MBRF – Multi-Band Radio with Filter

Version 3.0-21.1217 – January 23, 2023

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open source hardware

Overview

The Multi-Band Receiver with Filter (MBRF) is a Skyworks (nee Silicon Labs) Si4735 based radio receiver.

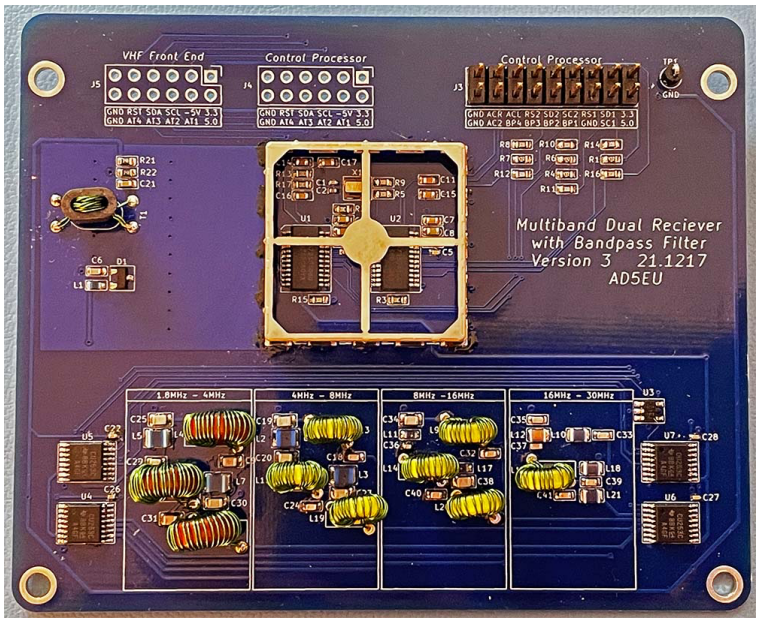


Figure 1: Multiband (Dual) Receiver with Band Pass Filter

The MBRF incorporates two (2) shielded Si4535-D60-GU receiver chips supported by a TXCO[1], and four front end bandpass filters with associated switching. The design of the MBRF is compliant to the Skyworks guidelines[2] for the Si4735. The board provides a platform, when paired with the user's processor of choice, to create a commercial grade multiband radio receiver capable of fully exploiting the Si4735.

Block Diagram

The block diagram to the right outlines the major functional blocks of the MBRF. The MBRF provides two separate antenna inputs: input 1 is intended for the SW band and input 2 is ESD protected and is intended for a whip antenna used on the FM band.

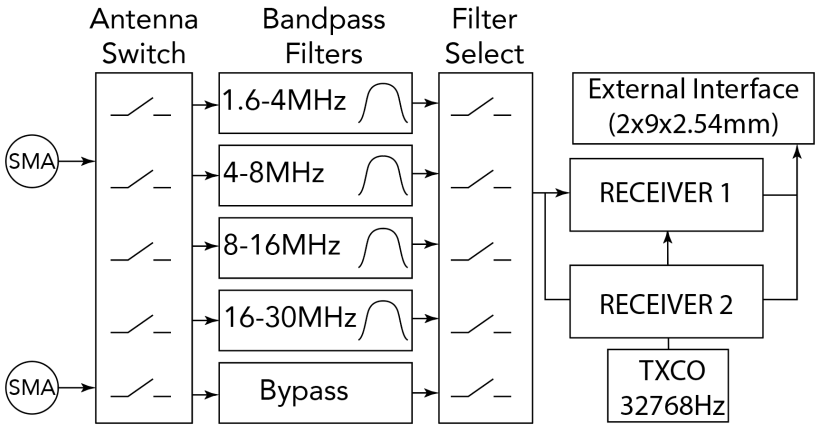


Figure 2: Simplified Block Diagram

[1] Temperature Controlled Crystal (X) Oscillator

[2] AN383: Si47xx Antenna, Schematic, Layout and Design Guidelines

The antenna switch, based on a low RDS_{ON}[3] analog switch is used to route the antenna input from input 1 to one of the 4 bandpass filters, or to the filter bypass or alternatively input 2 also through a filter bypass.

The bandpass filter section contains four LC[4] based filters which provide very good front end filtering.

The filter select function (which works in tandem with the antenna switch) routes the various filter/bypass inputs to the receiver section.

The receiver section contains two identical and independent multiband receivers chips. The receiver one (1) is intended for audio reception and receiver two (2) is intended for use in scanning the selected band for the creation of a signal strength waterfall[5] display.

The two receivers are supported by a temperature-controlled crystal oscillator (TXCO) which provides reception stability.

Last the board provides and external interface to the various board functions via a standard 2x9x0.1 (2.54mm) header.

Interface Connector

The interface connector (J3 – pictured to the right) is a 2x9x0.1 (2.54mm) odd/even header with pin one (1) located on the upper right hand side. The recommended header is a Sullins PBC09DAAN although any equivalent header can be substituted.

