A narrowband QO-100 transceiver connected and powered through a single UTP cable

Paul Dallas SV1UI, with input from many friends and fellow hams!

Version 3, modified November 12, 2023 06:36:17 PM

Change log

Version	Change	Pages affected
1	First issue	All
2	Corrected typos and added clarifications	All
	Added a plastic cover over the POTY antenna	99
	Figure 1 and figure 46: Corrected connection of 0VS and 5VS.	7, 86
	Added a project tree (figure 2)	8
	Updated parts list to PartslistVerB.ods	9
	P1, P2, J20 and J21 shown in figures 3, 5, 6a, 14 and associated parts lists	10, 11, 12, 13, 15, 29
	Figure 6a: Added a description for the small connector for LED D15.	15
	Figure 14: Changed 5V and 12V power supply F3 to 200mA, also in Pluto enclosure parts list	17, 29
	Changed the current drawn by the LNB to 120mA	22, 73
	Added section 2.4.3.6	25
	Added section 7.3	41, 73, 103ff
	Section 2.6.2.3: Added warning: Do not operate LNB without ext. clock	48
	Section 3.6.2.1: Updated mixer sound settings for FLDIGI	62
	Added section 7.1	101
3	Transmitting antenna change from POTY to Ice Cone v2.1: Updated cover picture, updated figure 1 and figure 46, updated sections 2.6.1 and 2.6.2 then swapped sections 2.6.2 and 2.6.3, added Appendix B	1, 7, 46, 47, 50, 86, 98ff.
	"5V switchmode power supply" renamed to "isolated 5V switchmode power supply"	7, 16, 22, 29, 31, 32, 79, 86
	Updated parts list to PartslistVerC.ods and component cost to 1430€	9
	Section 4.3.3: Corrected mains current consumption. Affects mains fuse selection (control box F2), figure 3 and section 2.3.2	11, 13, 77
	Section 2.4.1: Described connection of Pluto enclosure box to SK2.	14
	Section 2.4.3.6: Changed "sometimes" to "on rare occasions (once every two or three months)"	25
	Added new data to figure 11	26
	Figure 12: Removed GND symbol to avoid confusion	27
	Sections 2.4.6 and 4.3.4, figure 46: Isolated 5V switchmode power supply is no longer necessary	32, 79, 86
	Section 2.6.2.2: LNB front horn cover no longer removed	47
	Appendix B becomes Appendix C	101

Inhaltsverzeichnis

1 Introduction

This is yet another description of a QO-100 transceiver project. There are so many descriptions already on the internet, the obvious question is, "why one more"? Well, there are a couple of reasons:

- This transceiver arrangement is somewhat unusual in that the indoor and outdoor units are connected by a single CAT-5 UTP cable. No RF cables have to go through the wall, no separate power cables, just a single UTP cable. This was very important in my case, as I couldn't get any new cables from my shack up to the roof. It works with (and has been calculated for) 15m of UTP cable; it will probably be just fine with somewhat longer lengths.
- Despite my having done my homework diligently and in spite of my 35 years as an electronics professional, I found there were many pitfalls and things I hadn't thought of when I first put it together. Around half the items had to be redesigned and rebuilt. I hope that by publishing this, I might save fellow amateurs from repeating my mistakes!
- Last but not least, the performance of the set-up is pretty good. I don't only say so myself, fellow hams on the air seem to think it's pretty good too.

The system is based on an ADALM Pluto with DJ0ABR's excellent AMSAT-DL QO-100 Linux SDR Transceiver software. An Othernet Bullseye LNB is used for reception and a set of amplifiers from F1OPA and DX-Patrol for transmit. The LNB and the ADALM Pluto are both locked to an 100MHz OCXO. I had initially left the option open to lock the OCXO to GPS, but its stability turned out to be so good that I never bothered.

2 Construction details

I will first describe how it all goes together and then go into the design ins and outs. It is a complicated beastie, so it is probably easier to describe this way.

The unit is split into three separate boxes,

- the "control box" which is indoors and just has the mains transformers,
- the "Pluto enclosure" which is a waterproof aluminium box which carries the ADALM Pluto, the frequency reference PCB, the F1OPA driver amplifier, the USB to Ethernet converter and their power supplies,
- the "PA enclosure" which is a second waterproof aluminium box which carries the DX Patrol power amplifier, the PA control board and the 28V switchmode power supply.

There is also the modified LNB and the POTY antenna.

2.1 Block diagram

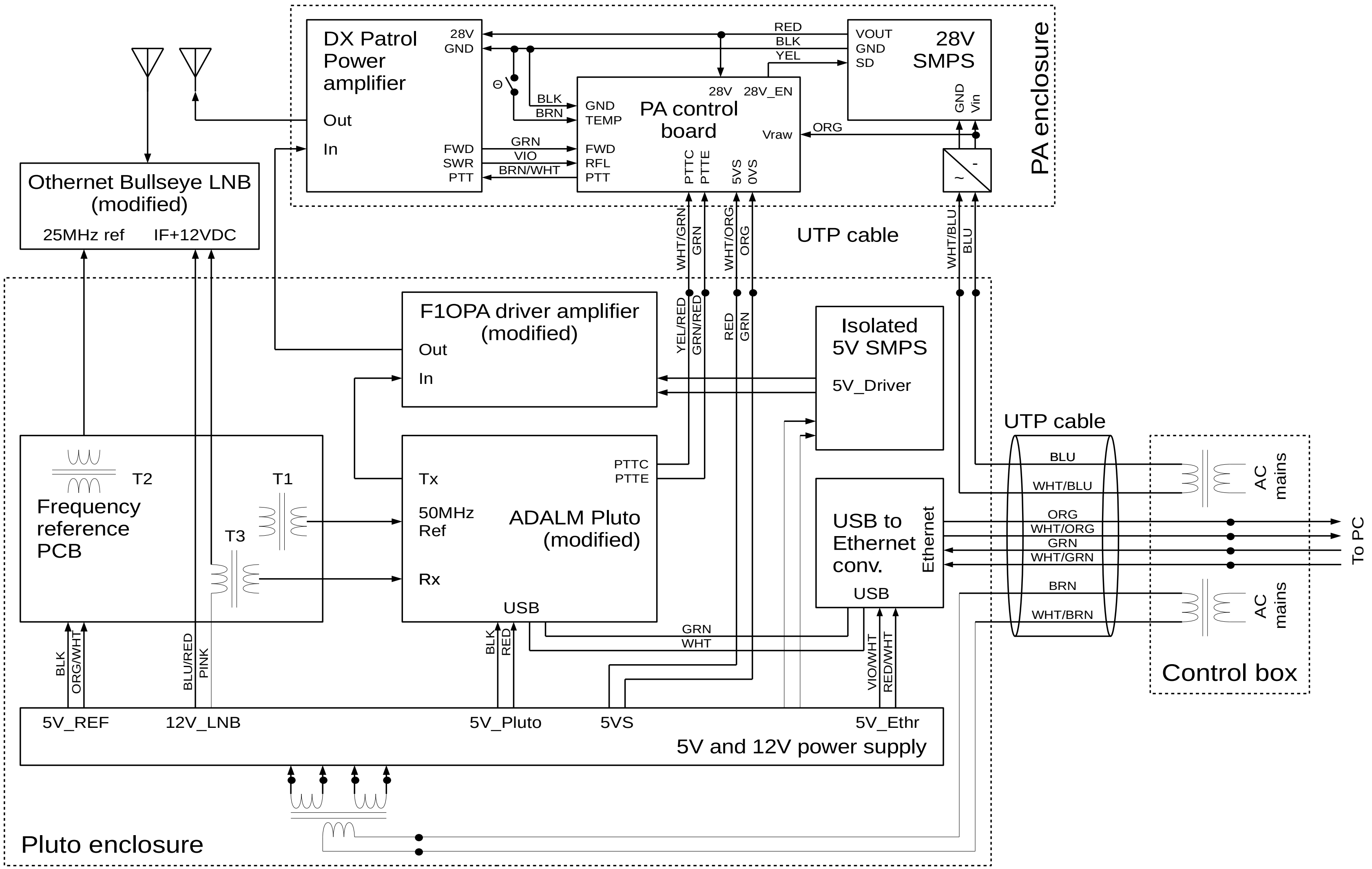

Figure 1: Block diagram and interconnections.

