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Technical Design Review Document

1.0 | Subsystem C Overview

Subsystem C is critical to the SDR by synthesizing LO signals, and managing I/O signals to support both user and computer-based operation. It consists of the Local Oscillator (LO) and User Interface (UI), both controlled by the Microcontroller Unit (MCU). It generates F_LO_0 and F_LO_90, which are sent to Subsystem A (RX) or Subsystem E (TX) based on the /TXEN signal, determining the SDR's operating mode [1].

The UI allows users to select frequency and mode, with the MCU adjusting the LO accordingly via I2C and enabling /TXEN to route signals correctly. The LO signals serve as the base frequency for TX and RX subsystems, the ICD mandates an LO accuracy of ±1 kHz to ensure proper functionality of Subsystems A and E [1].

2.0 | Input / Output Signals

Subsystem C outputs F_LO and /TXEN signals to the mainboard via J6 header. These signals ensure precise LO control, TX/RX switching, and reliable system communication, aligning with ICD requirements [1]. The table below summarizes key signals exchanged between subsystem C and other subsystems. **Appendix B** elaborates on internal I/Os within subsystem C.

Table 1. Subsystem C Input / Output signals based on ICD [1]

Signal	I/O	Source / Destination	Description
F_LO_0	Output	J6 → subsystem A, E	Quadrature LO signal (0° phase shift), used for mixing in TX/RX chains.
F_LO_90	Output	J6 → subsystem A, E	Quadrature LO signal (90° phase shift) which ensures proper frequency conversion.
/TXEN	Output	J6 → Mainboard, subsystem A, F	TX/RX mode selection (High = RX, Low = TX).
USB_TX (TXD)	Input	FTDI Chip → MCU	Serial data input from PC to MCU for remote SDR control via CAT protocol.
USB_RX (RXD)	Output	MCU → FTDI Chip → PC	Serial data output from MCU to PC for frequency/mode readout.

3.0 | Subsystem Design

Component selection was based on ICD compliance and designing a UI that aims to be intuitive. The Si5351A was tested for frequency stability, ensuring ±1 kHz accuracy [2] [3] [4]. The ATmega324PB's SPI/I2C communication was validated to ensure proper LO tuning and data transmission [5].

The Altium schematic for Subsystem C in **Appendix A** serves as a complete reference for the subsystem's electrical design. All critical connections, including SPI, I2C, /TXEN, LO outputs, and user inputs, are labelled. In addition to Table 2 below, **Appendices C, D, E** and **F** provide further technical validation for selection and comparison of key components.

Table 2. Description of Key components in Subsystem C design

Component	Function	Description
ATmega324PB	MCU	Receives TX/ RX selection and configures LO generator via I2C [8]. Sends LO control signals and displays updates.
		Chosen over ATmega328P for dual UART, SPI/I2C support and GPIO expandability [5].
Si5351A Clock Generator Breakout	LO Signal Generation	Accepts I2C control signals from MCU and generates F_LO_0 and F_LO_90 for TX / RX processing.
		Provides low phase noise and digital tunability via I2C, ensuring ±1 kHz frequency accuracy and offers greater stability compared to other oscillators such as Colpitts Oscillators [1] [2] [3] [4] .
Adafruit 4311 TFT Display	Liquid Crystal Display	Displays LO frequency and mode selection. Receives SPI updates from the MCU.
		Chosen over the Adafruit 938 OLED (1.3") for its larger 2" display size and better color capability [9].
FT232R Module	USB-to-Serial Interface	Converts USB data to UART, allowing remote control via SDR software. Sends frequency and mode settings to MCU [6].
		Alternative to Adafruit 284, which had limited availability [7].
Adafruit 1010 Push Buttons	User Input	**Input / Output Handling :** Sends manual control inputs to the MCU for frequency selection and mode switching.
		12mm size provides better tactile feedback than smaller 6mm alternatives. Through-hole mounting ensures secure PCB placement and durability [10].