The MBRF requires two separate power supplies: 3.3V and 5V. The 3.3V is used for the receiver however the analog switches used for antenna and filter selection require 5.0V. The MBRF contains only basic bypass filtering on the power supply lines and clean

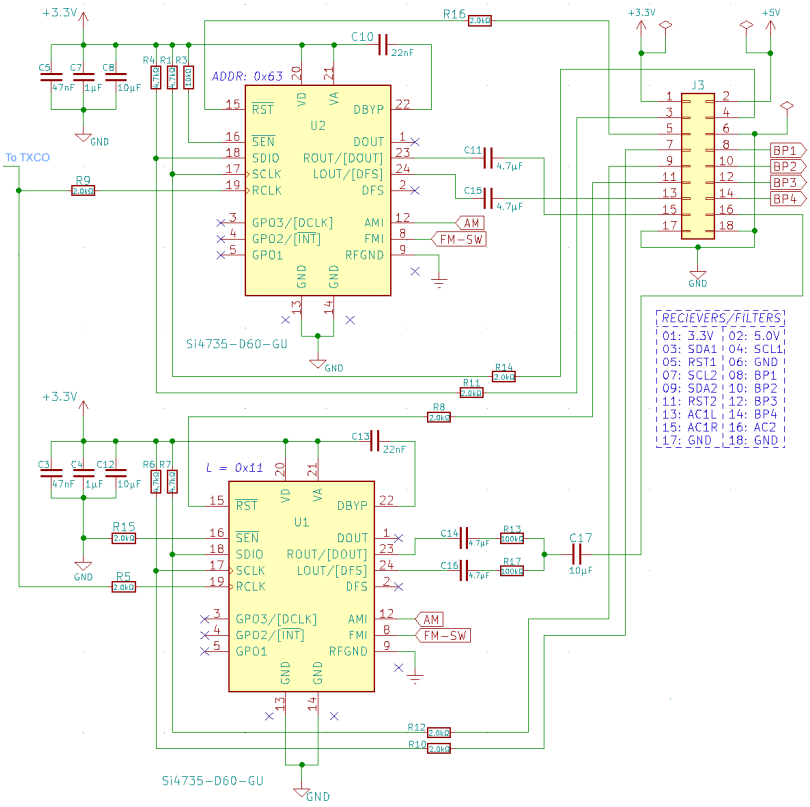
[3] Resistance Drain to Source in the switch ON condition
[4] LC (Inductor Capacitor)
[5] Description of waterfall

power is required to provide optimal receiver performance. All digital connections to the MBRF require 3.3V logic.

The interconnects of J3 are as follows:

Pin	Label	Function	Pin	Label	Function
1	3.3	3.3V Power[6]	2	5.0	5.0V Power
3	SD1	i2c data (receiver 1)	4	SC1	i2c clock (receiver 1)
5	RS1	Reset for receiver 1	6	GND	Power Ground
7	SC1	i2c clock (receiver 2)	8	BP1	Bandpass select LSB
9	SD1	i2c data (receiver 2)	10	BP2	Bandpass select 2^1 bit
11	RS2	Reset for receiver 2	12	BP3	Bandpass select 2^2 bit
13	ACL	Receiver 1 Left Audio	14	BP4	Bandpass select MSB
15	ACR	Receiver 1 Right Audio	16	AC2	Receiver 2 audio (mono)
17	GND	Power Ground	18	GND	Power Ground

Receivers



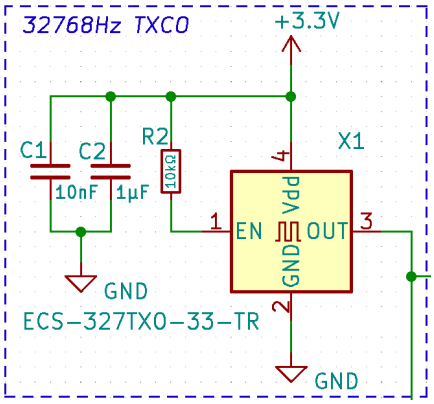
The MBRF contains two identical receivers , one intended for radio reception (U2) and the other (U1) intended for scanning the selected band to create a waterfall display or for use for a dual-watch[7] function. Both receivers share a common TXCO but separate i2c control lines. The first Si4735 (U1) has a combined right and left audio channel (AC2 – Audio Channel 2) which and the second Si4735 has independent Right and Left audio channels (AC1L and AC1R). If only one Si4735 is populated, it is recommended that U2 be populated.

[6] Power must be clean filter power – see section on power supply

[7] In dual watch Receiver 1 is tuned to 1 frequency and Receiver 2 to a second frequency and output on different audio channels.

The Si4735 design includes 2kΩ resistors on the various digital lines (SDIO, SCLK, RCLK, RST) as recommended in Sykworks application note AN383 for digital noise mitigation

TCXO



The Si4735 receiver chip requires a stable (100ppm) 37268Hz reference clock[8]. Although a simple crystal can be used, to optimize receiver stability and to avoid i2C interface timing issues, mistunes, false stops and poor SNR the MBRF uses a temperature-controlled crystal oscillator (X1). The recommended TXCO is an ECS ECS-327TXO-33-TR which provides a basic frequency tolerance of ±1.5ppm. The enable pin of the TXCO is pulled to logical high with a 10kΩ resistor (R2) and power is filtered with both a 10nF and 1µF capacitors (C1, C2). As the ECS-327TXO-33-TR is a low power (1.37µA operating) CMOS device the value of R2 is not critical (10kΩ-330kΩ) and C2 is optional.

Filters

The MBRF incorporates 4 front end bandpass filters with associated switching. The filters are fifth (5th) order Chebyshev[9] covering each of the following shortwave bands:

Filter	Address (BP4 - BP1)	Band(s)	Frequency
1	0 0 0 0	160m, 80m	1.6MHz – 4.0 MHz
2	0 0 0 1	60m, 40m	4.0MHz – 8.0 MHz
3	0 0 1 0	30m, 20m, 17m	8.0MHz – 16.0 MHz
4	0 0 1 1	15m, 12m, 10m	16.0MHz – 30.0MHz

Component selection for the filters is critical to insure proper filter operation and minimum loss. Either ±5% or ±10% C0G/NP0 MLCC[10] capacitors or strongly recommended and inductors have been carefully selected and should not be substituted.