2.2 Project structure

2.2.1 Project tree

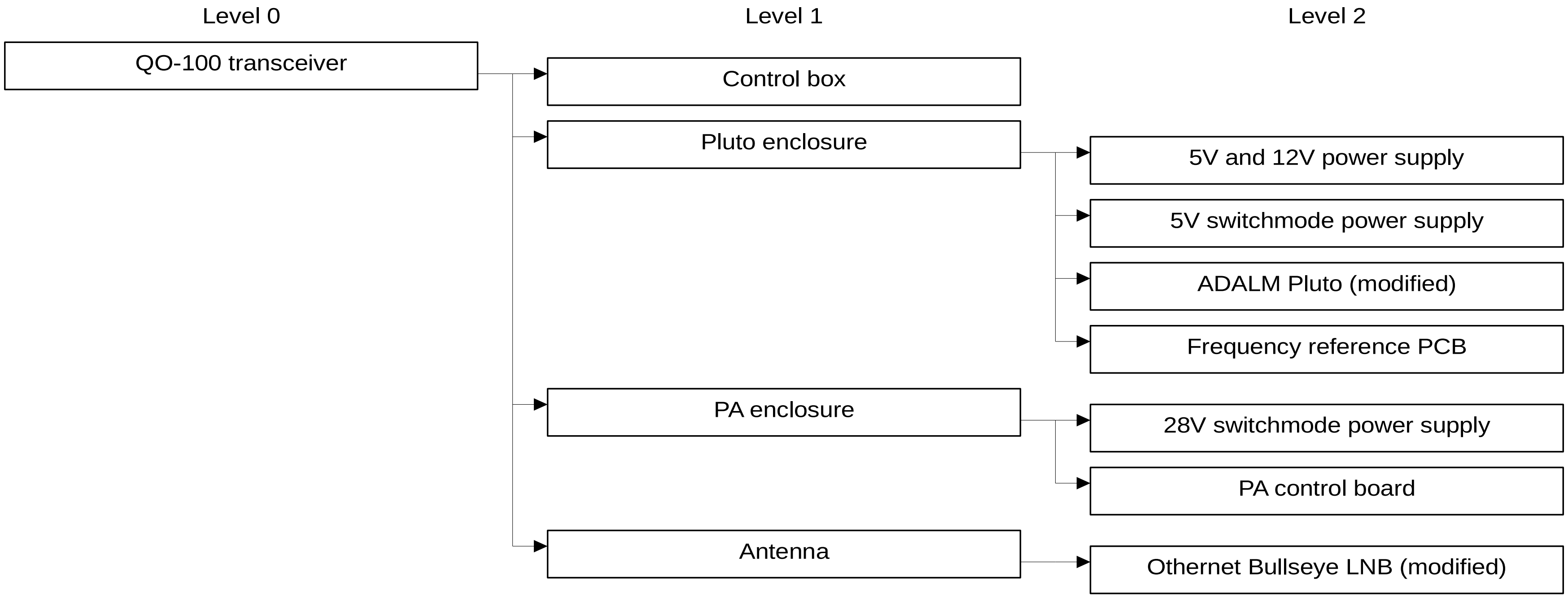

Figure 2: Major assembly tree showing project structure.
Items which are used as-purchased are not shown here, they are listed directly in the parts lists.

2.2.2 Parts list directory and general comments

The parts list is split into sections:

- one in section 2.3.2 on page 13 for the control box,
- one in section 2.4.2 on page 17 for the Pluto enclosure,

- one in section 2.5.2 on page 37 for the PA enclosure,
- one in section 2.6.1 on page 46 for the antenna and
- one in section 2.2.3 below which shows all parts not belonging to a specific major assembly.

The parts list can be found in PartslistVerC.ods.

Following ARRL's time-honoured tradition, the parts list description only shows component tolerances and ratings (voltage, power) when these are of some significance; otherwise, any reasonable component will do. If in doubt, check the part number given.

The total cost of the parts in the list comes to 1430€! Ouch. If anything, things are likely to be even more expensive nowadays because most items were purchased in year 2021 and many prices went up in 2022.

Furthermore, I would thoroughly recommend buying more of the small parts (especially SMD resistors, capacitors etc.) than listed, as they can get broken or lost during assembly. Buying spare fuses is also a good idea!

Note that "standard workshop items" such as solder, heatshrink sleeves, hookup wire are not included in the parts list. I just used what I had at hand. The Cat. 5E UTP cable is also not shown in the parts list, crucial though it may be for the operation of the project!

2.2.3 Parts list: Items not belonging to a specific major assembly

Vendor	Vendor P/N	Manufacturer	MPN	Description	Ref. designator	Price ea.	Qty.
Passion Radio	CABLE-COAXIAL-SMA-M-2M-3022			Cable, SMA male to SMA male low loss 2m long	Cable from DX Patrol power amplifier to POTY antenna	13,90 €	1
Mouser	530-415-0043-036	Cinch Connectivity Solutions	415-0043-036	Cable, SMA male to SMA male RG142 36" long (see text)	Cable from F1OPA driver amplifier to DX Patrol power amplifier	30,57 €	1
ACDC shop.gr	13118		FC-001/RG6	Connector, F type male straight twist-on for RG6	Connections from Pluto enclosure to LNB	0,34 €	4
Fanos.gr	522.ED10.000			PCB, perforated 0.1" spacing 100x160mm		4,00 €	1
Chang Da store (Aliexpress)		ZFHong		Machine screw, stainless steel M2.5x8, pack of 50		1,40 €	1
Chang Da store (Aliexpress)		ZFHong		Spring lock washer, stainless steel M2.5, pack of 100		1,44 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Ref. designator	Price ea.	Qty.
Chang Da store (Aliexpress)		ZFHong		Hexagon nut, stainless steel M2.5, pack of 50		1,98 €	1
Chang Da store (Aliexpress)				Machine screw, stainless steel M3x12, pack of 50		2,19 €	1
Chang Da store (Aliexpress)				Machine screw, Nylon M3x15, pack of 50		2,31 €	1
Chang Da store (Aliexpress)				Plain washer, stainless steel M3 pack of 100		1,01 €	1
Chang Da store (Aliexpress)		ZFHong		Spring lock washer, stainless steel M3, pack of 100		1,73 €	1
Chang Da store (Aliexpress)				Hexagon nut, stainless steel M3, pack of 50		1,85 €	1
Chang Da store (Aliexpress)				Spacer, ABS M3x5, pack of 50		0,97 €	1
Kafkas.gr	815130363	Central	01-60-467	Connector, plug RJ45 CAT5e	P1, P2	0,27 €	2

Notes:

- The Cinch 415-0043-036 (RG142) cable between the F1OPA driver amplifier (in the Pluto enclosure) and the DX Patrol power amplifier (in the PA enclosure) is a tremendous cable, but it is too long, too stiff and unnecessarily expensive. The much cheaper 2ft. long 415-0029-018 (RG316) would have done just as well, and would have been much easier to handle.

2.3 Control box

The control box is the "indoor unit". It just contains the two 220V to 48VAC transformers, power switches and some simple protection circuitry.

Two separate transformers provide 48VAC:

- T1 provides 48VAC to the PA enclosure via the BLU, WHT/BLU twisted pair of the UTP cable.
- T2 provides 48VAC to the Pluto enclosure via the BRN, WHT/BRN twisted pair.

The two Ethernet data pairs (GRN, WHT/GRN, ORG, WHT/ORG) are also physically routed through the control box, for the sake of connection simplicity; see figure 1.

2.3.1 Circuit diagram and layout

The schematic and component layout is shown in figures 3 and 4 below.

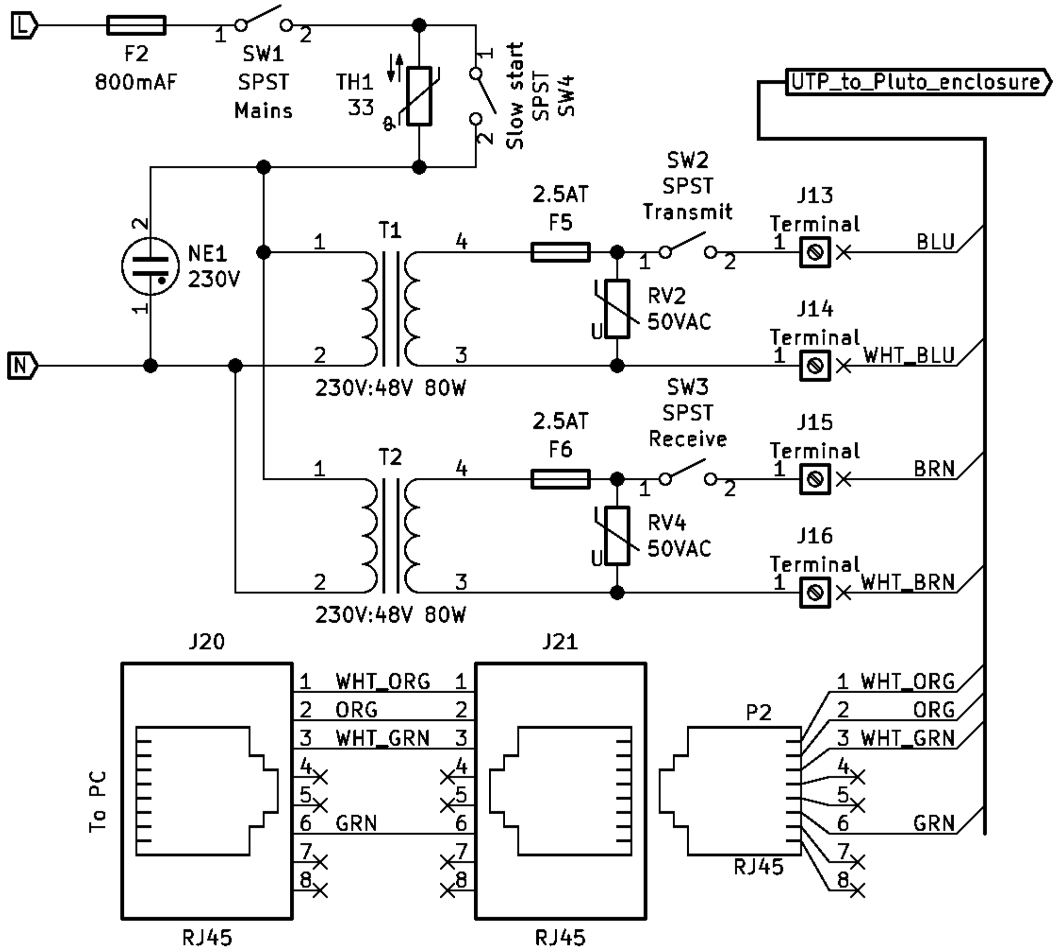

Figure 3: Schematic of the control box. This is version Q.

