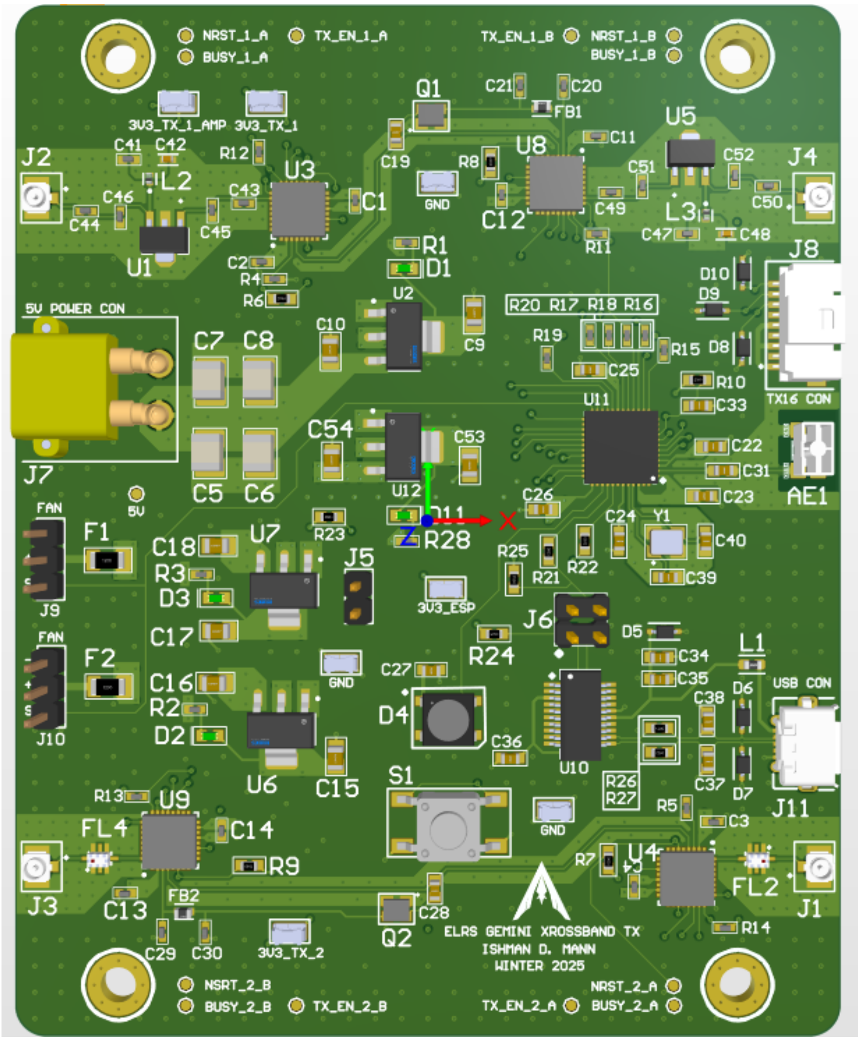
ELRS Gemini Xrossband TX

Project Whitepaper
Rev 1.0
Apr. 29/2025



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WARG

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Project Overview

Context

WARG uses the ExpressLRS (ELRS) protocol to communicate with its drones. Gemini technology has been used in the past by WARG to transmit signals with a pair of antennas operating at slightly different frequencies, decreasing the risk of data loss.

Xrossband is a dual-band technology that uses two Gemini pairs at very different frequencies, 900-910MHz and 2.4-2.44Ghz. This involves 4 antennas in total. The lower frequency pair offers higher range and is less sensitive to noise in aerial robotics competition settings. The higher frequency pair offers lower latency.

Requirements

Requirement	**Justification**
The TX module shall support full Gemini Xrossband operation using both antenna pairs.	This is the key innovation objective.
The TX module shall support normal Gemini operation using one of the antenna pairs.	Operation can continue if one pair fails.
The TX module shall have a transmission power of 27 to 30dBm.	This is the highest legal power limit.
Noise figure of the TX module should be minimal.	This helps keep SNR high.
The TX module shall be compatible with the TX16 Radio Controller over UART.	The TX16 decides what to transmit to the drone.
USB and Wi-Fi flashing of the microcontroller should be available.	Flexible flashing options are useful.
The clock reference of each Gemini pair should be synchronized.	Helps timing accuracy.
Fan headers should be present.	Microcontroller and LoRa chips need to be cooled.

Table 1. ELRS Gemini Xrossband TX requirements.

Architecture

An ESP32 microcontroller servers as the heart of this board and controls all other peripherals.

Each Gemini pair consists of two LR221 LoRa chips synchronized by a TCXO and powered by a dedicated LDO. The lower frequency pair can achieve 27-30dBm without amplification. The higher frequency pair reaches 27-30dBm using RF amplifiers powered by a separate LDO.