Appendix A | Altium Schematic

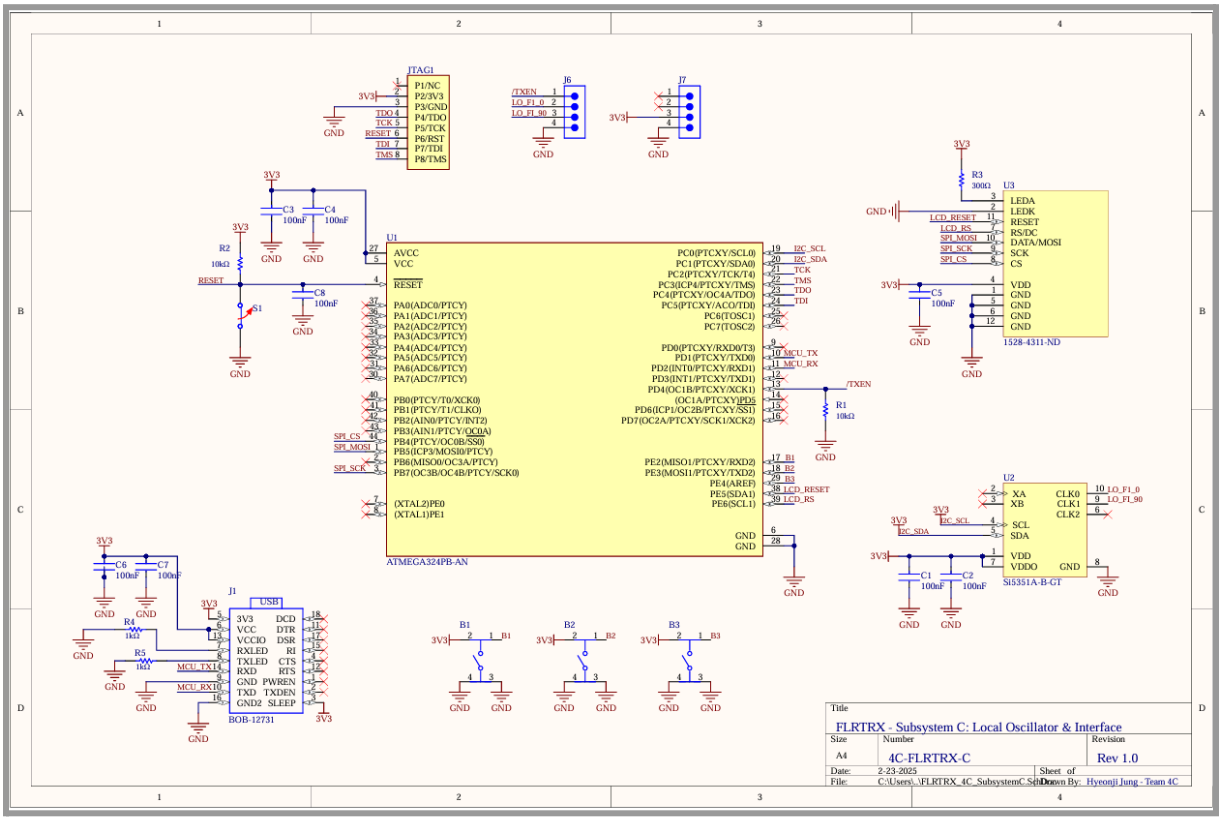


Figure A.1. Altium Schematic of Subsystem C design

Appendix B | Table of Input and Output Signals within Subsystem C

Table B.1. SPI communication Signals (Internal I/O)

Signal	I/O	Connected To	Description
SPI_MOSI	Output	MCU → LCD display	SPI Master Out Slave In, sends data from MCU to LCD.
SPI_SCK	Output	MCU → LCD display	SPI clock signal to synchronize LCD data transfer.
SPI_CS	Output	MCU → LCD display	Chip select signal, enabling LCD communication.
LCD_RS	Output	MCU → LCD display	Register select, toggles between command/data mode.
LCD_RESET	Output	MCU → LCD display	Resets LCD module.

Table B.2. I2C communication Signals (Internal I/O)

Signal	I/O	Connected To	Description
I2C_SDA	Bi-directional	MCU → Si5351A CLock Breakout Generator	Data line for configuring LO frequency.
I2C_SCL	Output	MCU → Si5351A CLock Breakout Generator	Clock line for I2C communication.

Table B.3. JTAG Debugging Signals (Internal I/O)

Signal	I/O	Connected To	Description
TDO	Output	MCU → JTAG programmer	JTAG test data out.
TDI	Input	JTAG Programmer → MCU	JTAG test data in.
TCK	Input	JTAG Programmer → MCU	JTAG test clock signal.
TMS	Input	JTAG Programmer → MCU	JTAG test mode select.
RST	Output	MCU → JTAG programmer	Active-low reset signal from JTAG.

Table B.4. User Interface (Push Buttons)

Signal	I/O	Connected To	Description
B1 (Button 1)	Input	User → MCU	Push button for manual frequency selection.
B2 (Button 2)	Input	User → MCU	Push button for tuning adjustments.
B3 (Button 3)	Input	User → MCU	Push button for SDR mode switching.

