "A" is issued

The rising edge of the signal on the WAKE_SW pin triggers UART output CMD and indicates that UART is ready to receive ASCII commands. If the ASCII

commands are received and parsed successfully, the Status AOK status will be sent by the RN4020 module. If there is an error, then the Status ERR will be sent. The Reboot command outputs the message Reboot before rebooting.

Figure 5 shows the firmware flowchart.

FIGURE 5: FIRMWARE FLOWCHART



APPLICATION SOFTWARE

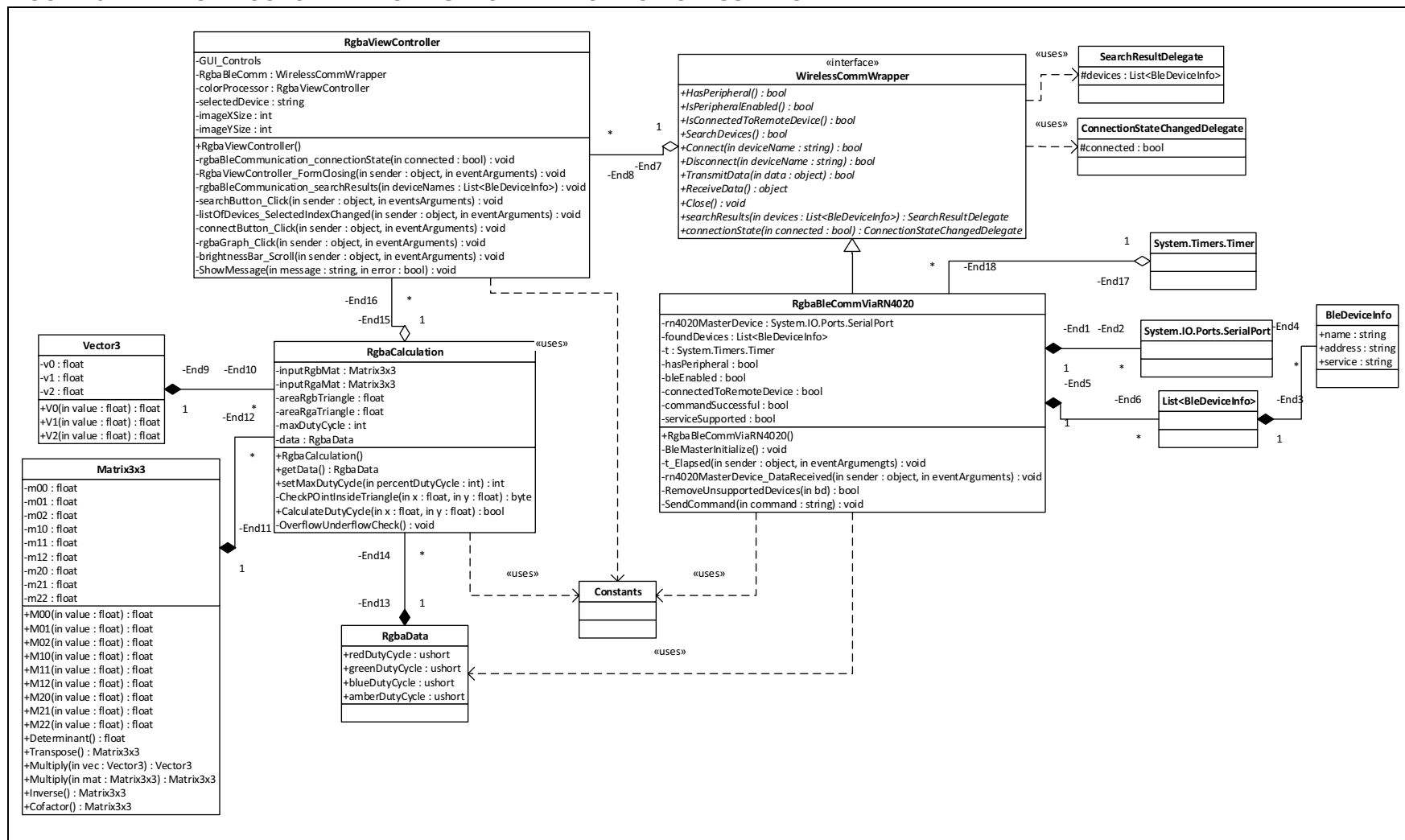
When the RGBA Board is operating in Mode 2, the desired LED color is selected from the chromaticity chart in the chromaticity selector application either from the RGBA Color Mixing desktop application or the RGBA Color Mixing Android application. The red, blue, green and amber PWM duty cycles are calculated by the application. The duty cycle values are passed on to the board by a BLE connection.