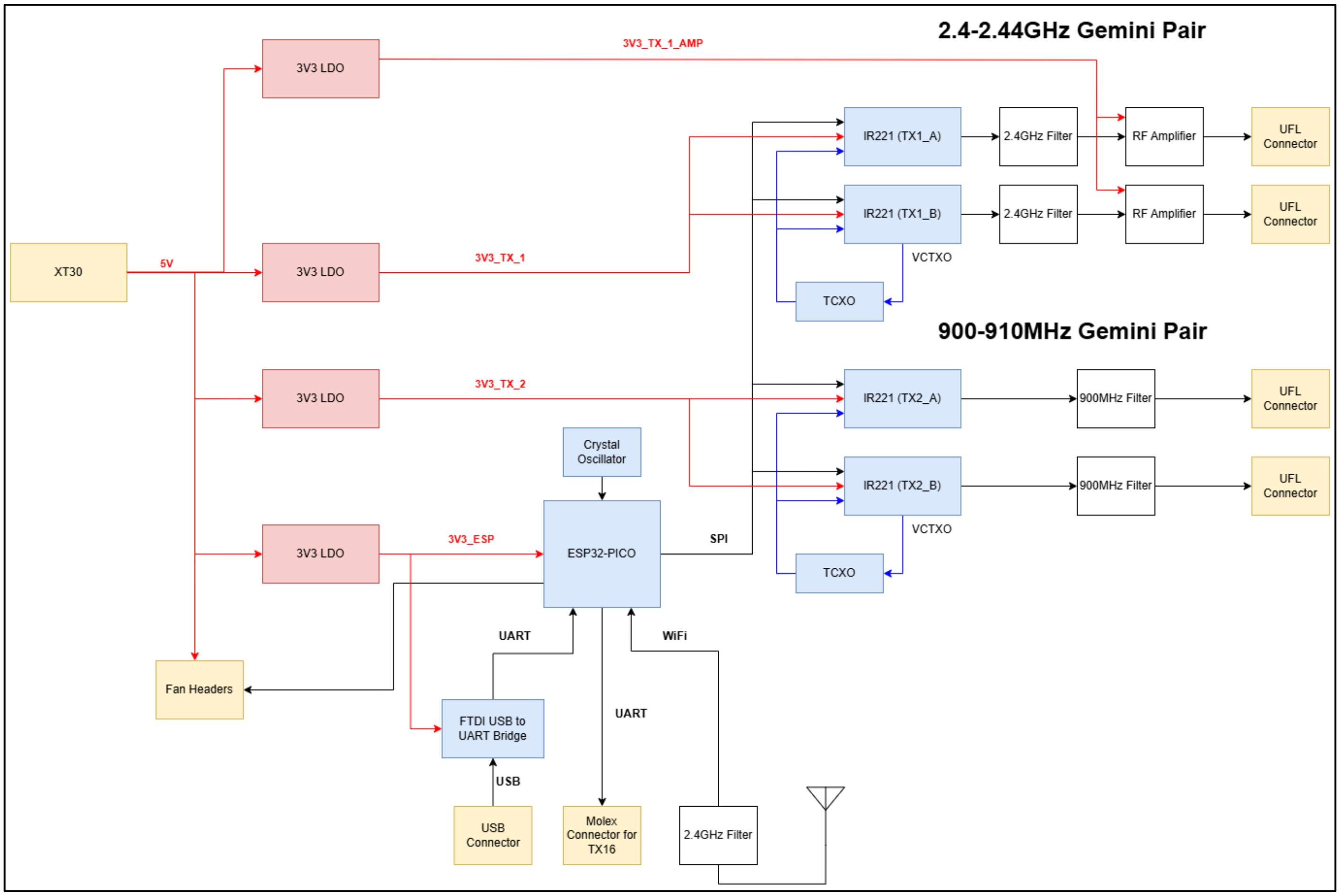

Figure 1. System architecture. Detailed connections not shown.

Electrical Overview

Component Selection

Microcontroller
The ESP32-PICO-D4 was selected for its wireless connectivity peripherals and ease of use.

LoRa Chips
The Semtech LR1121MLTRT was chosen as it supports both sub-GHz and 2.4GHz LoRa transmission, allowing for Xrossband. The chip also supplies TCXO power.

Amplifier
The SKY65162-70LF amplifier was chosen as it would add a 13-14dB gain to the 13dBm 2.4GHz signals from the LoRa chips. This makes for a 26-27dBm output prior to additional amplification by the antennas.

Filter
A simple LPF was used for the low-frequency Gemini pair. Basic capacitor filtering per the SKY65162-70LF specification was used for the high-frequency Gemini pair.

Layout Considerations

The PCB layout consists of a 6-layer stack-up with controlled impedance traces using an FR4 substrate. The lowest possible Dk material with a reasonable fabrication price by JLCPCB was selected.

Layer	Material	Thickness (mil)	Thickness (mm)
L1	Outer Copper Weight1oz	1.38	0.0350
Prepreg	3313 RC57% 4.2mil	3.62	0.0920
L2	Inner Copper Weight	1.18	0.0300
Core	0.7mm 1/1OZ without copper	27.56	0.7000
L3	Inner Copper Weight	1.18	0.0300
Prepreg	2116 RC54% 4.9mil	4.29	0.1090
Prepreg	2116 RC54% 4.9mil	4.29	0.1090
L4	Inner Copper Weight	1.18	0.0300
Core	0.7mm 1/1OZ without copper	27.56	0.7000
L5	Inner Copper Weight	1.18	0.0300
Prepreg	3313 RC57% 4.2mil	3.62	0.0920
L6	Outer Copper Weight1oz	1.38	0.0350

Figure 2. JLCPCB material choice.