Note that NTC thermistor TH1 requires special handling; see https://product.tdk.com/system/files/dam/doc/product/protection/current/ntc-limiter/data_sheet/50/db/icl_16/s153.pdf for details.

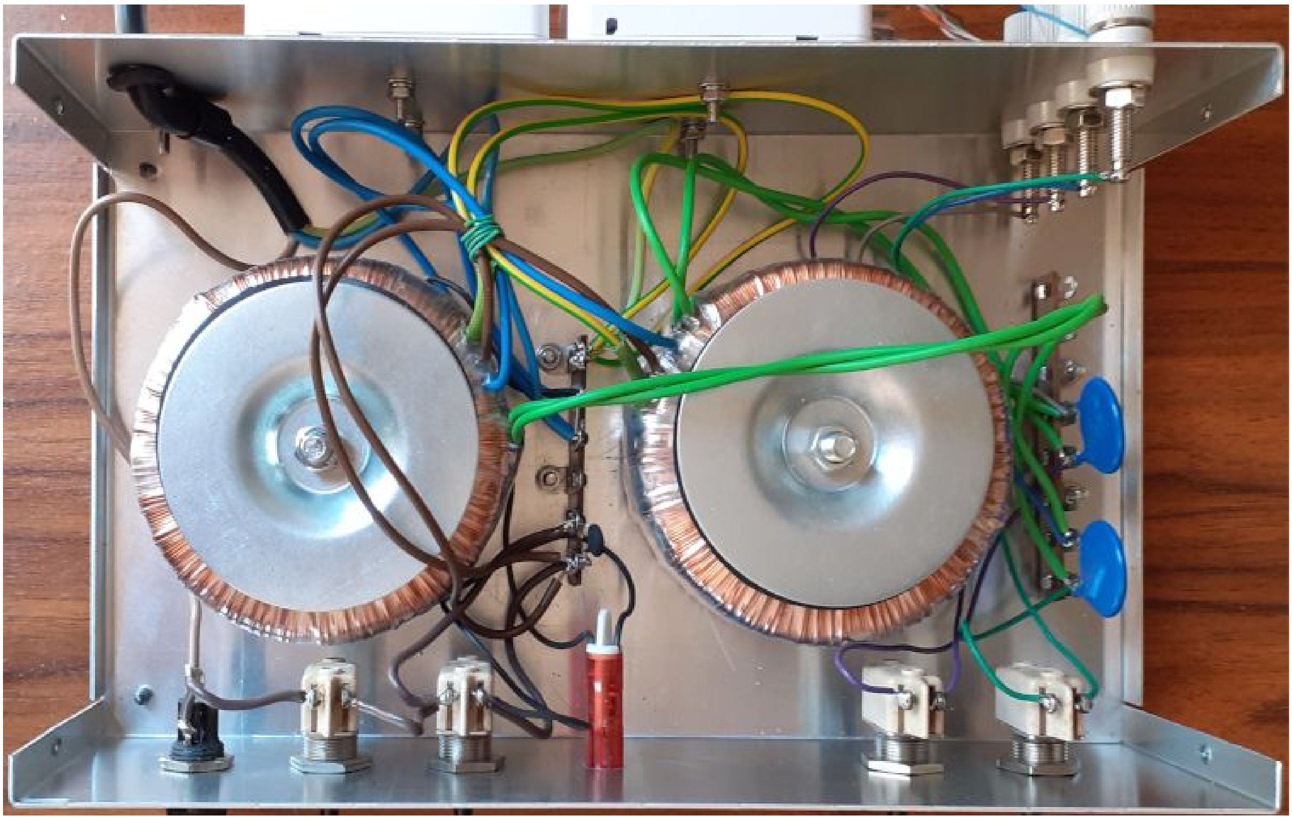

Figure 4: Layout of the control box. Wires have been left long (and messy) deliberately, so I can re-use the components should I decide to take this unit apart in future!
Note that this picture was taken before I installed F5 and F6.

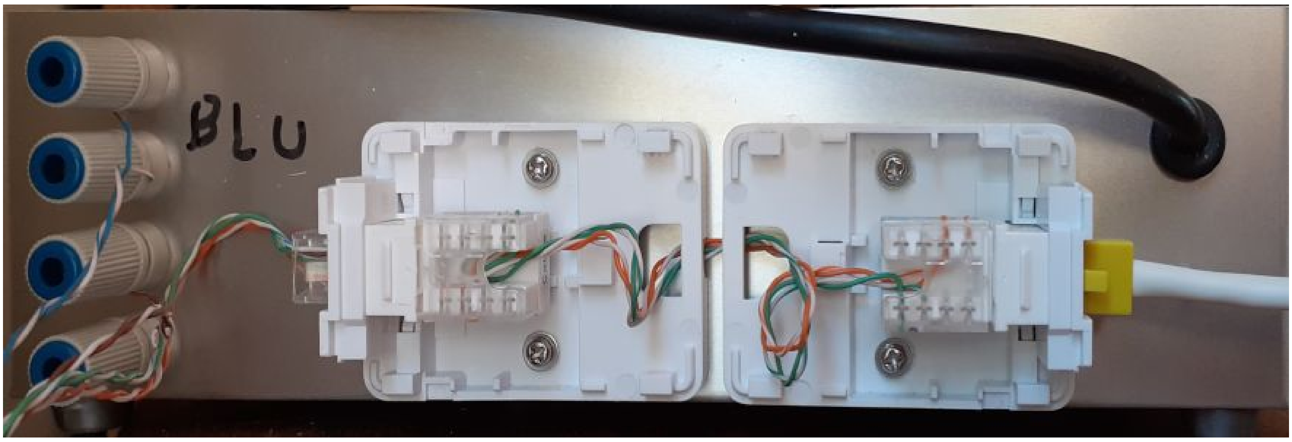

Figure 5: Control box rear showing how the UTP cable (left) from the Pluto enclosure is split into separate pairs. The terminal posts (top to bottom) are J13, J14, J15 and J16.
The white RJ-45 sockets are J21 and J20. P2 from the Pluto enclosure plugs into J21 on the left, while the UTP cable from the PC plugs into J20 on the right.

2.3.2 Parts list: Control box

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Fanos.gr	420.504.000	Norma box	D-504	Enclosure, Aluminium 250x160x70mm	Control box		Box	13,05 €	1
ACDC shop.gr	37087	Eska	520.616 ZKS-0.8A	Fuse, 800mAF 5x20mm	Control box		F2	0,13 €	1
Junkbox	530-5TT2.5-R	Bel Fuse	5TT 2.5-R	Fuse, 2.5AT 5x20mm	Control box		F5, F6	0,48 €	2
Junkbox	710-696211001102	Würth Elektronik	696211001102	Holder, fuse 5x20mm panel mount	Control box		F2, F5, F6	1,86 €	3
TLZWLA Official Store (Aliexpress)				Terminal, binding post	Control box		J13, J14, J15, J16	0,94 €	4
Kafkas.gr	815125216	Central	01-60-187/M	Connector, socket RJ45 CAT5e wall surface mount	Control box		J20, J21	4,40 €	2
Mouser	607-2151A1	VCC	2151A1	Indicator, Neon 230VAC	Control box		NE1	4,47 €	1
Mouser	871-B72220S0500K551	EPCOS / TDK	B72220S0500K551	Varistor, 50VAC THT	Control box		RV2, RV4	0,78 €	2
Mouser	690-7105B	Electroswitch	7105B	Switch, SPST 250VAC 3A panel mount	Control box		SW1, SW2, SW3, SW4	5,59 €	4
E-giatras.com	1803054800	E-giatras.com	1803054800	Transformer, toroidal 80VA, 230V pri., 48V sec., with internal screen	Control box		T1, T2	44,64 €	2
Mouser	871-B57153S0330M000	EPCOS / TDK	B57153S0330M000	Thermistor, NTC S 153/33 M THT	Control box		TH1	0,53 €	1

2.4 Pluto enclosure

The Pluto enclosure is a diecast box which contains the majority of the system's electronics. It is mounted near the antenna, and connects to the indoor control box via a single UTP cable.

2.4.1 Circuit diagram and layout

The block diagram is shown in figure 1 and circuit diagrams are in figures 12 and 14. The equipment layout is shown in figures 6a and 6b.

Note that to avoid ground loops (very important, due to the presence of a transformer in the box), the box itself was initially not connected electrically to any part of the circuit. A small amount of hum on the receive signal was detected, and this was finally eliminated by connecting the box to the shield of SK2. Different locations may work better with your set-up, grounds are mysterious things!

Printed circuit boards are supported using nylon screws and plastic spacers, to prevent electrical contact to the box.