Desktop Application Design

The RGBA desktop application software class diagram is shown in [Figure 6](#). The application is developed using Visual Studio C#.Net. The application follows the MVC principle with the following classes:

1. **RgbaViewController:** The class acts as the Graphical User Interface (GUI) or view manager and also as the controller of the application. This class is at the top of the hierarchy responsible for making new objects of classes and performing dependency injection. It also handles all the GUI events and calls appropriate methods.
2. **RgbaCalculation:** The class is responsible for finding out if the selected point is either inside the RGB or the RGA triangle or outside of these triangles, and calculates the duty cycle per color for all LEDs.
3. **Matrix3x3:** The class implements all 3x3 matrix math operations like inverse, determinant, transpose, co-factor and multiply.
4. **Vector3:** The class implements column vector of size 3 to be used in Matrix math for the Matrix 3x3 class.
5. **RgbaData:** The class is a custom data type to store the duty cycle values of all colors.
6. **WirelessCommWrapper:** The interface contains all the methods required by the wireless communication to implement the RGBA application. This interface can be used by any wireless communication method like BLE, BTC, etc. The BLE communication is done using the RN4020 PICtail™ card through RS-232 communication by implementing this interface for the RGBA Board. The programmer can make a new class to implement BLE communication through built-in BLE libraries in visual studio or third party libraries. This interface decouples the implementation of the communication from the actual controller, so that if new communication is implemented, the ViewController and other classes will not change.
7. **RgbaBleCommViaRN4020:** The class implements the WirelessCommWrapper interface for BLE communication with the RGBA Board. The RN4020 PICtail card is used and connected to a PC as the UART/RS232 port. The serial communication is established and commands are sent for BLE communication.
8. **BleDeviceInfo:** The class stores the basic information about the remote BLE device (i.e., name, address and supported server service). The information is used to identify and connect to a remote device.
9. **SearchResultDelegate:** The delegate services the event from BLE class when it finishes the search for devices and the devices are available as a list for the user. The necessary time for the search operation is ten seconds.
10. **ConnectionStateChangeDelegate:** The delegate services the event from BLE class to determine if the master BLE RN4020 PICtail card is connected to a remote device or not and displays the current connection state to user.
11. **Constants:** The class stores all the constants required for the application, such as RN4020 commands and responses, service and characteristic UUIDs etc.