Filters were designed assuming a 50Ω input and output impedance.

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[8] See Skyworks Si4735 datasheet section 4.18 Reference Clock

[9] Chebyshev filters are filters that have a steeper roll-off than other filters, and they minimize the error between the idealized and the actual filter characteristic over the range of the filter.

[10] MLCC – Multilayer Ceramic Capacitor

1.8-4Mhz (Filter 1)

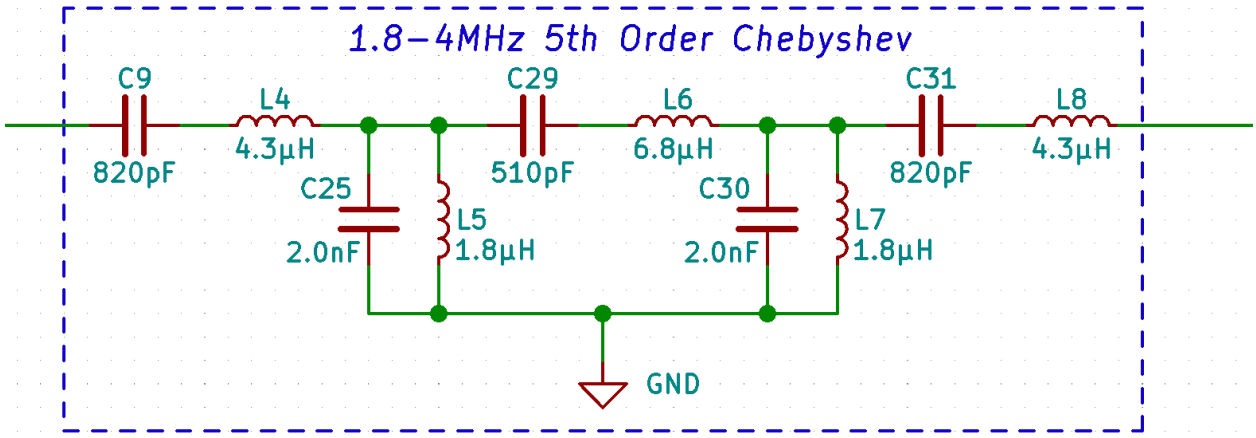


Figure 3: Filter 1 Schematic

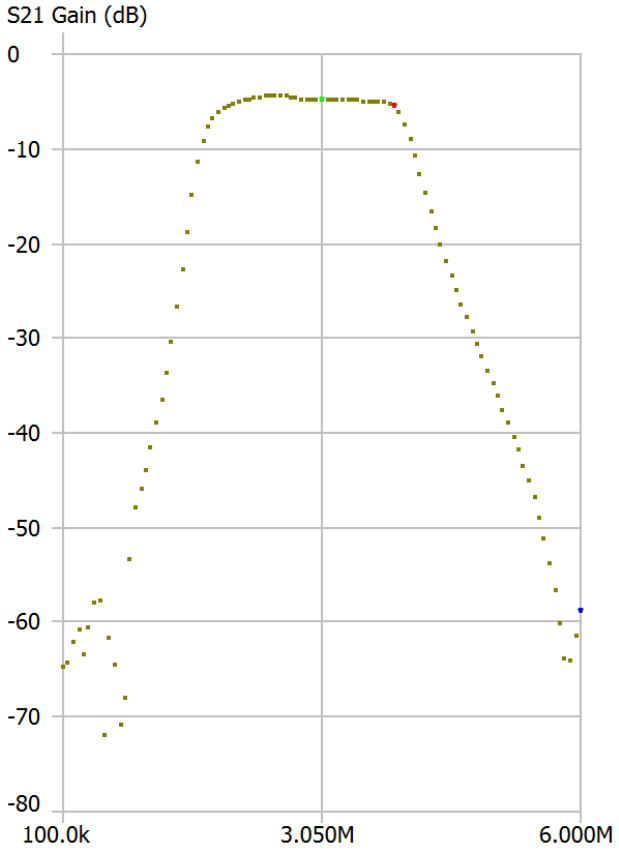


Figure 4: Performance (Actual)

4-8Mhz (Filter 2)