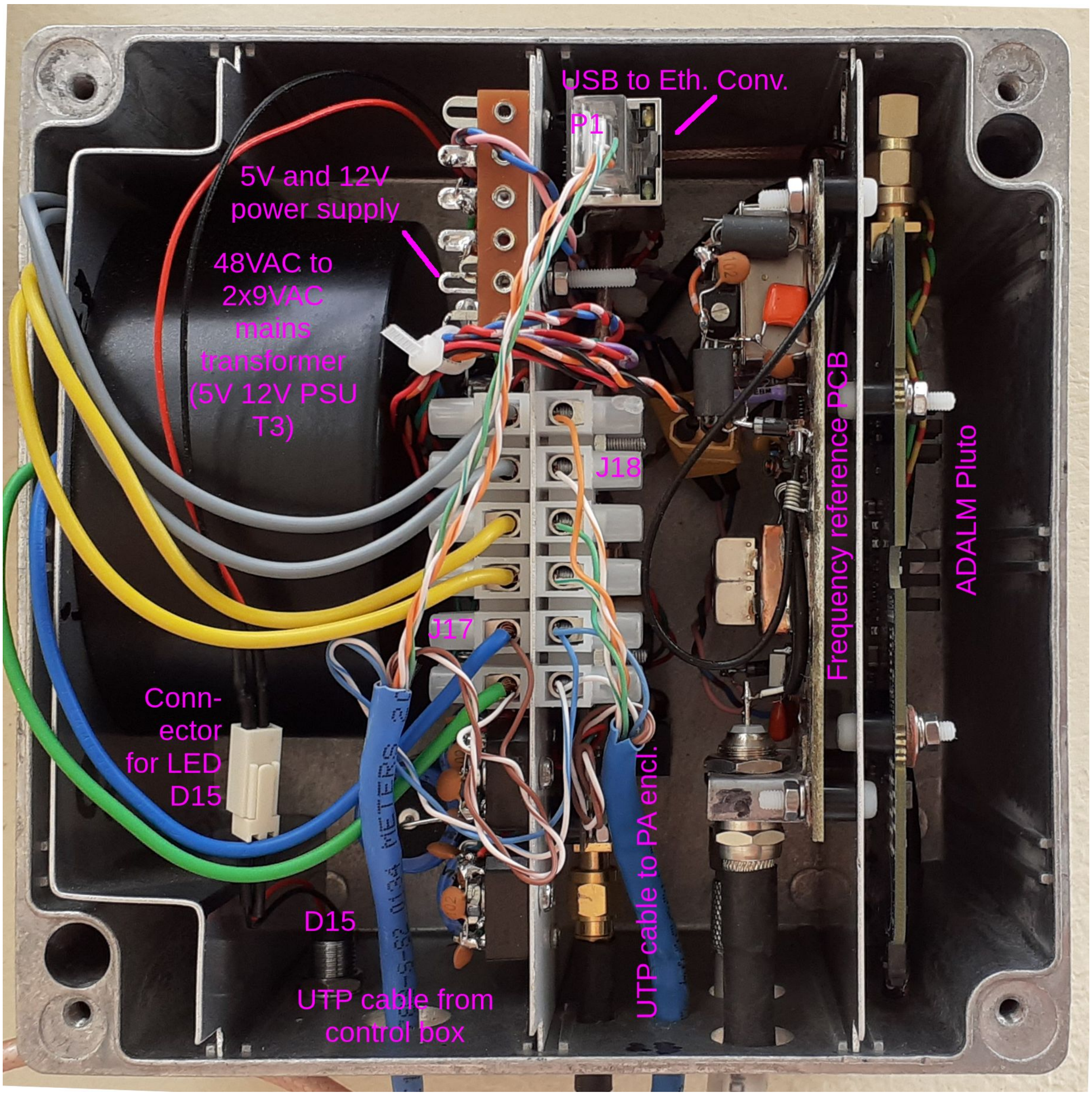

Figure 6a: Pluto enclosure. A small in-line connector has been used in the wire connected to LED D15; this is only shown here. This was a junkbox item, any connector will do.

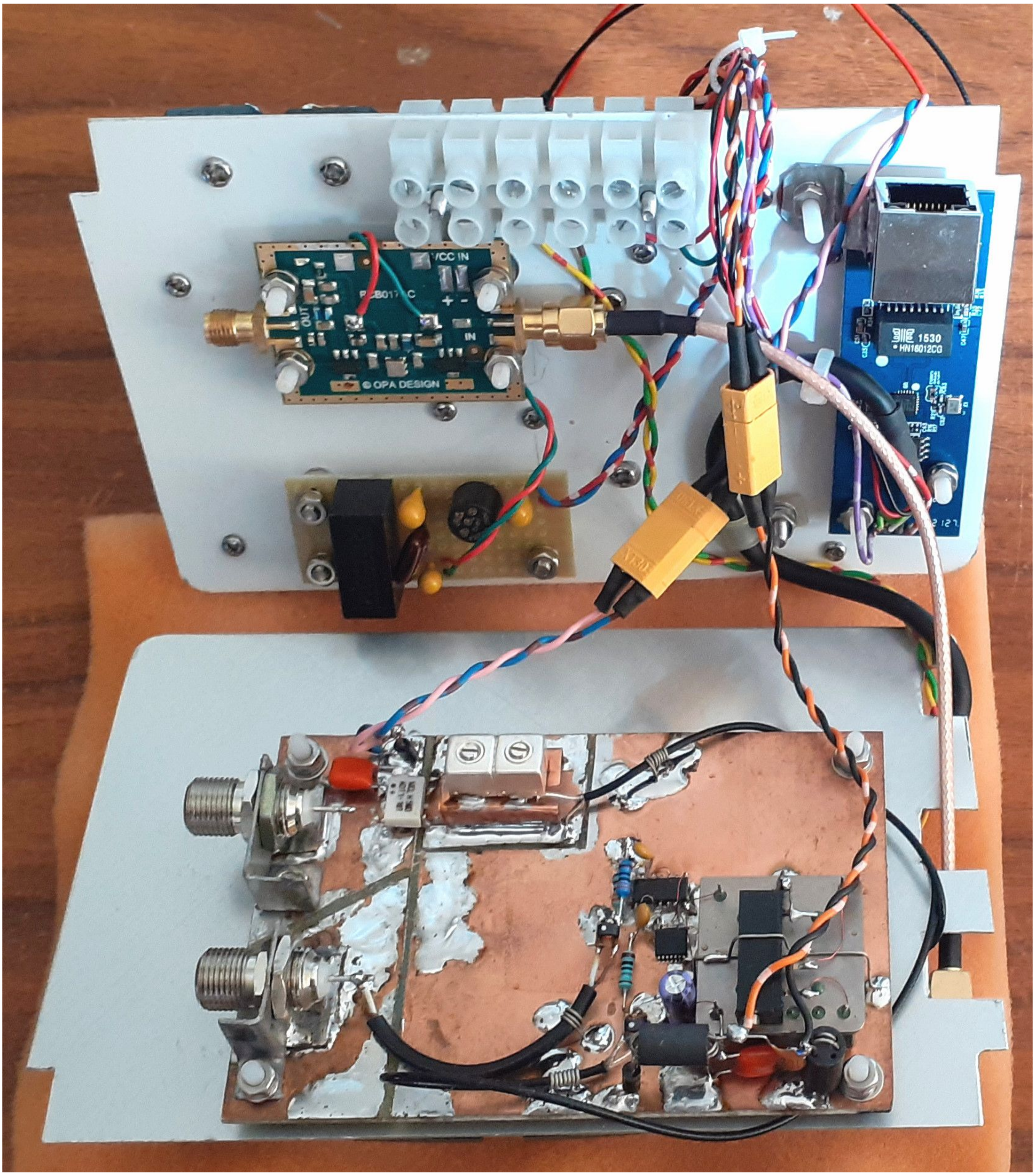

Figure 6b: Interconnections between the two subchassis of the Pluto enclosure.
Upper subchasis: USB to Ethernet converter, F1OPA driver amplifier, isolated 5V switchmode power supply.
Lower subchassis: Frequency reference PCB.
The 5V and 12V power supply is on the other side of the upper subchassis.
The ADALM Pluto is on the other side of the lower subchassis.

2.4.2 Parts list: Pluto enclosure

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Stathis.net	024399	Gainta	G139	Enclosure, Aluminium diecast IP65 158.5x158.5x101.5mm	Pluto enc.		Box	37,05 €	1
Mouser	584-ADALM-PLUTO	Analog Devices	ADALM PLUTO	ADALM Pluto (says it all)	Pluto enc.		ADALM Pluto	227,56 €	1
Good Luck RF connector store (Aliexpress)				Cable, 90° SMA male to SMA male RG316 15cm long	Pluto enc.		ADALM Pluto TX to F1OPA driver amplifier	2,24 €	1
Mouser	539-FL1M8CW-4-G12V	Mallory Sonalert	FL1M-8CW-4-G12V	Indicator, LED 12VDC green IP65	Pluto enc.		D15	2,53 €	1
ACDC shop.gr	29787	Ninigi	NS25-G2	Connector, 2-pin housing	Pluto enc.		D15	0,02 €	1
ACDC shop.gr	28849	Ninigi	NS25-T	Connector, contact	Pluto enc.		D15	0,02 €	2
ACDC shop.gr	29799	Ninigi	NS25-W2P	Connector, 2-pin male	Pluto enc.		D15	0,04 €	1
Passion Radio	QO100-F1OPA-AMPLI2400-938	OPA Design	OPA_PA20DBM_2G4	Amplifier, 100mW 2.4GHz	Pluto enc.		F1OPA driver amplifier	53,00 €	1
Grobotronics	39-00011823		XT30	Connector, male-female pair 2 contact polarized in-line	Pluto enc.		On 5V_REF/ 0V_REF and 12V_LNB/ 0V_LNB cables	1,60 €	2