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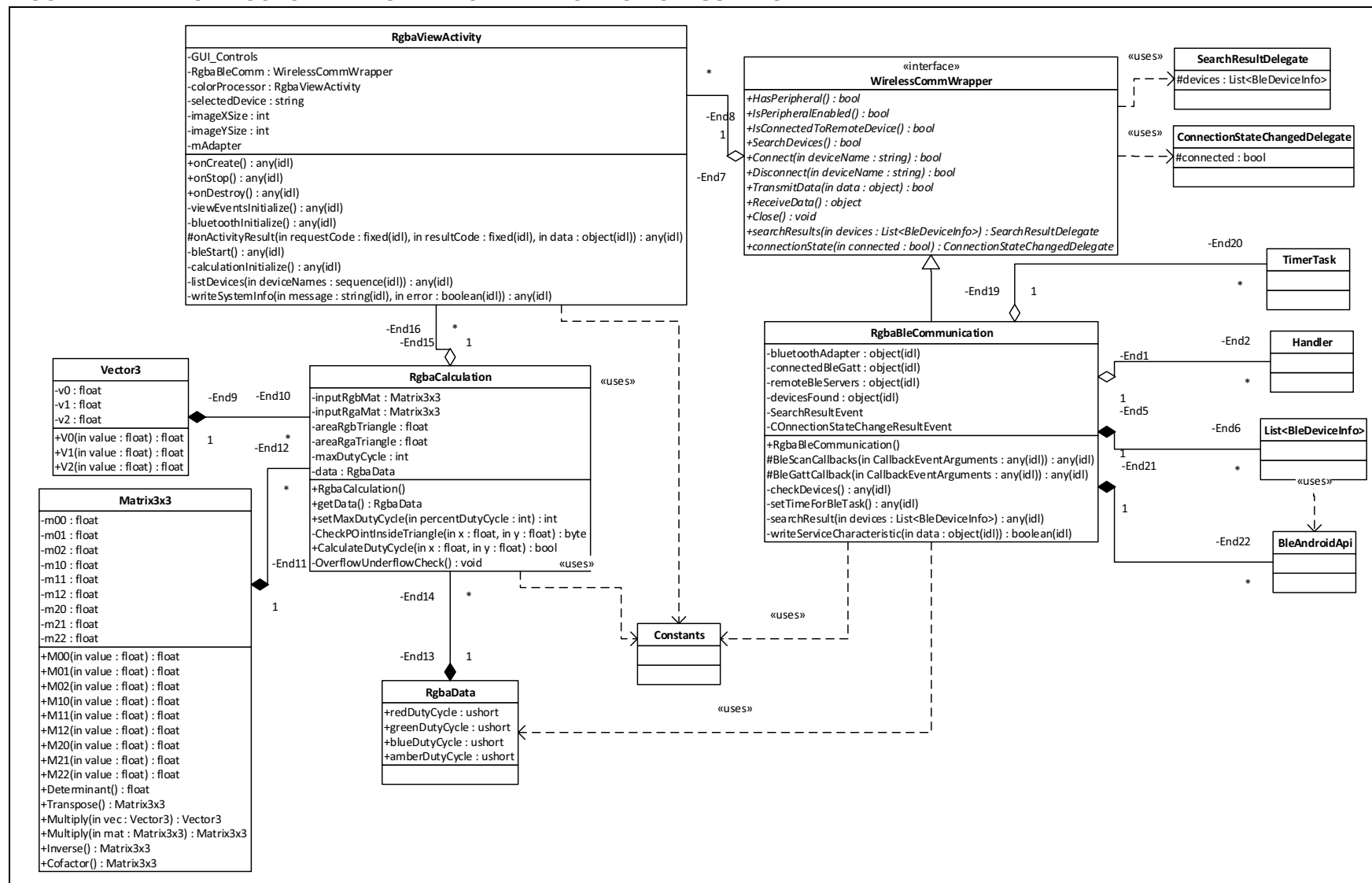


Android Application Design

Figure 7 shows the Java application class diagram for the Android operating system (OS). This application follows the MVC principle closely as well, using Android activity classes which are structurally similar to the desktop application. The differences between the desktop and the Android applications are listed below:

1. The Android application uses the built-in BLE hardware of the Android phone. Android provides all the necessary libraries for BLE communication with all required events and callbacks.
2. `RgbaViewActivity` class is similar to the `ViewController` class on a desktop except for the GUI controls, which are defined in a XML file instead of a class.

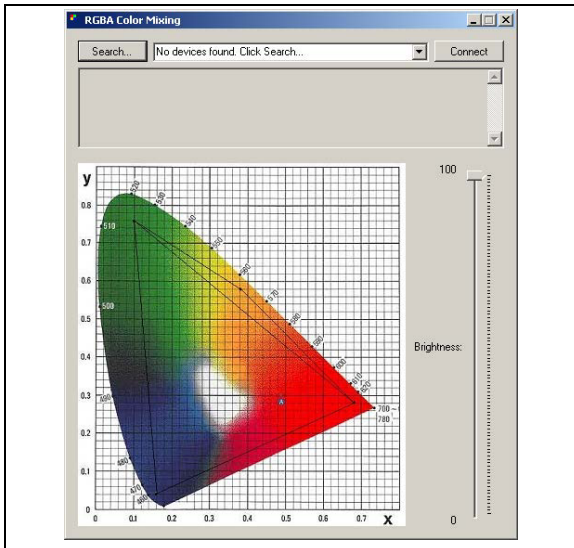
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Installation and Usage of the Desktop Application

1. Copy the RgbaColorMixingDesktop.exe to any folder on your computer and make sure to have .net 4.5 or a higher version of library. If it is not available, install the .net 4.5 library update.
2. Start the RgbaColorMixingDesktop.exe application. A GUI will appear, as shown in Figure 8.