#	Name	Material	Type	Weight	Thickness	Dk	Df
	Top Overlay		Overlay				
	Top Solder	Solder Resist	Solder Mask		0.01016mm	3.8	
1	L1 Top Layer	1oz copper	Signal	1oz	0.03505mm		
	Dielectric 1	3313 RC57%...	Prepreg		0.09195mm	4.1	0.02
2	L2 GND1	1oz copper	Signal	1oz	0.02997mm		
	Dielectric 2	0.7mm 1/1O...	Core		0.70002mm	4.8	0.02
3	L3 PWR	1oz copper	Signal	1oz	0.02997mm		
	Dielectric 3	2116 RC54%...	Dielectric		0.21793mm	4.16	
4	L4 SIG	1oz copper	Signal	1oz	0.02997mm		
	Dielectric 4	0.7mm 1/1O...	Core		0.70002mm	4.8	0.02
5	L5 GND2	1oz copper	Signal	1oz	0.02997mm		
	Dielectric 5	3313 RC57%...	Prepreg		0.09195mm	4.1	0.02
6	L6 Bottom Layer	1oz copper	Signal	1oz	0.03505mm		
	Bottom Solder	Solder Resist	Solder Mask		0.01016mm	3.8	
	Bottom Overlay		Overlay				

Figure 3. Stackup.

Appendix A: PCB Layout

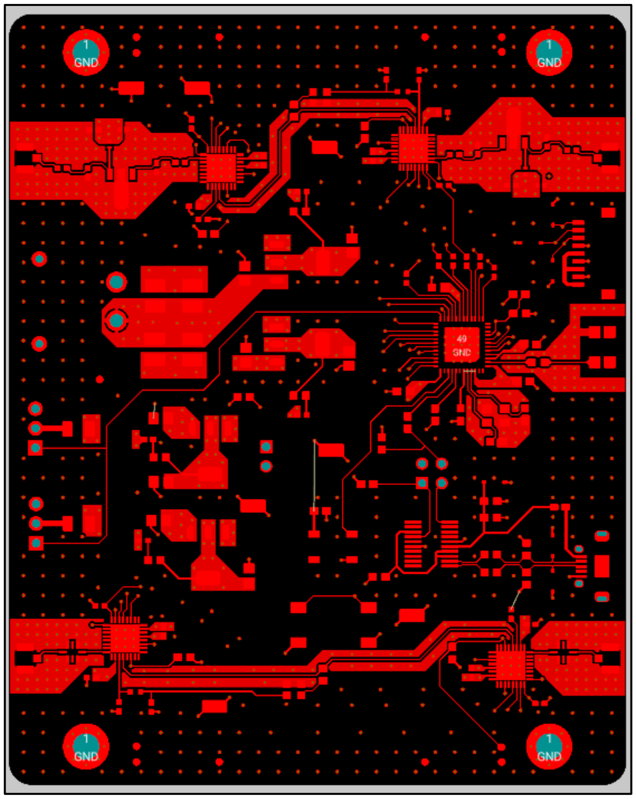

Figure 4. L1 Top Layer.

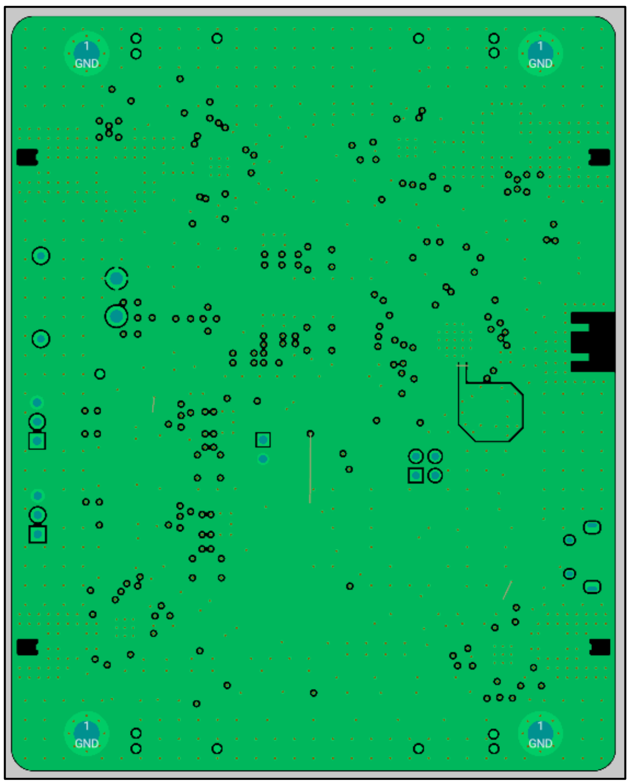

Figure 5. L2 GND1.