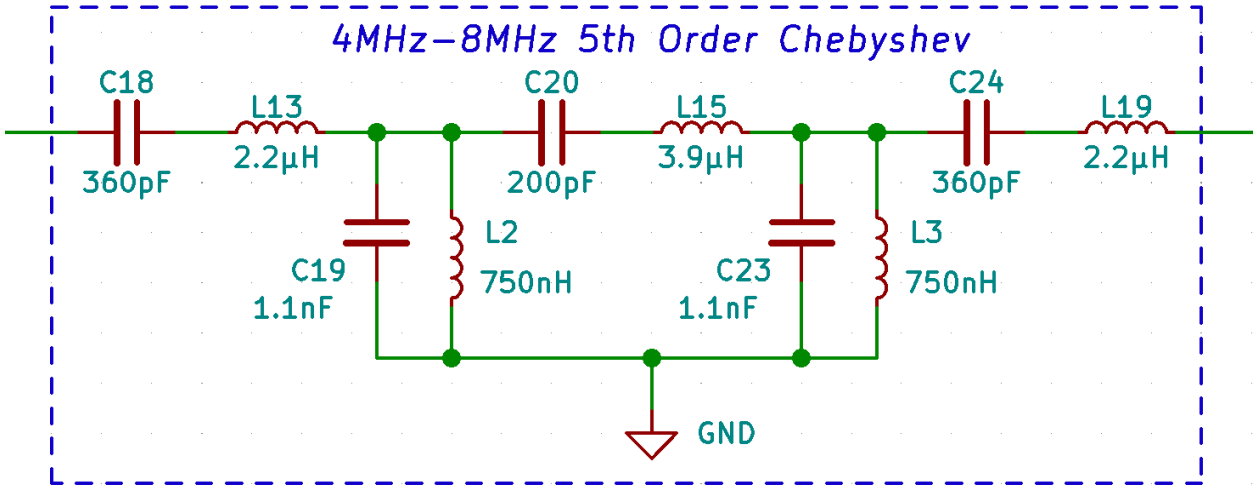


Figure 5: Filter Schematic

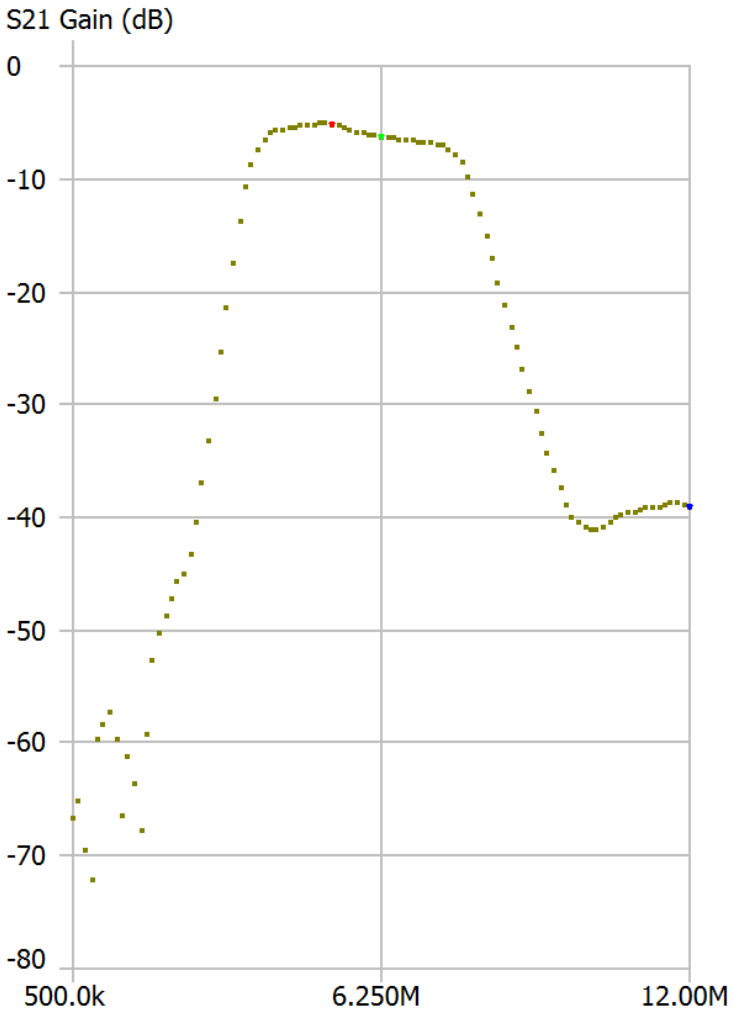


Figure 6: Performance (Acutal)

8-16Mhz (Filter 3)