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	144-22CC37B0187E	Essentra	22CC37B0187E	Cable accessory, P clip 4.8mm hold 3.5mm screw	Pluto enc.		Supports USB cable as it leaves the USB-to-Ethernet adapter	0,12 €	1
Public.gr	MRK1222174	Powertech	CAB-U035	Converter, USB3.0 το Gigabit Ethernet RTL8153 (see text)	Pluto enc.		USB-Eth adapter	13,31 €	1
Mouser	534-3121	Keystone	3121	Washer, fibre size 6 OD 9.5mm	Pluto enc.		USB-Eth adapter and ADALM Pluto support	0,10 €	2
Mouser	581-TAP226K010SCS	Kyocera AVX	TAP226K010SCS	Capacitor, 22μF 10V Tantalum THT	Pluto enc.	5V 12V PSU	C12, C16	0,70 €	2
Mouser	594-2222-021-15682	Vishay	MAL202115682E3	Capacitor, 6800μF 16V Aluminium electrolytic axial	Pluto enc.	5V 12V PSU	C13, C17, C25	5,36 €	3
Mouser	581-TAP106M035SCS	Kyocera AVX	TAP106M035SCS	Capacitor, 10μF 35V Tantalum THT	Pluto enc.	5V 12V PSU	C14, C18, C28	0,69 €	3
Mouser	594-2222-021-25222	Vishay	MAL202125222E3	Capacitor, 2200μF 16V Aluminium electrolytic axial	Pluto enc.	5V 12V PSU	C20, C24	4,04 €	2
Mouser	505-MKS2-1/63/10A	WIMA	MKS2-1/63/10A	Capacitor, 1μF 63V Polyester THT	Pluto enc.	5V 12V PSU	C27	0,62 €	1
Mouser	583-BR62	Rectron	BR62	Diode, bridge rectifier 200V 6A	Pluto enc.	5V 12V PSU	D2, D4	1,07 €	2
Junkbox	750-1N4001T-G	Comchip Technology	1N4001T-G	Diode, THT	Pluto enc.	5V 12V PSU	D5, D11, D12, D13	0,11 €	4
ACDC shop.gr	37225	Eska	520.610 ZKS-0.2A	Fuse, 200mAF 5x20mm	Pluto enc.	5V 12V PSU	F3	0,16 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	576-64700001003	Littelfuse	64700001003	Holder, fuse 5x20mm cable type	Pluto enc.	5V 12V PSU	F3	0,74 €	1
Mouser	571-1776293-6	TE Connectivity	1776293-6	Terminal block, barrier 8mm spacing 6 pole	Pluto enc.	5V 12V PSU	J17, J18	4,55 €	2
E-giatras.com	1702254809	E-giatras.com	1702254809	Transformer, toroidal 50VA, 48V pri., 9V 2.2A sec.#1, 9V 2.2A sec.#2, with magnetic shield	Pluto enc.	5V 12V PSU	T3	48,36 €	1
Mouser	584-LT1086IT-5#PBF	Analog Devices	LT1086IT-5#PBF	IC, voltage regulator LDO 5V 1.5A	Pluto enc.	5V 12V PSU	U3, U5	6,56 €	2
Mouser	595-UA7812CKCT	Texas Instruments	UA7812CKCT	IC, voltage regulator 12V 1.5A	Pluto enc.	5V 12V PSU	U8	0,74 €	1
ACDC shop.gr	13180		MICA-TO220	Pad, thermally conductive Mica TO220	Pluto enc.	5V 12V PSU	U3, U5, U8	0,02 €	3
ACDC shop.gr	13035		NIPPEL-TO220	Bush, shoulder, insulating TO220	Pluto enc.	5V 12V PSU	U3, U5, U8	0,04	3
ACDC shop.gr	19029	AG Termopasty	TERMOGLUE-10	Compound, thermally conductive 10g tube	Pluto enc.	5V 12V PSU	U3, U5, U8	4,43 €	0,5
Mouser	534-859TS	Keystone	859	Terminal, miniature tag strip 4 position + 2 ground	Pluto enc.	5V 12V PSU		2,23 €	7
TME	CCK-1N	SR Passives	CCK-1N	Capacitor, 1nF 100V Ceramic THT	Pluto enc.	5V 12V PSU	C30, C31, C32, C33, C34, C35, C36, C37	0,03 €	8
Mouser	581-TAP106M035SCS	Kyocera AVX	TAP106M035SCS	Capacitor, 10µF 35V Tantalum THT	Pluto enc.	5V SMPS	C19, C21	0,69 €	2
Mouser	581-TAP226K010SCS	Kyocera AVX	TAP226K010SCS	Capacitor, 22µF 10V Tantalum THT	Pluto enc.	5V SMPS	C26	0,70 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Junkbox				Capacitor, 330pF silvered mica THT (see text)	Pluto enc.	5V SMPS	C29		1
Mouser	530-MRF200	Bel Fuse	MRF 200	Fuse, 200mAF PCB mount THT	Pluto enc.	5V SMPS	F4	0,41 €	1
Mouser	919-RLS-567	Recom	RLS-567	Inductor, 5.6µH special SMD	Pluto enc.	5V SMPS	L2	0,87 €	1
Mouser	919-RS3-2405SZ/H2	Recom	RS3-2405SZ/H2	Converter, DC-DC isolated 9-27Vin 5Vout 3W	Pluto enc.	5V SMPS	U6	22,98 €	1
Mouser	530-142-0701-851	Cinch	142-0701-851	Connector, SMA female PCB edge mount	Pluto enc.	ADALM Pluto	TX1A	4,02 €	1
Mouser	490-HSB02-101007	CUI Devices	HSB02-101007	Heatsink, 10x10x7 mm	Pluto enc.	ADALM Pluto	Heatsinks on ADALM Pluto	0,66 €	2
Mouser	859-LTV-354T	Lite-On	LTV-354T	IC, optocoupler	Pluto enc.	ADALM Pluto	U7	0,49 €	1
Hardware shop		Henkel		Adhesive, 2-part epoxy 5-minute curing 12g pack	Pluto enc.	ADALM Pluto	Heatsinks on ADALM Pluto, wires from U7	3,80 €	1
Mouser	667-ERJ-3EKF51R0V	Panasonic	ERJ-3EKF51R0V	Resistor, 51Ω 0603	Pluto enc.	ADALM Pluto	R2	0,09 €	1
Mouser	530-1280711201	Cinch	128-0711-201	Connector, UMC female SMD	Pluto enc.	ADALM Pluto	SK1, RX1A	0,59 €	2
Mouser	581-08055C223KAT4A	Kyocera AVX	08055C223KAT4A	Capacitor 22nF X7R 0805	Pluto enc.	Freq. ref.	C1, C2	0,14 €	2
Mouser	594-K472K15X7RH53L2	Vishay	K472K15X7RH53L2	Capacitor, 4.7nF X7R THT	Pluto enc.	Freq. ref.	C3, C6	0,22 €	2
Junkbox	505-MKS2.1/63/5	Vishay / BC Components	MKS2-.1/63/5	Capacitor, 100nF Polyester THT	Pluto enc.	Freq. ref.	C5, C13	0,51 €	2

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
TME	CCK-1N	SR Passives	CCK-1N	Capacitor, 1nF 100V Ceramic THT	Pluto enc.	Freq. ref.	C7, C8	0,03 €	2
Mouser	581-06031A101K	Kyocera AVX	06031A101KAT2A	Capacitor, 100pF C0G 0603 (see text)	Pluto enc.	Freq. ref.	C9	0,10 €	1
Mouser	232-10ML47MEFC5X5	Rubycon	10ML47MEFC5X5	Capacitor, 47µF 10V Aluminum electrolytic THT (see text)	Pluto enc.	Freq. ref.	C21	0,29 €	1
Junkbox	750-1N4001T-G	Comchip Technology	1N4001T-G	Diode, THT	Pluto enc.	Freq. ref.	D1, D2	0,11 €	2
TEMWell	TDS2143D-740M	TEMWell	TDS2143D-740M	Filter, 2 element helical, CF 740MHz BW 17MHz	Pluto enc.	Freq. ref.	FL1	12,96 €	1
Junkbox			VK-200	Inductor, RF choke Ferrite	Pluto enc.	Freq. ref.	L1, L2		2
Mouser	530-415-0108-250	Cinch	415-0108-250	Cable, 90° UMC male to bare end 25cm long	Pluto enc.	Freq. ref.	P1, P2	2,82 €	2
Mouser	594-5043ED180R0F	Vishay	SFR2500001800FR500	Resistor 180Ω THT	Pluto enc.	Freq. ref.	R1	0,11 €	1
Mouser	667-ERJ-P06F43R0V	Panasonic	ERJ-P06F43R0V	Resistor, 43Ω 0805	Pluto enc.	Freq. ref.	R4	0,16 €	1
Mouser	667-ERJ-6ENF82R0V	Panasonic	ERJ-6ENF82R0V	Resistor, 82Ω 0805	Pluto enc.	Freq. ref.	R5	0,10 €	1
Junkbox	594-5043ED330R0F	Vishay	SFR2500003300FR500	Resistor, 330Ω THT	Pluto enc.	Freq. ref.	R6	0,20 €	1
Junkbox	594-5043ED3K300F	Vishay	SFR2500003301FR500	Resistor, 3.3KΩ THT	Pluto enc.	Freq. ref.	R8	0,20 €	1
Mouser	71-1280G-10K-K	Vishay Precision Group	Y005610K0000K0L	Potentiometer, trimmer multiturn 10KΩ 15PPM/°C THT	Pluto enc.	Freq. ref.	RV1	20,74 €	1
Mouser	523-222144	Amphenol	222144	Connector, F type female straight chassis mount	Pluto enc.	Freq. ref.	SK2, SK5	1,71 €	2