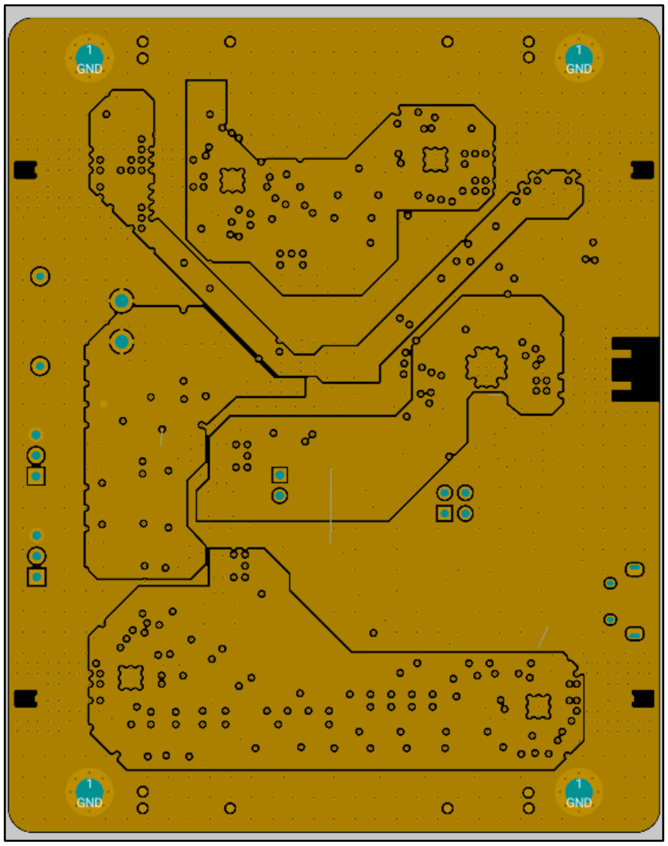

Figure 6. L3 PWR.

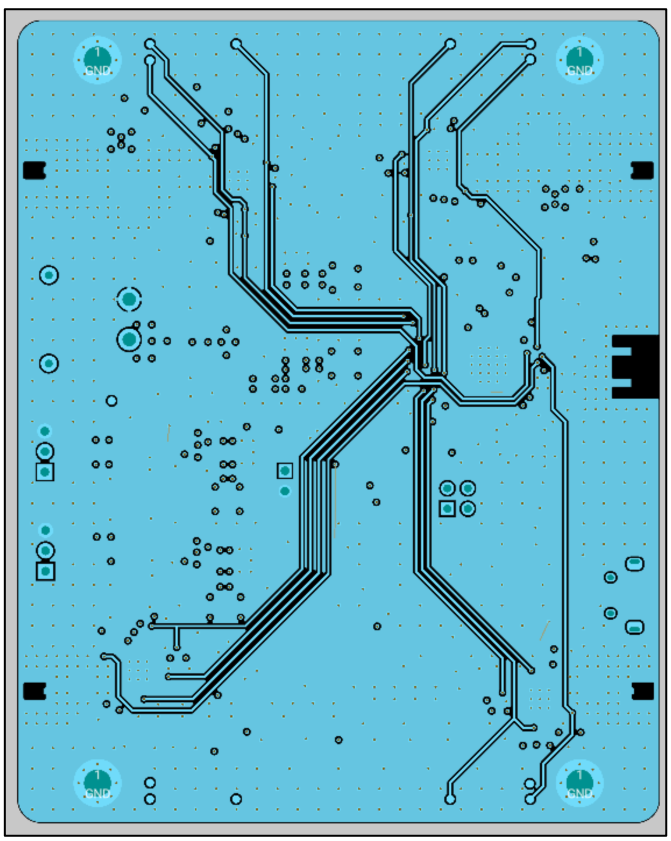

Figure 7. L4 SIG.

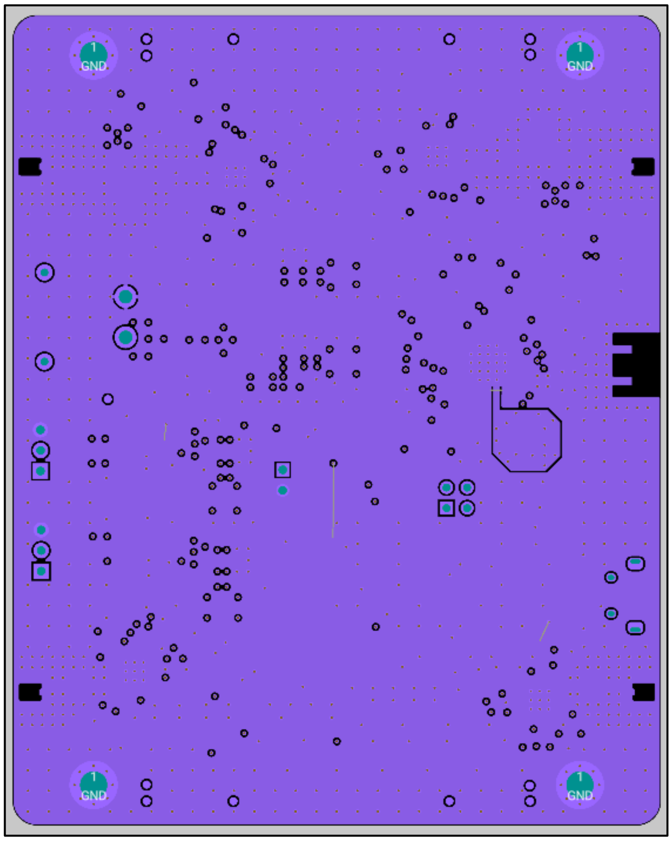

Figure 8. L5 GND2.