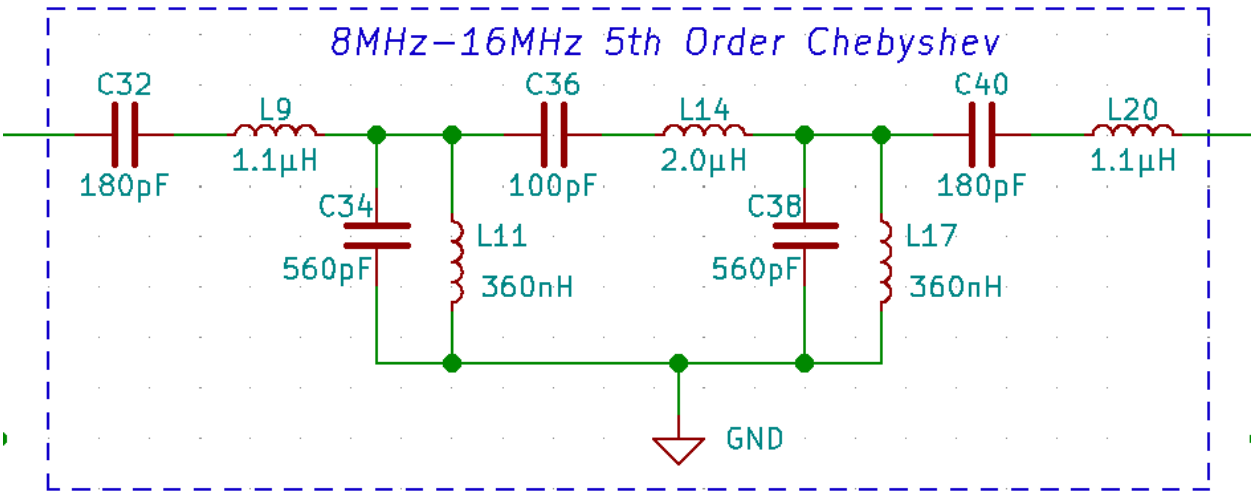


Figure 7: Filter 3 Schematic

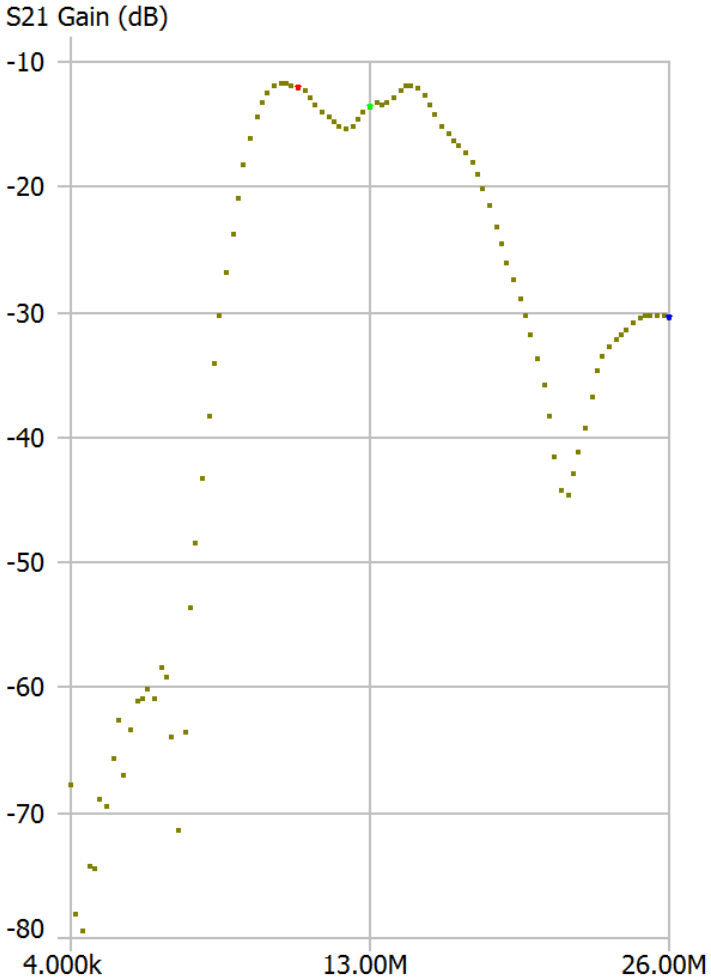


Figure 8: Performance (Actual)

16-30Mhz (Filter 4)