FIGURE 8: RGBA COLOR MIXING DESKTOP APPLICATION

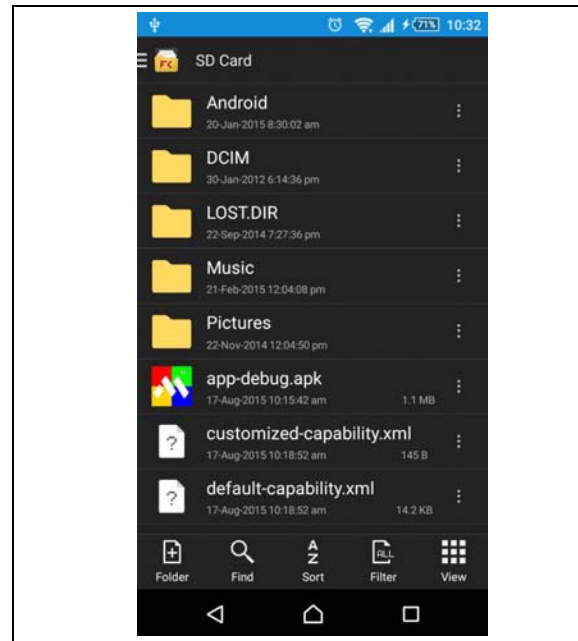


3. Click on the Search button to start searching for the RGBA color mixing badge boards. The search will take a minimum ten seconds to complete.
4. Once the search operation is completed, the devices found are shown in a list box beside the Search button.
5. Select one of the listed devices and click on the Connect button. If the device connects successfully, the Connect button will change to Disconnect.
6. Click on any color within the triangle or change the color and send it to the RGBA Board of the LEDs.
7. Change the brightness level to adjust the brightness of the LEDs.
8. The text box will display all the color values in terms of duty cycle and the corresponding xy coordinates.
9. The text box will also show error messages for the user during the usage of the desktop application.
10. The application is tested for Windows 7.

Installation and Usage of the Android Application

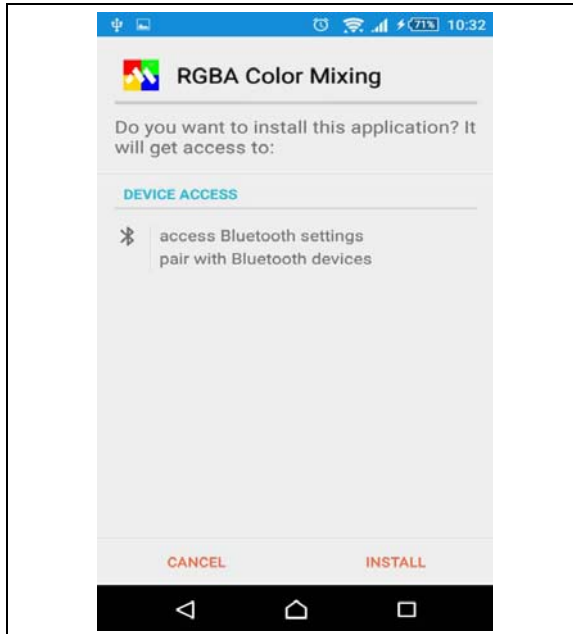
1. Copy the app-debug.apk to the Android phone on the SD card.
2. Make sure to have Android 4.4 (KitKat) or a higher version of the OS installed on the phone.
3. Once copied, go to the File Manager application on the phone and start it.
4. Find the app-debug.apk file and click on it; the installation prompt will appear as shown in Figure 9.

FIGURE 9: APK LISTING IN FILE MANAGER



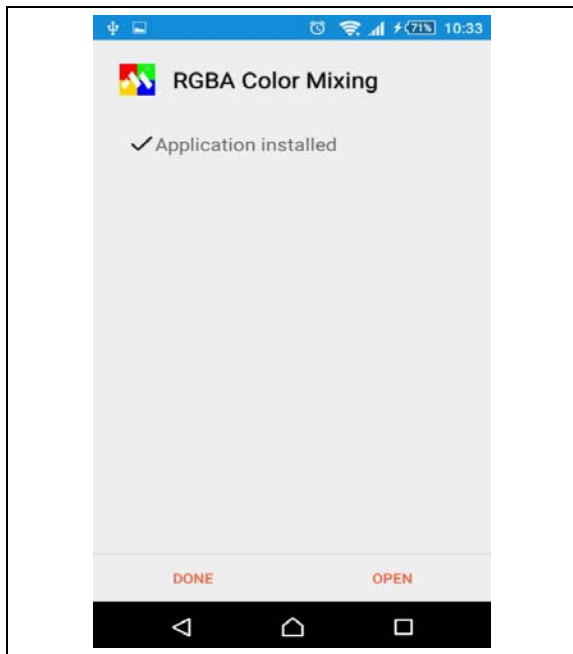
5. After selecting the file, the installation prompt will appear as shown in Figure 10.