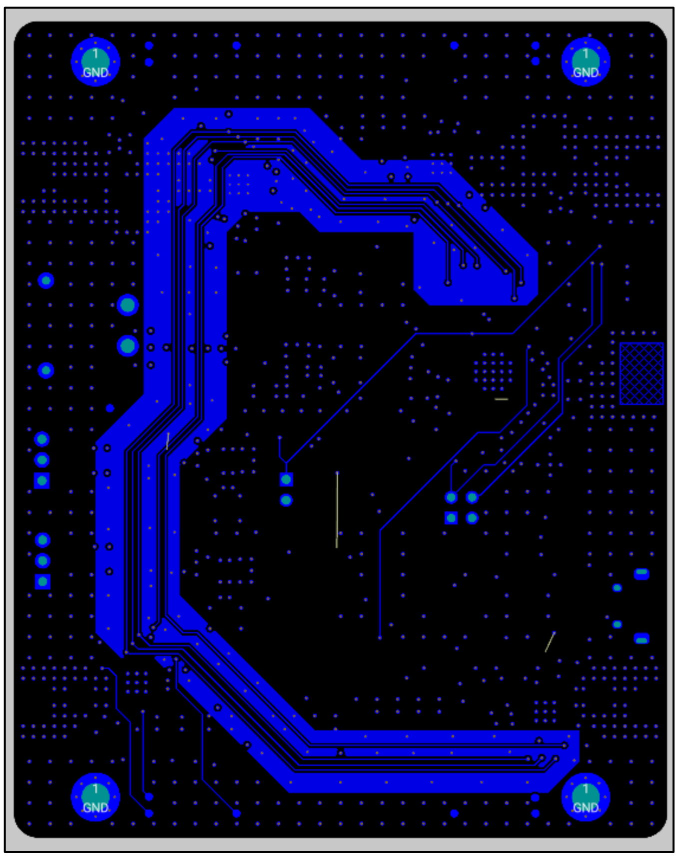

Figure 9. L6 Bottom Layer.

Appendix B: Schematic

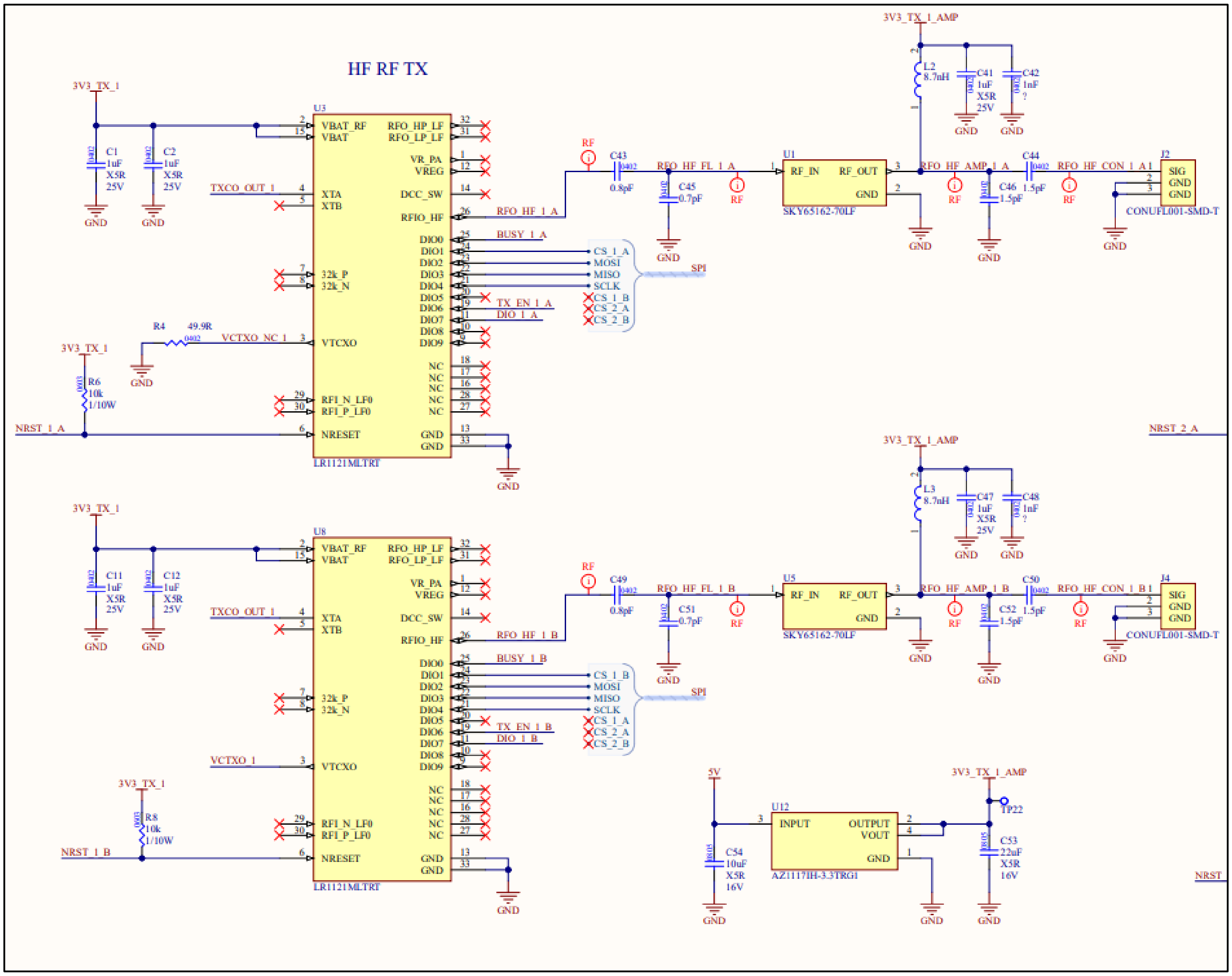

Figure 10. Schematic: high-frequency Gemini pair.