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	139-TC4-6T	Mini-Circuits	TC4-6T+	Transformer, pri. 50Ω sec. 200ΩCT 1.5 to 600MHz SMD	Pluto enc.	Freq. ref.	T1, T2	2,65 €	2
Mouser	139-ADT1-1WT	Mini-Circuits	ADT1-1WT+	Transformer, pri. 75Ω sec. 75ΩCT 0.4 to 800MHz SMD (see text)	Pluto enc.	Freq. ref.	T3	6,06 €	1
Mouser	595-SN74AC04DR	Texas Instruments	SN74AC04DR	IC, hex inverter	Pluto enc.	Freq. ref.	U1	0,43 €	1
Mouser	757-74VHC393FT	Toshiba	74VHC393FT	IC, dual counter	Pluto enc.	Freq. ref.	U2	0,36 €	1
Mouser	815-AOCJY3A-100M-F	ABRACON	AOCJY3A-100.000MHz-F	IC, VCOCXO 100.0000MHz CMOS output	Pluto enc.	Freq. ref.	U3	122,69 €	1

Notes:

- The USB to Ethernet converter is a Powertech CAB-U035. The first one I bought was a genuine RTL8153-based USB3.0 to Gigabit Ethernet converter. I did managed to ruin it while rewiring, so I bought a second one from the same vendor. This came in the same package, in fact in the exact same box. However, it is a sort-of fake: It is a USB2.0 to 100Mbps Ethernet converter based on an RTL8152! It is adequate for the purpose, none-the-less. Still, I do feel cheated...
- C29 on the isolated 5V switchmode power supply is shown as a silvered mica. Any half-decent ceramic should also do though.
- C9 on the frequency reference PCB is an 0603-sized 100pF. The manufacturer's datasheet[1] shows that this is self-resonant at about 400MHz. The frequency it is decoupling is 740MHz, so a higher self-resonant frequency would probably be much better. A 47pF or even a 33pF capacitor might be a better choice here.
- C21 on the frequency reference PCB is actually an old 22µF I had in my junkbox. I've bought the new one, I will replace it one day...
- T3 on the frequency reference PCB is a Mini Circuits ADT1-1WT+. This is the only decent true (i.e. separate primary, secondary) transformer I could find which works well at 740MHz. DC power to the LNB is supplied through the secondary of T3, and the LNB and the LNB draws up to 120mA nominal, 200mA on a bad day[2]. However, the ADT1-1WT+ is rated 30mA max. I do not know why this rating is so low; the ADT1-1WT+ is wound with relatively thick wire which is certainly capable of handling more than 30mA. I also very much doubt core saturation is a problem. It has been working fine for a year now, I hope it will survive!

1 https://eu.mouser.com/datasheet/2/40/C0GNP0_Dielectric-951274.pdf.
2 See sections 4.3.2 and 2.6.2.3 (warning).

2.4.3 ADALM Pluto

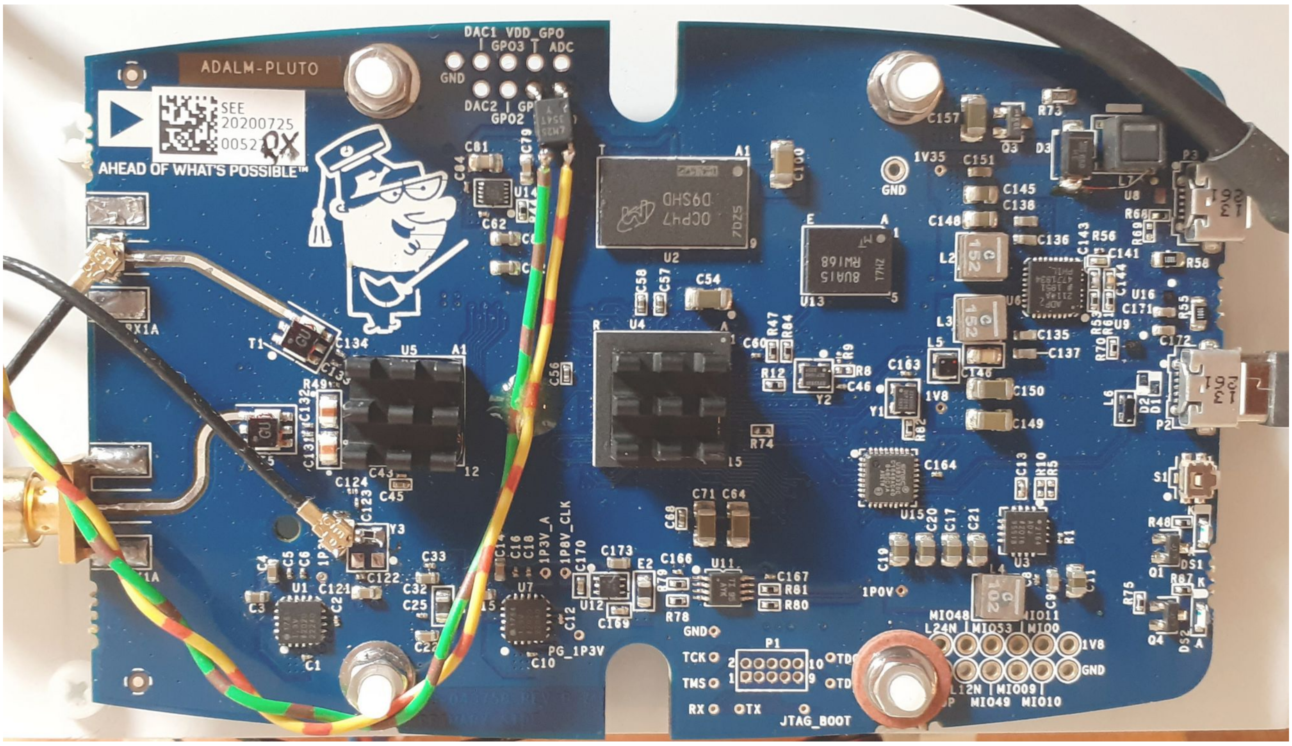

Figure 7: Rev. B ADALM Pluto showing modifications made.
Note the use of a fibre washer under one of the supporting nuts.

2.4.3.1 Small heatsinks

It seems to be a generally known fact that the main ICs of the ADALM Pluto need heatsinking. Whether this is true I do not know but, just to be on the safe side, I stuck a couple of small heatsinks on the main ICs (see figure 7). These were stuck on with the thinnest possible layer of standard two-part epoxy. Not ideal, I know, but the case of the ICs is epoxy anyway, so a thin extra layer shouldn't affect things much.

2.4.3.2 50MHz external clock

The modification proposed by Analog Devices[3] was made. The original crystal oscillator was removed by baking it atop with one soldering iron, while going around the pads with a second soldering iron. An UMC connector was fitted in its place (SK1 in figure 12), see figure 8. Also, a 51Ω terminating resistor (R2 in figure 12) was connected between pads 2 (GND) and 3 (signal) where the original OCXO went, to terminate the transmission line carrying the 50MHz external clock.

Some settings needed to be changed on the ADALM Pluto; see section 3.4.2.

3 https://ez.analog.com/adieducation/university-program/f/q-a/77922/will-it-be-possible-to-feed-in-a-reference-clock-to-the-adalm-pluto