FIGURE 10: INSTALLATION PROMPT



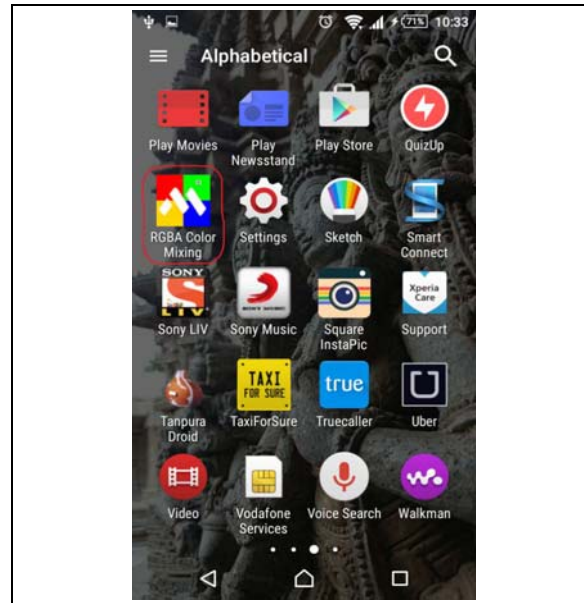
6. Select **Install**. After installation, a successful prompt will appear as shown in [Figure 11](#).

FIGURE 11: SUCCESSFUL INSTALLATION OF ANDROID APPLICATION



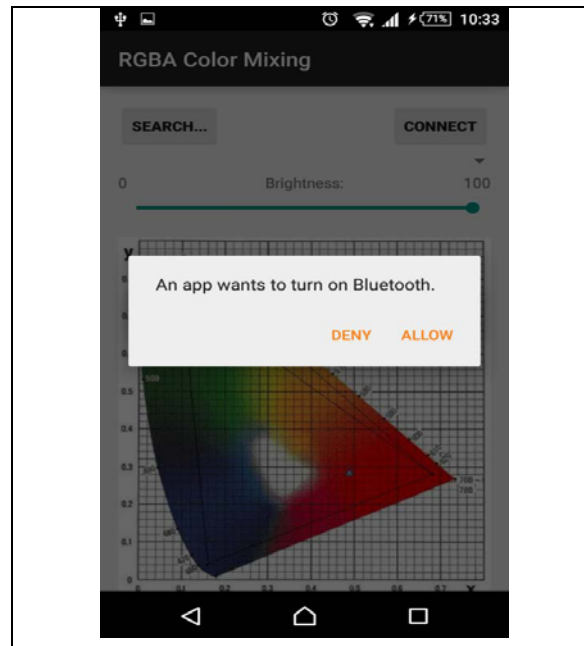
7. Go to menu and find the installed RGBa Color Mixing application as shown in [Figure 12](#).

FIGURE 12: RGBA COLOR MIXING INSTALLED APPLICATION



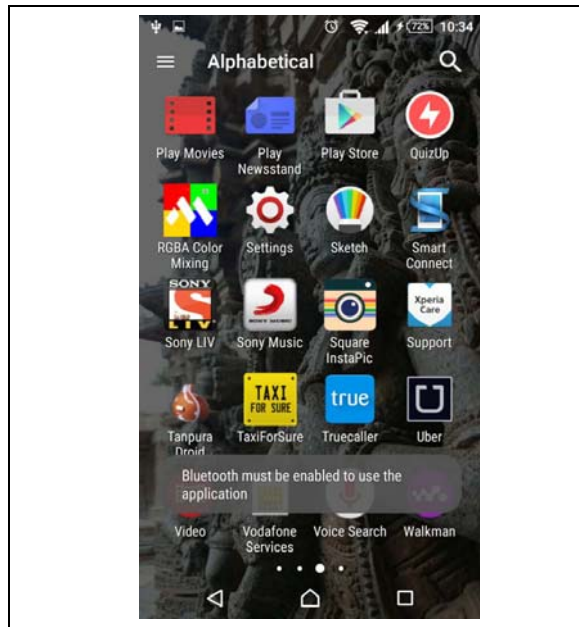
8. Selecting the application will enable the Bluetooth, as shown in [Figure 13](#).