Table B.5. Power and Ground

Signal	Type	Connected To	Description
+3.3V	Power	J6, J7, JTAG → System	Regulated 3.3V DC

		Power	supply.
GND	Ground	All connections	Electrical ground reference.

Appendix C | Detailed Requirements for the Component Selection

Table C.1. Requirement table for the **physical constraints**

Objective	Metric	Specification	Explanation
1. High-Level Objective - Physical Constraints			
1.1 - All components of the subsystem must fit on the PCB.	Dimensions (mm x mm)	128.27 mm × 50.80 mm [2]	The design is constraine by the PCB size [2].

Table C.2. Requirement table for the **LO**

Objective	Metric	Specification
2. High-Level Objective - Accuracy of the LO		
2.1 - Minimize difference in output frequency over time	Change in the output frequency (kHz)	Frequency accuracy should be ±1 kHz.
Explanation	Ensuring that the output frequency remains within ±1 kHz prevents from sending incorrect input signals to subsystems A and E [2][7][8].	
2.2 - Two signals must have the same amplitude and frequency, with a 90° phase difference.	Amplitude and frequency of the two generated signals (LO_F1_0 and LO_F1_90).	Operating frequency range should be within 8 MHz - 16 MHz. Output voltage must be 3.3 Vpp unipolar.
Explanation	Matching these parameters allows Subsystems A and E to filter and process desired frequency signals.	
3. High-Level Objective - User-Interactivity		
3.1 - The LO must be capable of interfacing with a microcontroller.	Frequency is correctly regulated to ±1 kHz.	The interface must support standard communication protocols [A].

Explanation	Interfacing with a microcontroller allows adjustments to frequency and mode settings [6].

Table C.3. Requirement table for the **UI and I/O**

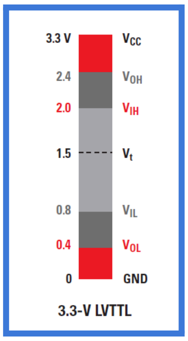
<table>
<tr><th>Objective</th><th>Metric</th><th>Specification</th></tr>
<tr><td colspan="3">4. High-Level Objective - Accurate I/O</td></tr>
<tr><td>4.1 - TX/RX mode is correctly enabled to other subsystems.</td><td>Output 3.3V to the SDR databus via J6 header.</td><td>Output is << 3.3 V [2]</td></tr>
<tr><td>Explanation</td><td colspan="2">TX/RX Enable must output 3.3 V LVTTL as specified by the ICD [2]. LVTTL requires an output voltage that falls within the range shown in Figure 3.


Figure 3.The range of voltage values for LVTTL [4].
V > 1.5 is high. V < 1.5 is low.</td></tr>
<tr><td>4.2 - The microcontroller must communicate with the computer via USB-serial module.</td><td>A computer connects only via USB.</td><td>Converts USB to UART via CAT specification.</td></tr>
<tr><td>Explanation</td><td colspan="2">The microcontroller must interface with the computer through a separate module that translates the computer’s instructions into UART. This enables communication with all components of the SDR [2]. The module must use the CAT specification to ensure proper interface with the computer’s software.</td></tr>
<tr><td>4.3 - The subsystem interfaces correctly with the power supply and other subsystems.</td><td>Use J6 and J7 to interface with the SDR.</td><td>Power supply is 3.3 VDC and 5 VDC using J7.</td></tr>
<tr><td>Explanation</td><td colspan="2">Interfaces with all other subsystems are done through the “J” type [2] connectors to ensure proper output signals.</td></tr>
</table>

Appendix D | Component Selection Justification

Table D.1. Component Choice and justification for the LO

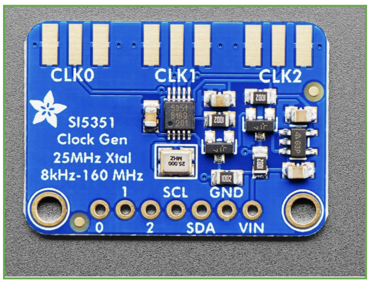
<table>
<tr><th>Component</th><th>Specifications</th><th>Justification</th></tr>
<tr><td>

Figure 5. Adafruit Si35351A Clock Generator Breakout [9]</td>
<td>Frequency: 8 kHz to 160 MHz.
Output Voltage: 3.3Vpp unipolar
Input Voltage: 3.3V to 5V
25.4 mm x 17.8 mm
Communicates via I2C</td>
<td>The output frequency stays within ±1 kHz, ensuring accurate output signals [2].