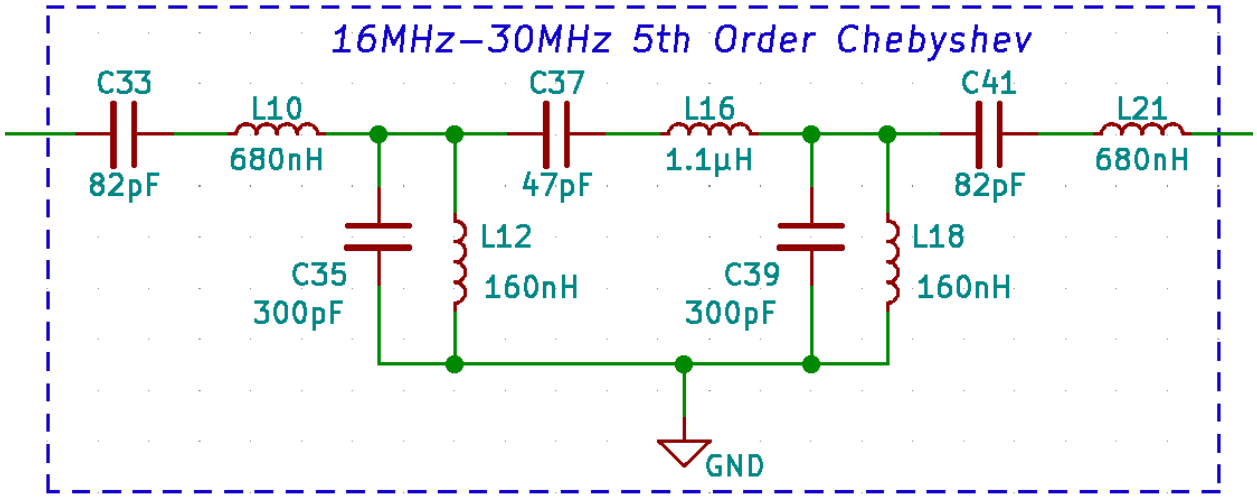


Figure 9: Filter 4 Schematic

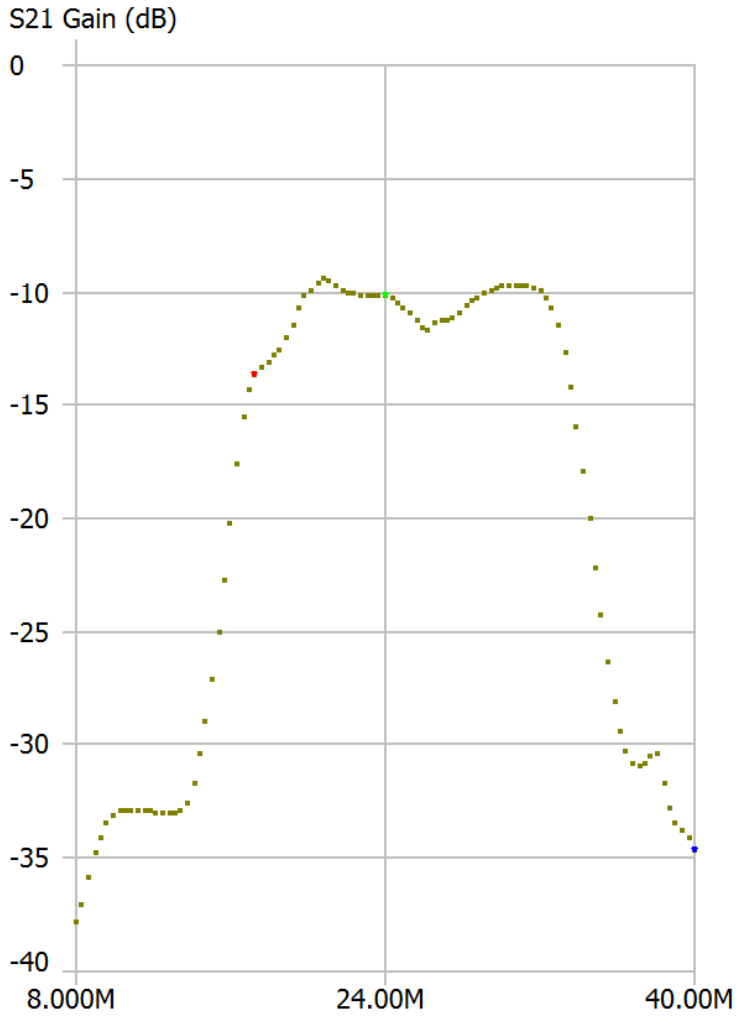
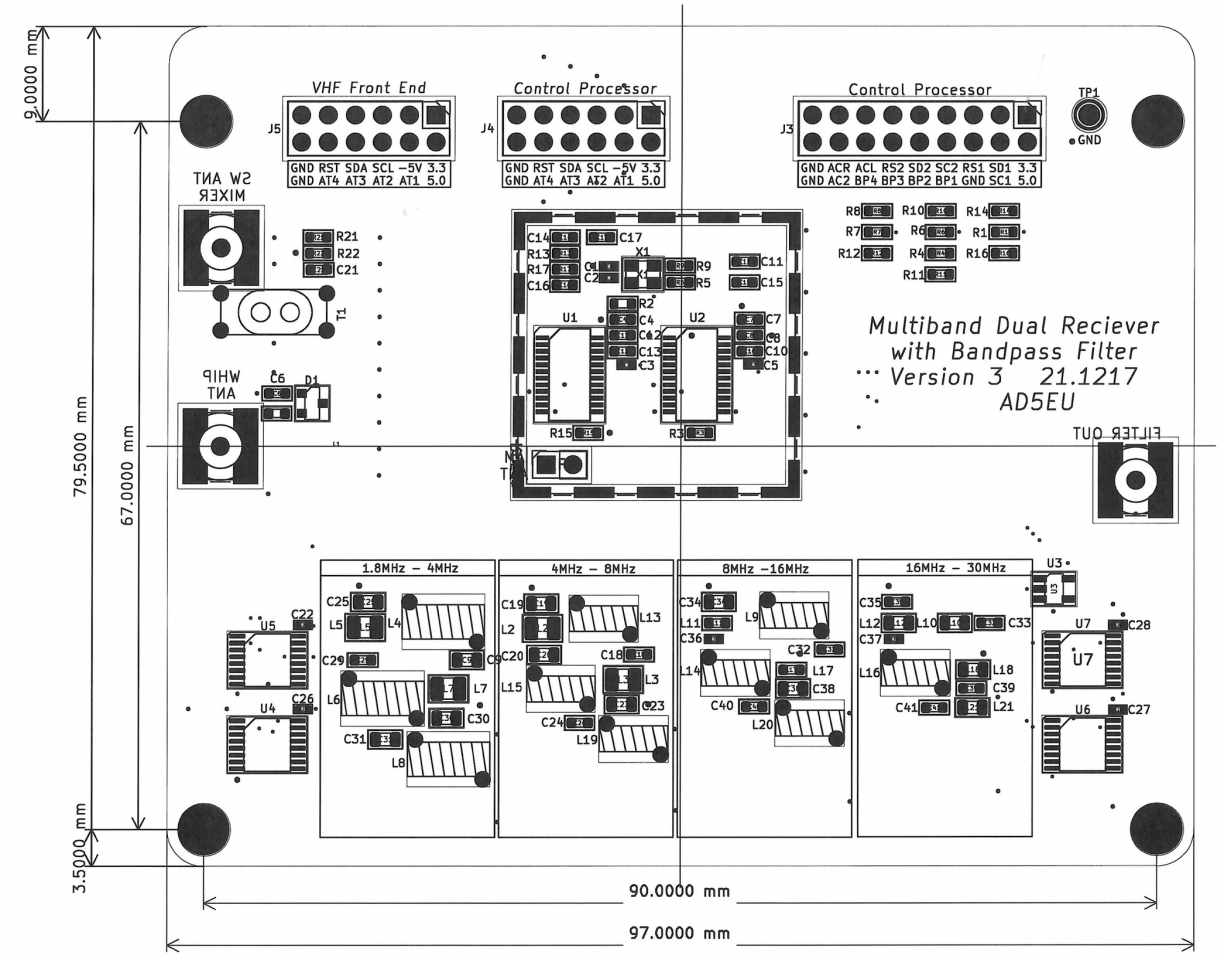