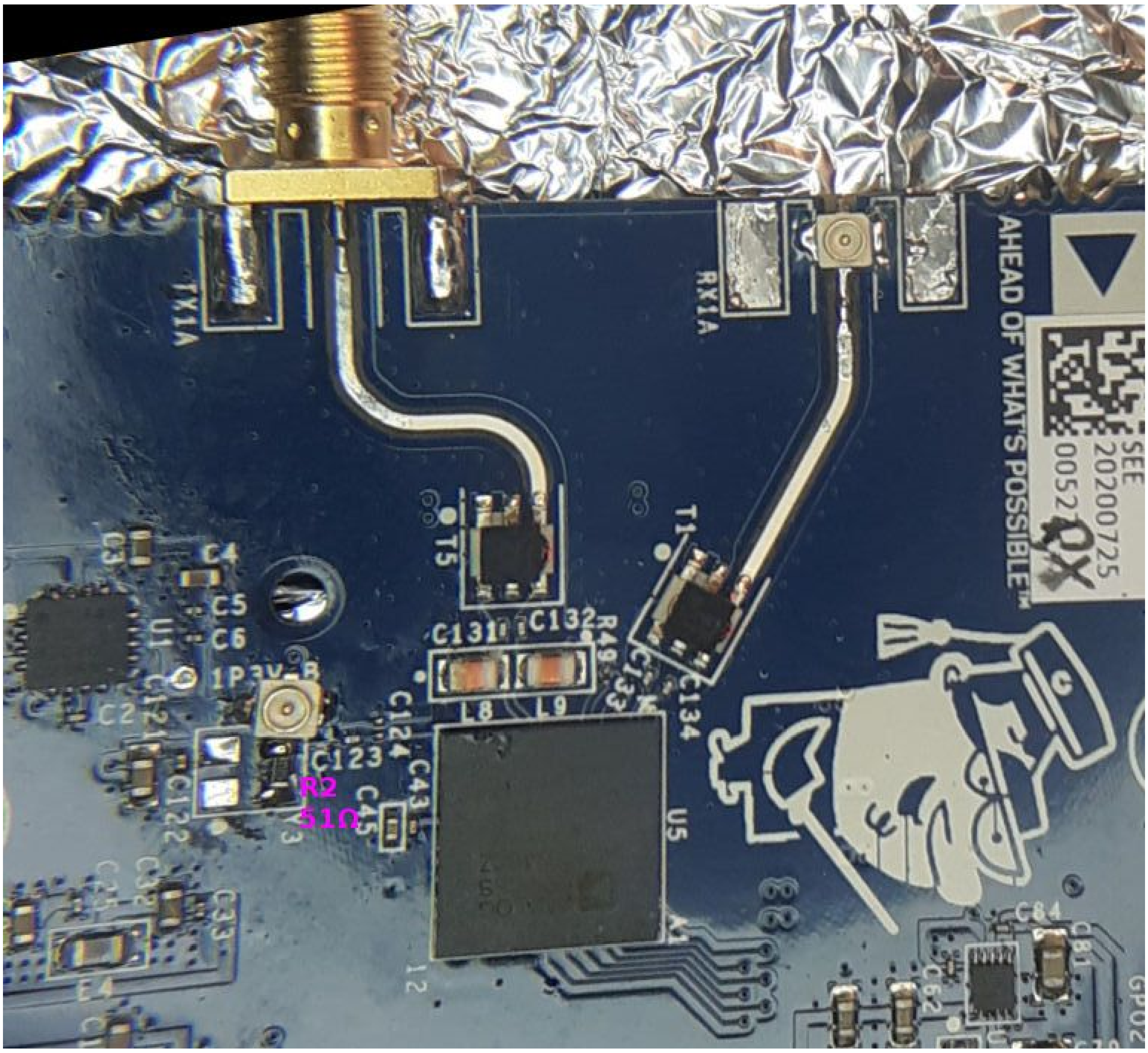

Figure 8: UMC RX1A and clock connectors and shorter SMA TX1A receptacle fitted on ADALM Pluto. The 51Ω clock terminator is shown to the left of C123, below the UMC connector.

2.4.3.3 RF receptacle modification

The two SMA RF receptacles of the ADALM Pluto were replaced, because they protruded too far to comfortably fit in the box. The transmit receptacle TX1A was replaced by a shorter SMA receptacle (Cinch 142-0701-851) while the receive receptacle RX1A was replaced with an SMD UMC connector (Cinch 128-0711-201). The arrangement is shown in figure 8.

2.4.3.4 Earth connection modification

DK1ML shows[4] that a "GND modification" is required "so that Pluto doesn't crash anymore if you power any device nearby". I did actually find this to be necessary; the modification is shown in figure 9.

4 https://forum.amsat-dl.org/index.php?thread/3372-pluto-mods-just-1-part-ptt-dc-mod-gpsdo-mod-ethernet-connect/.

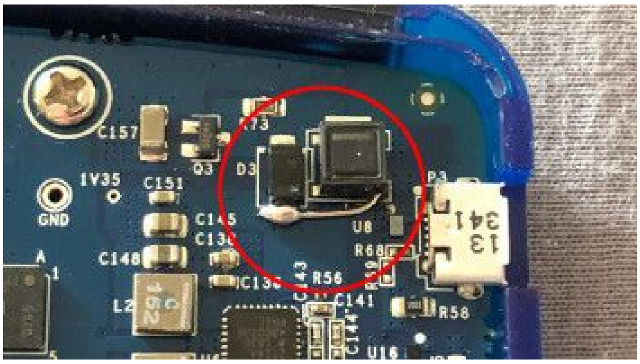

Figure 9: ADALM Pluto GND modification, from DK1ML's webpage[4].

Figure 10: ADALM Pluto PTT modification. A drop of epoxy glue has been used to support the optocoupler wires below ADALM Pluto's U5.

2.4.3.5 PTT modification

DK1ML[4] has come up with a nice modification showing how an optocoupler can be used to provide PTT. The idea has been stolen unashamedly. The optocoupler U7, an LTV-354T, is connected as shown in figures 10 and 14. I added a blob of two-part epoxy to the board, to keep the wires in place (see figure 10).

2.4.3.6 Known problem: ADALM Pluto will sometimes not start

The ADALM Pluto will, on rare occasions, refuse to start. It can be fine for weeks and one day it will just stubbornly refuse to - there has been an occasion when I had to turn power off and back on again eight times ro get it to start! I have not really found the reason for this, but my guess is it has to do with the slow risetime of the 5V_Pluto supply; see section 7.1 for a potential solution.

2.4.4 Frequency reference PCB

The frequency reference PCB provides the following:

- A stable 50MHz reference for the ADALM Pluto.
- A stable 25MHz reference for the Othernet Bullseye LNB.
- Duplexer functions for providing phantom power to the LNB.

The schematic and component layout is shown in figures 12 and 13 below. The layout is actually pretty terrible, as it started off as something very different (see figure 56).

The precise frequency of the OCXO is set by trimmer potentiometer RV1. A frequency counter is not needed for this; I adjusted this by bringing the QO-100 satellite PSK beacon (the middle one with the double hump) right-on frequency (10489.750MHz) on the receive waterfall. Ultrafine tuning may then be affected via the "LNB Offset" software setting (see figure 28).

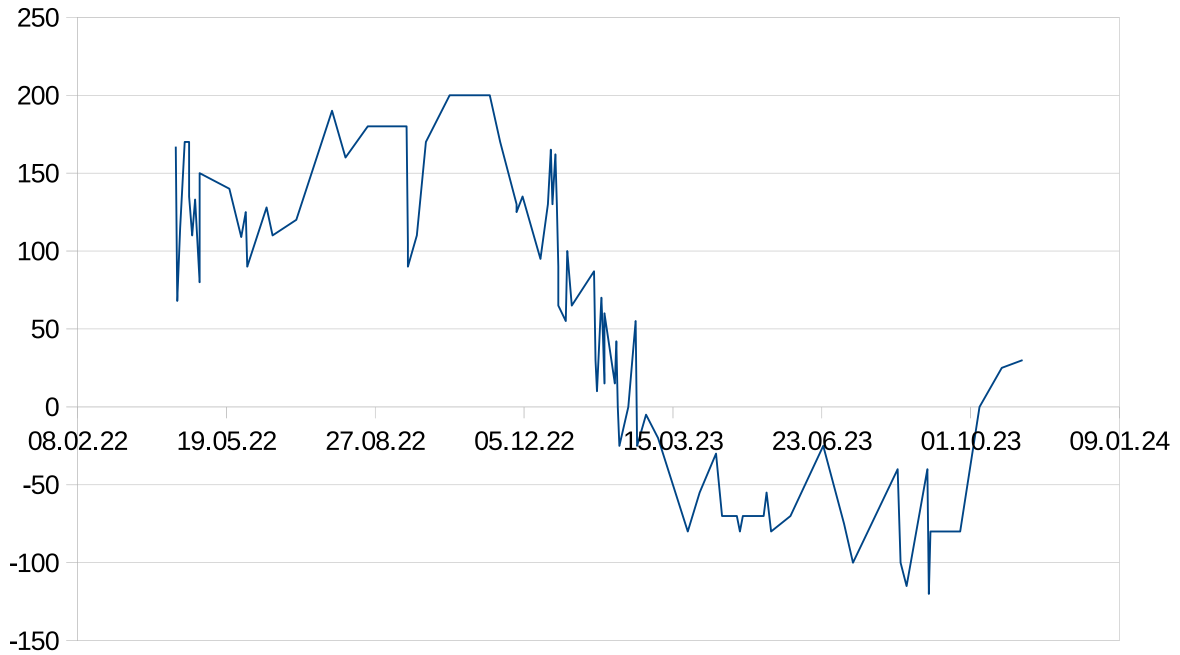

Figure 11: LNB Offset setting, in Hz, needed to bring the transmit and receive CW tone to the same frequency. How much of this is OCXO drift and how much is due to other phenomena, I do not know...