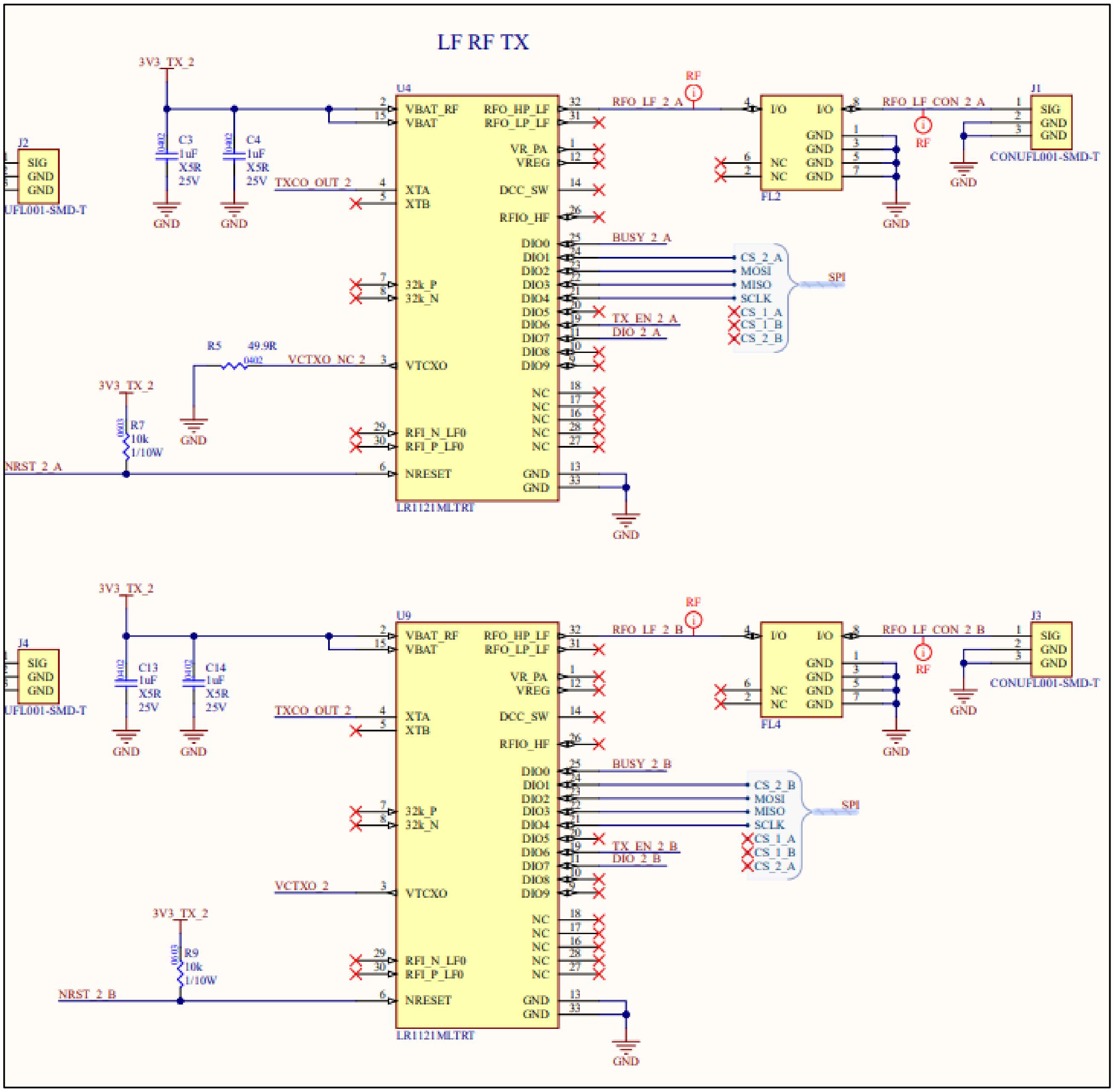

Figure 11. Schematic: low-frequency Gemini pair.