FIGURE 13: BLE ENABLE PROMPT



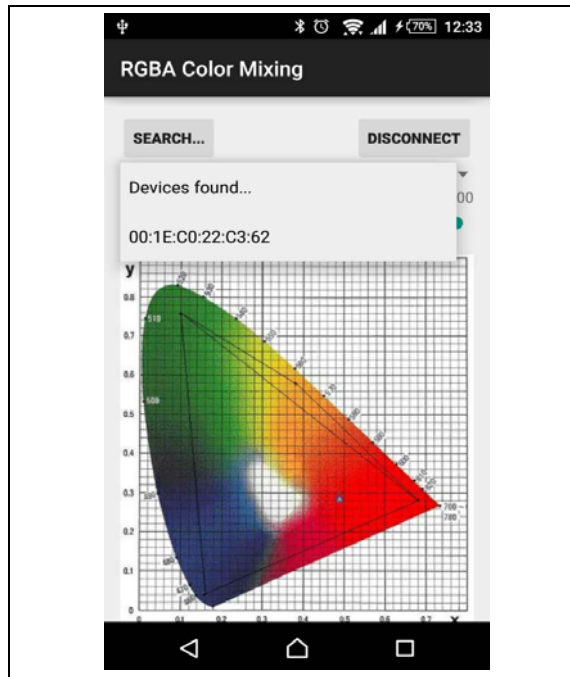
9. If **Deny** is selected, the application will exit with an error message, as shown in [Figure 14](#).

FIGURE 14: BLE NOT ENABLED ERROR



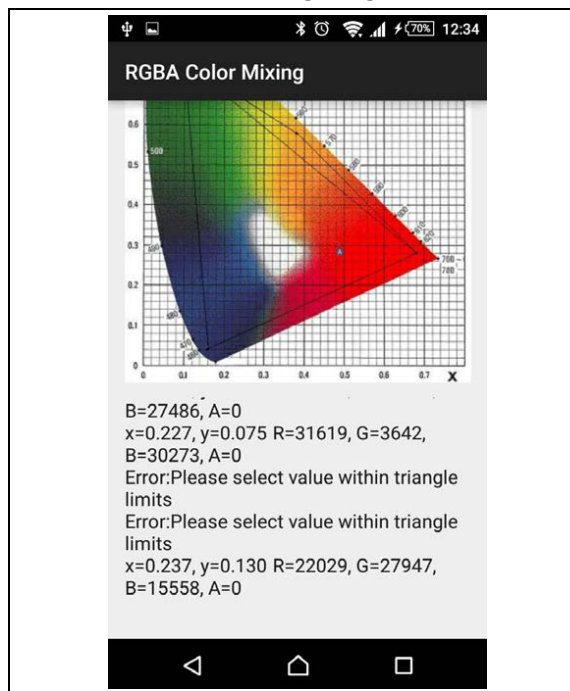
10. If **Allow** is selected, the application will start.
11. Select **Search** to find the nearby RGBA Boards. The search operation will take approximately ten seconds.
12. Once the search operation is completed, the devices found are shown in a list box below the Search button.
13. If no device has been found, click on the Search button again, after starting the RGBA Board.
14. As shown in [Figure 15](#), select one of the devices found and click on Connect. If the device connects successfully, the Connect button will change to Disconnect.

FIGURE 15: LIST OF DEVICES FOUND



15. Select any color from the triangle to change the color on the RGBA Board. Adjust the brightness to see the brightness change on the RGBA Board.
16. The user error messages are displayed along with the duty cycle and xy co-ordinates, below the chromaticity chart, as shown in [Figure 16](#).