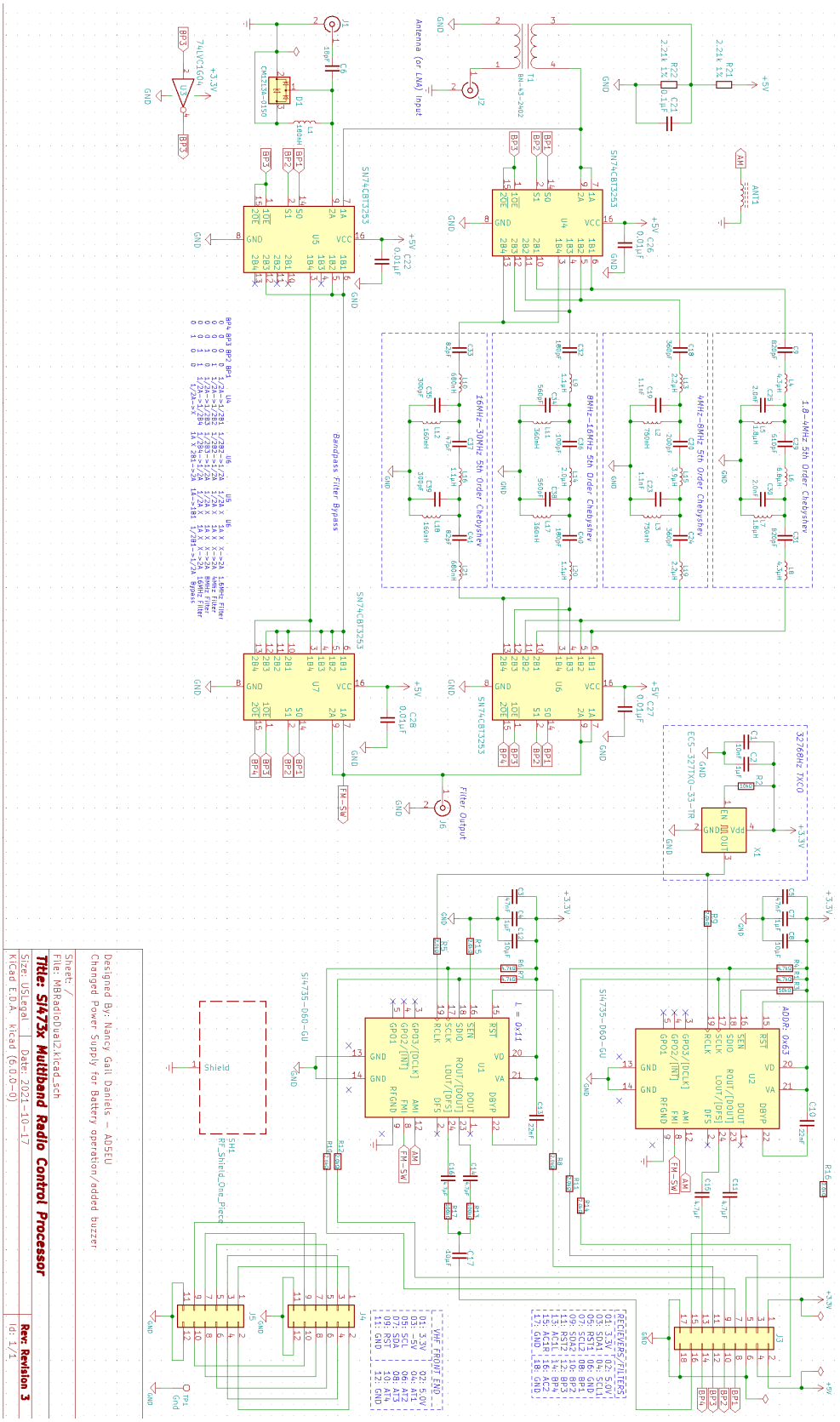
Figure 10: Performance (Actual)

Board Layout

The MBRF was designed using KiCAD (Version 5) and is a 97mmx79.5mm board with M3 mounting holes on each corner offset 3.5mm left and right and 9mm at the top and 3.5mm at the bottom. The board is a two-layer design with the bottom layer consisting primarily of power ground plane. Standard FR4 1.6mm board material is recommended.



Schematic


Antenna (or LNA) Input
Filter Output
1.8-4MHz 5th Order Chebyshev
4MHz-8MHz 5th Order Chebyshev
8MHz-16MHz 5th Order Chebyshev
16MHz-30MHz 5th Order Chebyshev
Bandpass Filter Bypass
32768Hz TXCO
Si4735-D60-GU
Shield
VHF FRONT END
Title: Si473x Multiband Radio Control Processor
Rev: Revision 3
Designed By: Nancy Gail Daniels - AD5EU
Changed Power Supply for Battery operation/added buzzer

Bill of Materials (MBRF)

Multiband Radio with Filter Version 3.0-21.1217 - Bill of Materials - January 23, 2022