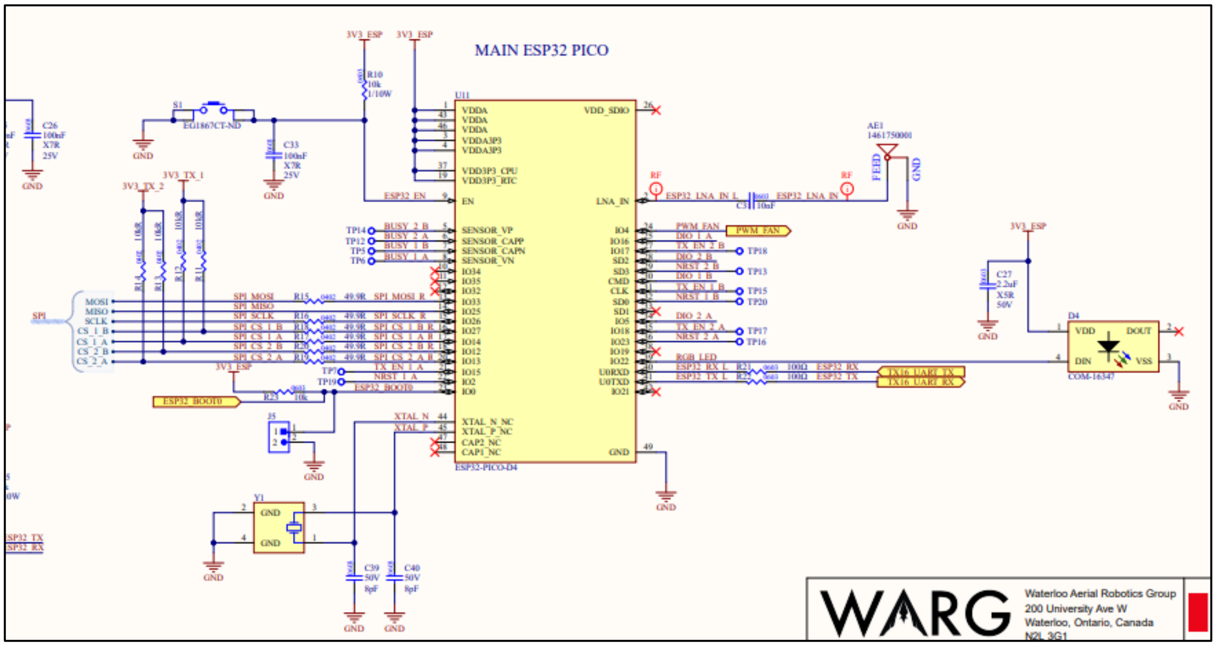

Figure 12. Schematic: ESP32 microcontroller.

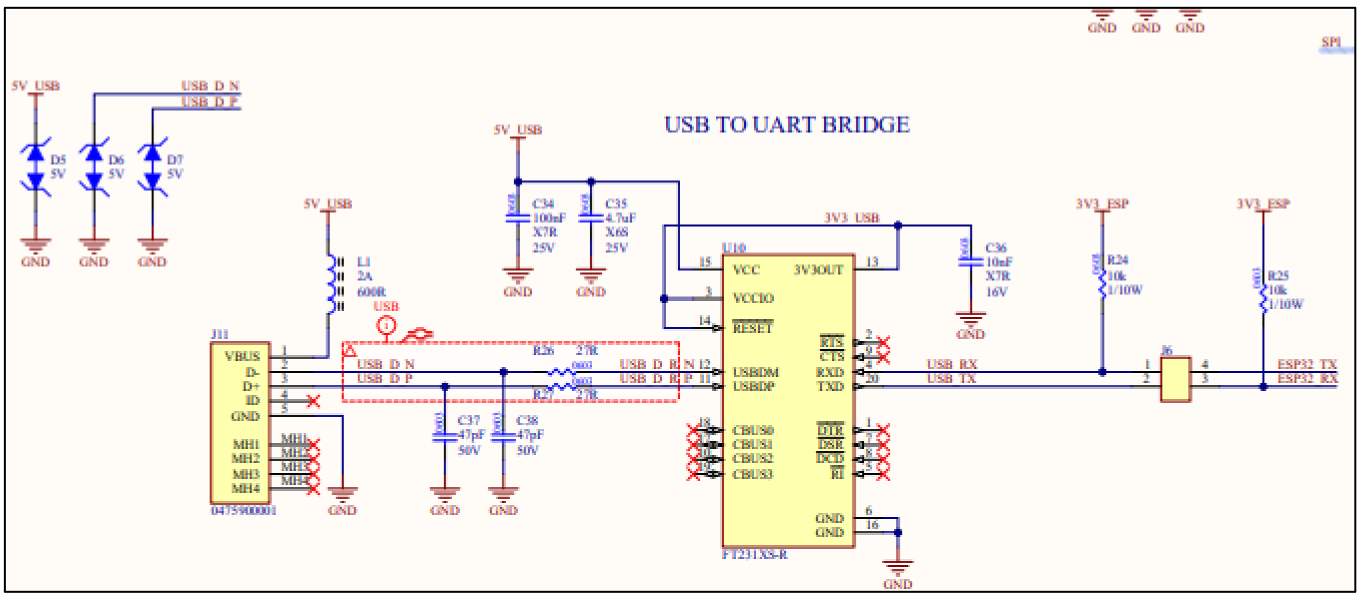

Figure 13. Schematic: USB flash circuitry.

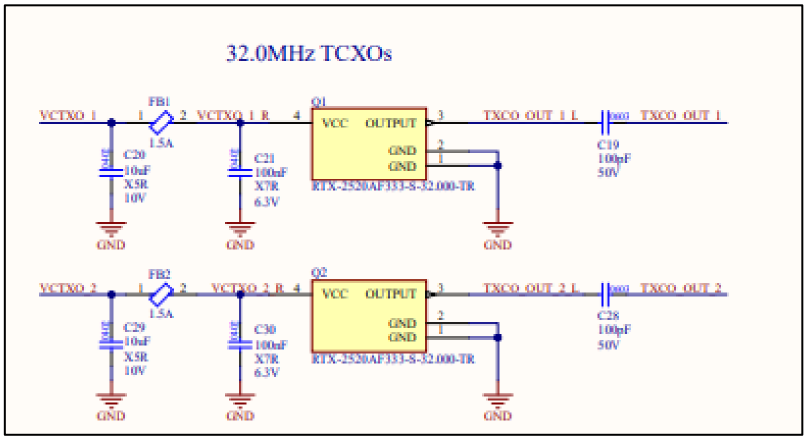

Figure 14. TCXOs for Gemini pairs.