It satisfies the 90° phase shift requirement. Its compact size fits physical constraints and is compatible with the microcontroller [9].</td></tr>
</table>

Table D.2. Component Selection and justification for the UI

<table>
<tr><th>Component</th><th>Specifications</th><th>Justification</th></tr>
<tr><td colspan="3">LCD Display</td></tr>
<tr><td><u>Adafruit Industries LLC 4311</u>

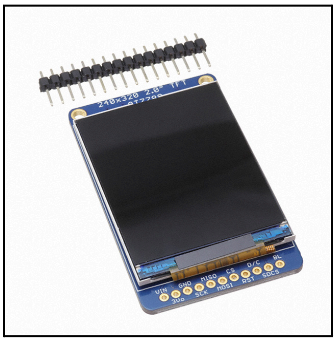
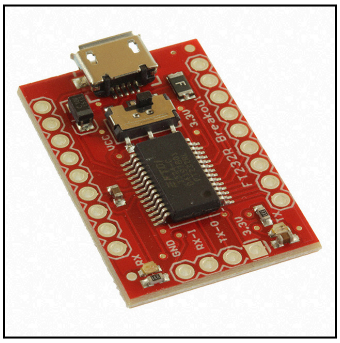
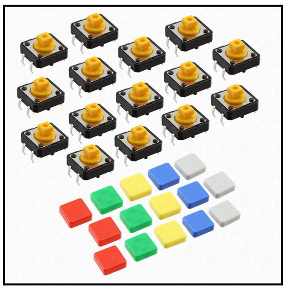



Figure 8. 4311 display by Adafruit [14].</td>
<td>IPS full colour display
Uses SPI
2” (50 mm) screen size. 59.2 × 35.5 × 3.7 mm.
3.3 V LVTTL</td>
<td>This display uses the required communication protocol and functions on 3.3 V logic, ensuring proper interface with the microcontroller.

Unlike other options, the display is full colour, allowing greater customizability in displaying visual queues to the user.

It is larger than most other LCD displays at 2” improving the viewing experience for the user rather than 0.96” - 1.3” options.</td></tr>
<tr><td colspan="3">USB to UART Converter</td></tr>
<tr><td><u>SparkFun Electronics BOB-12731</u></td>
<td>Uses FT-232 module that converts USB 2.0 to UART via CAT specification.</td>
<td>This module is used to convert USB data input from the computer into UART in order to interface with the microcontroller.

The ICD [2] specifies that USB to UART should be done using an FT-232 module.</td></tr>
</table>

 **Figure 9.** BOB-12731 module[18].	• Supports 3.3 V LVTTL	
Buttons		
<u>**Adafruit Industries LLC 1010**</u>  **Figure 10.** 1010 buttons by Adafruit [16].	• 12 mm × 12 mm buttons. • Voltage rating is 12 VDC • Through-hole mounted	The large size of these buttons makes them easier to press than the common 6 mm buttons. They can tolerate the voltages and currents of the subsystem specified by the ICD [2]. The buttons are easily mountable on either the breadboard during testing, and on the PCB in the final design.

Appendix E | Detailed UI Component Selection Process

I. Buttons

Many different types of buttons were considered when making this selection. The buttons should be easy to interface with, eg. not provide too much resistance or be awkward for the user to press. The requirements below are based on research from: “Push Button Switches - Types And Applications,” *ElectronicsHub*, [11].

Requirements and Objectives for Buttons:

1. The pushbuttons must transmit a 3.3 V signal when pressed, and 0 V otherwise.
2. Easily mountable on breadboard or PCB.
3. Ideally larger size to prevent discomfort during use.
4. Single throw, normally open switch.

II. LCD Screen

In order for this component to function as intended, it must be compatible with the microcontroller. This limits the options to displays that use either I2C or SPI protocol, which are supported by the ATmega324PB MCU. Another consideration to be made is the size of the display, touch screen capability, LCD display mode, and panel type.

A larger display is preferred to ease the viewing experience. The team determined that touch screen capability only further complicates the system, as additional drivers and code must be programmed into the MCU. Furthermore, touch capable displays tend to be more expensive than their non-touch counterparts. Spending more of the team's budget on the display would limit the amount that can be allocated to other components.

Both the display mode and panel type are not relevant for this use case. The display mode affects how the display looks in different lighting environments [12]. Since the SDR likely will not operate outdoors, reflective or transflective displays are not required. The panel type refers to the structure of underlying cells that make up the screen. Generally OLED panels are more expensive but more environmentally friendly than IPS, VA, or TN panels. Ideally the team will use an OLED or IPS panel due to superior clarity and colour contrast over the other options.

Requirements and Objectives for the Display:

1. Supports I2C or SPI protocol.
2. Larger display is better within the size constraints (Section 3.1).
3. Not touch screen.