Qty	Desig	Value	Package	Vendor	Data / Vendor PN	Digikey/Mouser
5	C1,C22, C26-C28	10nF ±10% 10V X7R	0402	Samsung	CL05B103KP5NNNC	1276-1502-1-ND
2	C3, C5	47nF ±10% 10V X7R	0402	Samsung	CL05B473KP5NNNC	1276-1573-1-ND
1	C6	18pF ±5% 50V C0G/NP0	0603	AVX	06035U180JAT2A	478-11831-1-ND
3	C2, C4, C7	1µF ±10% 10V X5R	0603	Samsung	CL10A105KP8NNNC	1276-1182-1-ND
3	C8, C12, C17	10µF ±20% 6.3V X5R	0603	Samsung	CL10A106MQ8NNNC	1276-1119-1-ND
2	C9, C31	820pF ±5% 50V C0G/NP0	0805	Vishay	VJ0805D821JXJQJHT	720-VJ0805D821JXJQJHTCT-ND
2	C10, C13	22nF ±10% 16V X7R	0603	Samsung	CL05B223KO5NNNC	1276-1175-1-ND
4	C11, C14-C16	4.7µF ±10% 10V X5R	0603	Samsung	CL10A475KP8NNNC	1276-1044-1-ND
2	C18, C24	360pF	0603	Kemet	C0603C361G5GAC7867	399-14514-1-ND
2	C19, C23	1.1nF ±5% 50V C0G/NP0	0805	Kemet	C0805C112J5GAC7800	399-14552-1-ND
1	C20	200pF	0805	Vishay	VJ0805D201KXPAJ	720-1346-1-ND
1	C21	100nF ±10% 16V X7R	0603	Yageo	CC0603KRX7R7BB104	311-1088-1-ND
2	C25, C30	2.0nF ±5% 50V C0G/NP0	0805	Kemet	C0805C202J5GAC7800	399-15025-1-ND
1	C29	510pF ±5% 50V C0G/NP0	0603	Kemet	C0603C511J5GAC7867	399-C0603C511J5GAC7867CT-ND
2	C32, C40	180pF ±5% 50V C0G/NP0	0603	Vishay	VJ0603D181KXAAJ	720-1328-1-ND
2	C33, C41	82pF ±1% 50V C0G/NP0	0603	Kemet	CBR06C820F5GAC	399-16259-1-ND
2	C34, C38	560pF	0805	Vishay	VJ0805D561KXBAJ	720-1354-1-ND
2	C35, C39	300pF	0603	Vishay	VJ0603D301KXAAJ	720-1332-1-ND
1	C36	100pF	0402	Kemet	CBR04C101F3GAC	399-11246-1-ND
1	C37	47pF ±5% 50V C0G/NP0	0402	Kemet	CBR04C470F3GAC	399-17536-1-ND
1	D1	CM1213A-01SO	SOT-23	Onsemi	CM1213A-01SO	CM1213A-01SOOSCT-ND
3	J1, J2, J6	Coaxial Connector	SMA Vertical	Amphenol	132134RP	ACX1231-ND
1	J3	Vertical Header	2x09x2.54mm	Sullins	PBC09DAAN	S2011E-09-ND
2	J4, J5	Vertical Header	2x06x2.54mm	Sullins	PBC06DAAN	S2011E-06-ND
1	L1	180nH	0603	Murata	LQW18ANR18J00D	490-6928-1-ND
2	L2, L3	750nH	2520	Coilcraft	1008CS-751XJLC	994-1008CS-751XJLC
2	L4, L8	4.3µH	T30-2 Toroid	Amidon	32 turns	RED
2	L5, L7	1.8µH	2520	Murata	LQW2UAS1R8G0CL	81-LQW2UAS1R8G0CL
1	L6	6.8µH	T30-2 Toroid	Amidon	40 turns	RED
2	L10, L21	680nH	0805	Coilcraft	0805HP-681XJRC	994-0805HP-681XJRC
2	L11, L17	360nH	0603	Coilcraft	0603HP-R36XGLW	994-0603HP-R36XGLW
2	L13, L19	2.2µH	T25-6 Toroid	Amidon	29 turns	YELLOW
1	L15	3.9µH	T25-6 Toroid	Amidon	38 turns	YELLOW

4	L9, L14, L16, L20	1.1µH	T25-6 Toroid	Amidon	20 turns	YELLOW
2	L12, L18	150nH	0805	Coilcraft	0805HP-151XGRC	994-0805HP-151XGRC
2	R2, R3	10kΩ ± 1% 0.1W	0603	Yageo	RC603FR-0710KL	311-10.0KHRCT-ND
4	R1, R4, R6, R7	4.7kΩ ± 1% 0.1W	0603	Yageo	RC0603FR-074K7L	311-4.70KHRCT-ND
9	R5, R8-R12, R14-R16	2.0kΩ ± 1% 0.1W	0603	Yageo	RC0603FR-072KL	311-2.00KHRCT-ND
2	R13, R17	100kΩ ± 1% 0.1W	0603	Yageo	RC0603FR-07100KL	311-100KHRCT-ND
2	R21, R22	2.21k ± 0.5% 0.1W	0603	Yageo	RT0603DRE072K21L	311-2513-1-ND
1	SH1	RF Shield	26.21^2mm	Laird Tech	BMI-S-203-F	903-1052-1-ND
1	SH2	RF Shield Cap	26.27^2mm	Laird Tech	BMI-S-201-C	903-1015-ND
1	T1	Balun	BN43-2402		BN-43-2402	
1	TP1	Test Point-Black	4.57x1.02mm	Keystone	5001	36-5001-ND
2	U1, U2	RF Receiver	SSOP-24	Skyworks	SI4735-D60-GU	336-2140-ND
1	U3	74LVC1G04	SOT-23-5	TI	SN74LVC1G14DBVR	296-11607-1-ND
4	U4-U7	SN74CBT3253	TSSOP-16	TI	SN74CBT3253CPWR	296-19207-1-ND
1	X1	32768Hz TXCO (4 Pin)	3.2x2.5mm	Abracon	ECS-327TXO-33-TR	XC3158CT-ND