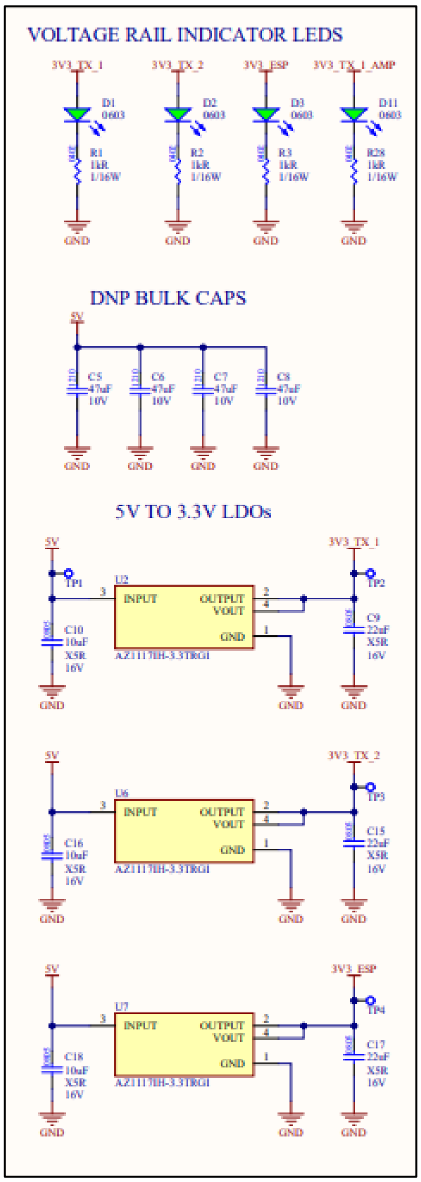

Figure 15. Primary LDOs.

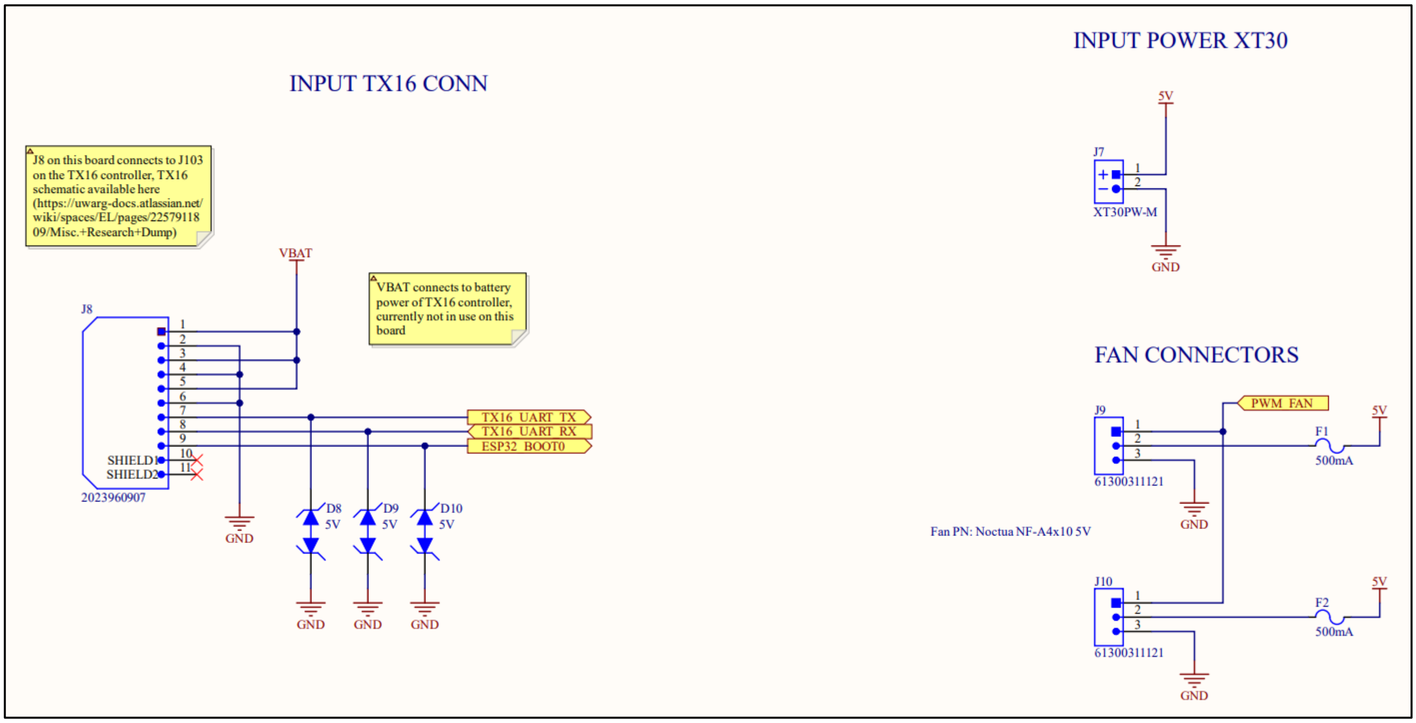

Figure 16. Connectors.

Appendix C: References

[1] FPV Guru. “ExpressLRS Gemini Xrossband: The Future of Dual-Band FPV Control.” fpvguru.in. [Online]. Available: https://fpvguru.in/blogs/expresslrs-gemini-xrossband-the-future-of-dual-band-fpv-control/