FIGURE 16: USER MESSAGES AND ERROR IN THE ANDROID APPLICATION

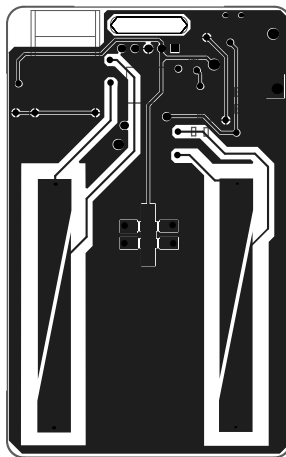
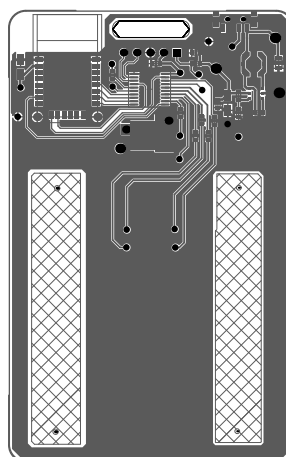


CONCLUSION

The application note demonstrates the RGBA LED color mixing using Microchip's PIC16F1579. The 16-bit PWM allows precise control over the intensity of each LED. The RGBA LED color mixing board has slider capacitive touch buttons for color input and brightness control functions. This mTouch CVD Library is used to implement the slider functions. It also uses the RN4020 Bluetooth 4.1 low energy module for communication. BTLE communication allows the user to send PWM values to the RGBA Board to output the desired color. The color is selected on a chromaticity selector application on a Windows desktop or on an Android phone.

REFERENCES

1. *PIC16(L)F1574/5/8/9 14/20-Pin MCUs with High Precision 16-Bit PWMs Data Sheet* (DS40001782)
2. *AN1562 High Resolution RGB Color Mixing* (DS00001562)
3. *RN4020 Bluetooth® Low Energy Module Data Sheet* (DS50002279)
4. *RN4020 Bluetooth® Low Energy Module Command Reference User's Guide* (DS70005191)
5. *AN1478 mTouch™ Sensing Solution Acquisition Methods Capacitive Voltage Divider* (DS01478)
6. Microchip Libraries for Applications: www.microchip.com/MLA

APPENDIX B: PCB LAYOUT**FIGURE B-1: PCB FRONT VIEW****FIGURE B-2: PCB REAR VIEW**

APPENDIX C: BILL OF MATERIALS

TABLE C-1: BILL OF MATERIALS

Designator	Description	Manufacturer Part Number
B1	Battery Holder AAA SMD	1020
C1	Cap, Ceramic, 4.7 uF, 10V, 20% X7R 0805	C2012X7R1A475M125AC
C2,C7	Cap, Ceramic, 10 uF, 16V 10% 1206	T491A106K016AT
C3,C8	Cap, Ceramic, 0.1 uF, 50V 20% X7R 0603	C1608X7R1H104M080AA
C4	Cap, Ceramic, 1 uF, 16V 10% X5R 0603	C1608X5R1C105K080AA
L1	Low Profile 4.7 uH 1.2A 20% SMD	LPS4414-472MRB
LD1	High-Power LEDs – Single Color RED, 62 lm	XQERED-00-0000-000000601
LD2	High-Power LEDs – Single Color GREEN, 100 lm	XQEGRN-00-0000-000000C03
LD3	High-Power LEDs – Single Color BLUE, 39.8 lm	XQEBLU-00-0000-000000205
LD4	High-Power LEDs – Single Color Amber, 80.6 lm	XQEAPA-00-0000-000000901
R1,R5	Res, 10K, 1/10W 1%	RMCF0603FT10K0
R2	Res, 665K 1/10W 1%	ERJ-3EKF6653V
R3	Res, 383K, 1/10W 1% 0603	RMCF0603FT383K
R8	RES, 324 Ohm 1/ 10W 1% 0603	RMCF0603FT324R
R12,R13	Res, 200 Ohm, 1/10W 1% 0603	RMCF0603FT200R
R9	RES SMD 510 Ohm 1% 1/10W 0603	RMCF0603FT510R
R10,R11	RES SMD 270 Ohm 1% 1/10W 0603	RMCF0603FT270R
S2	Switch, Slide, SPDT, Rt Angle, SMT, Low Profile	MLL1200S
U1	Voltage Regulators – Switching Regulators 500 kHz 300 mA Syn. PWM/PFM enabled SOT-23	MCP1640T-I/CHY
U3	Microchip Technology 14 KB Flash 1 KB RAM 16b PWM 10b ADC TSSOP-20	PIC16F1579-E/SO
U4	Bluetooth®/802.15.1 Modules Bluetooth 4.1 module w/ built-in antenna	RN4020-V/RM

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
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Fax: 34-91-708-08-91

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Fax: 44-118-921-5820