After researching components, a few displays that were in stock met these requirements:

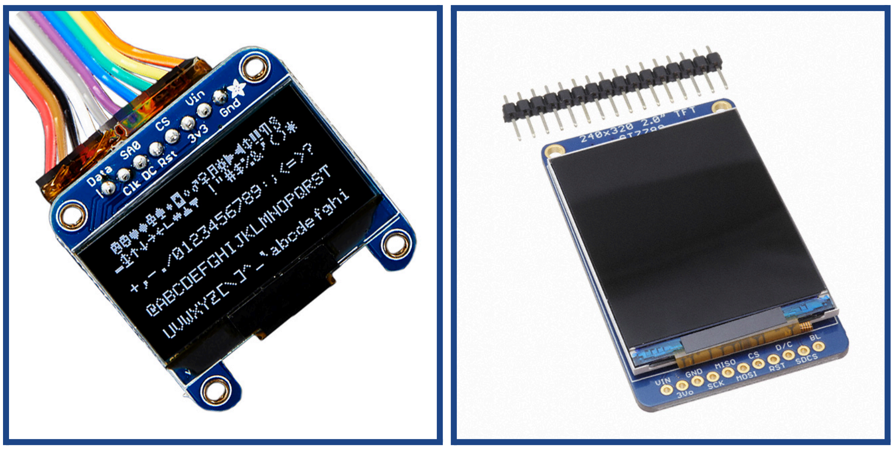


Figure D.1. 938 Display [13] (left), and 4311 Display [9] (right) by Adafruit.

The 938 display has an OLED panel, making the screen very high quality. Its screen is 1.3" (33.3 mm) across the diagonal, and it supports both I2C and SPI.

The 4311 display is an IPS panel but is larger than the 938 at 2” (50.8 mm). It only supports the SPI protocol. Unlike the previous display, the 4311 supports full colour. The team decided to use this display due to its larger size and colour capability in hopes that it will make the viewing experience for the user easier.

III. USB to UART Module

It is recommended in Appendix A of the ICD [1] that the FT232R integrated circuit (IC). This is because it is a single chip IC that performs the translation via the CAT specification. Modules using this IC can therefore be used in the subsystem to correctly translate the Computer’s instructions into radio-like commands that can be operated on by the MCU.

The recommended module in the ICD is the 284 by Adafruit Industries LLC [14]. Due to poor availability on DigiKey however, the team will use a similar module BOB-12731 by SparkFun Electronics [7]. More recent modules such as this one tend to use USB-C rather than USB 2.0+. This is not an issue as a USB-C to USB 2.0+ module can be used to interface with the computer if necessary.

Appendix F | Table of Various Oscillators

Table F.1. Comparison of various oscillators based on section 3.1

<table>
<tr><th>Design Type</th><th>Stability</th><th>Frequency Range</th><th>Complexity of the design</th><th>Fit for LO Based on requirements</th></tr>
<tr><td rowspan="2">Crystal Oscillator</td><td>Very High</td><td>Fixed by crystal</td><td>Low</td><td>Limited</td></tr>
<tr><td colspan="4">The Crystal Oscillator offers the best stability but is limited to fixed frequencies, making it unsuitable for the tunable 8-16 MHz.</td></tr>
<tr><td rowspan="2">Wein Bridge Oscillator</td><td>Moderate</td><td>1Hz- 1MHz</td><td>Medium</td><td>Poor</td></tr>
<tr><td colspan="4">The Wein Bridge Oscillator operates primarily at lower frequencies (1 Hz - 1 MHz), making it impractical for the LO .</td></tr>
<tr><td rowspan="2">Colpitts Oscillator</td><td>High</td><td>1MHz-20MHz</td><td>Medium</td><td>Sufficient</td></tr>
<tr><td colspan="4">The Colpitts Oscillator supports a wide frequency range (1 MHz - 20 MHz) and provides high stability.</td></tr>
<tr><td>555 timer oscillator</td><td>Low</td><td>Adjustable</td><td>Low</td><td>Poor</td></tr>
</table>

	The **555 Timer Oscillator** generates a square wave, which requires extensive filtering to produce a sine wave, which adds complexity and lowers the stability of the LO.

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[12] “What LCD Modes Mean: Reflective, Transmissive, Transflective,” *New Vision Display*, Mar. 14, 2017. https://www.newvisiondisplay.com/lcd-modes/

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[14] Adafruit Industries LLC, "Adafruit 284," *Digi-Key*, [Online]. Available: https://www.digikey.ca/en/products/detail/adafruit-industries-llc/284/5975010. [Accessed: Feb 7, 2025].