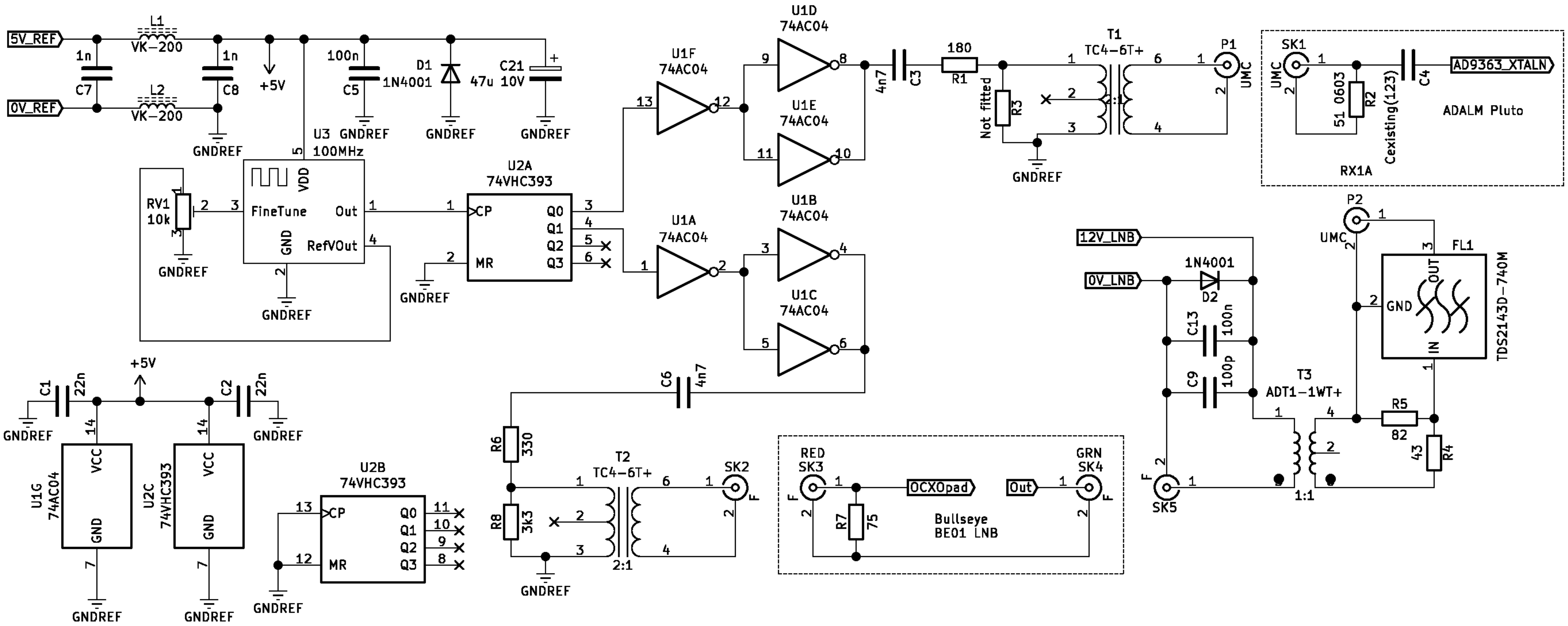

Figure 12: Schematic of the frequency reference PCB. This is version G. See figure 1 for overall interconnections.

Figure 13: Layout of the frequency reference PCB.

2.4.5 5V and 12V power supply

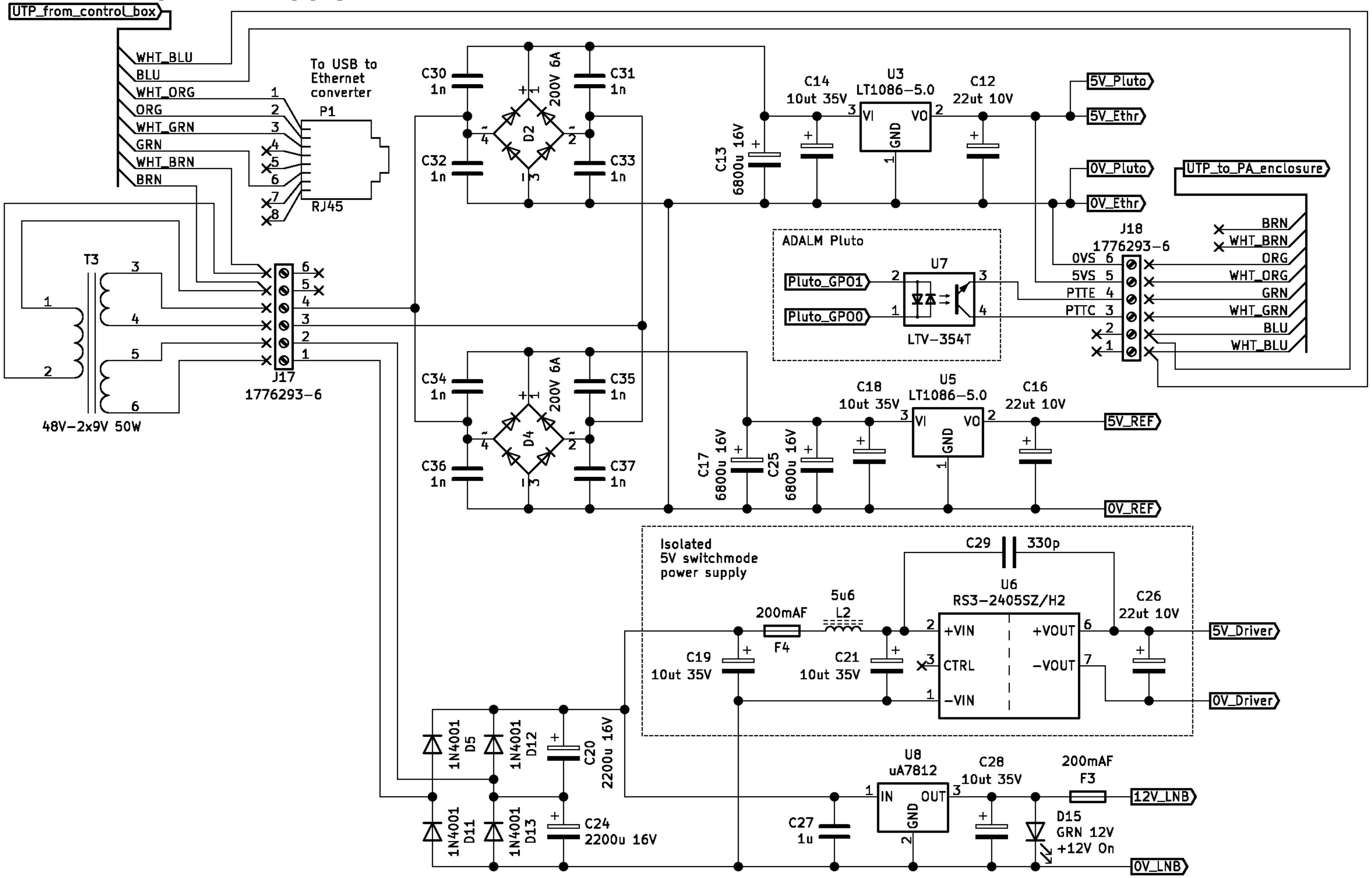

Figure 14: Schematic of the 5V and 12V power supply and the isolated 5V switchmode power supply. This is version Q.

A custom-made transformer, T3, transforms the 48VAC from the control box to 9&9VAC for the Pluto enclosure electronics. One 9V winding powers the 5V electronics while the other is used with a voltage doubler to power the 12V electronics.

This power supply is mostly built on tag strips on the back of the aluminium sheet carrying the F1OPA driver amplifier. M2.5 hardware has been used for supporting the tag strips and screw terminals, and M3 hardware for everything else. Layout is rather tricky, as one has to make sure the screws for items on one side of the aluminium sheet are accessible on the other side of the aluminium sheet! An exception to this are the three holes for the screws supporting the 5V switchmode PSU (see figure 16b); the screwheads are under the main electrolytics C17, C25 and are inaccessible. So, before fitting the electrolytics, I put in the screws for the 5V switchmode PSU and tightened (really hard!) a nut on the back, so they act as permanent studs upon which the 5V switchmode PSU is mounted. Note that these three screws are stainless steel, not plastic; the 5V switchmode PSU board is a perforated board which insulates the screwholes anyway.

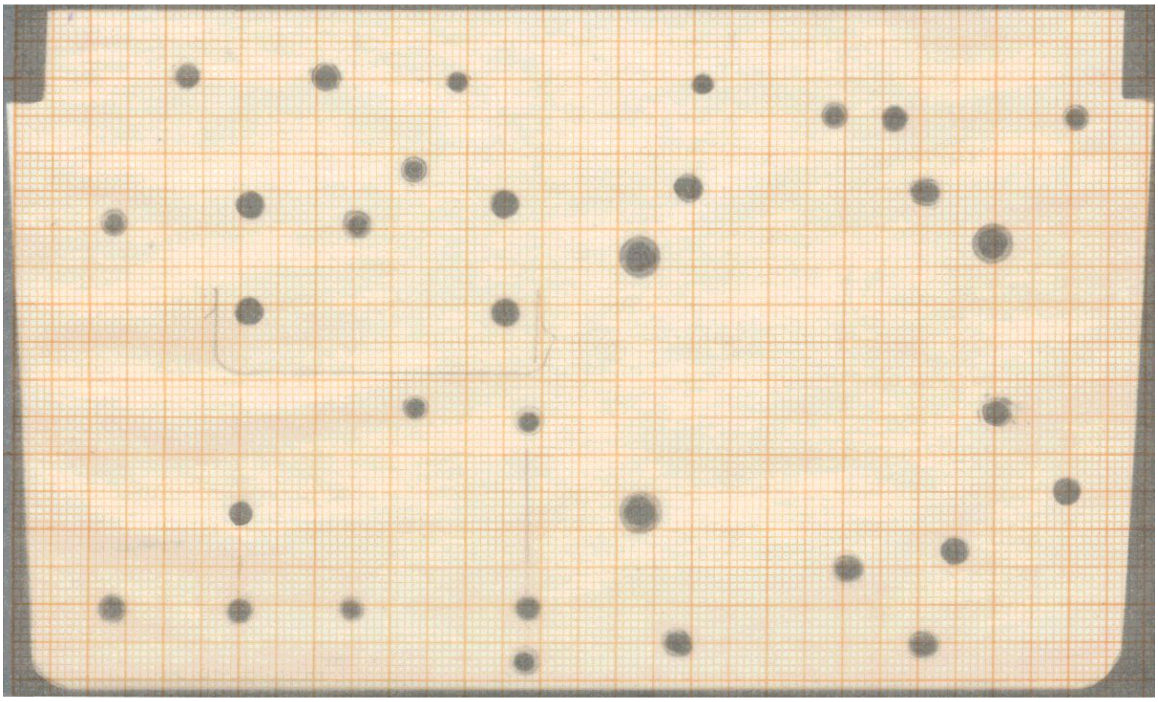

Figure 15: Cut-out and drilling pattern for the aluminium plate which forms the chassis supporting the F1OPA driver amplifier, USB to Ethernet converter and 5V and 12V power supply.

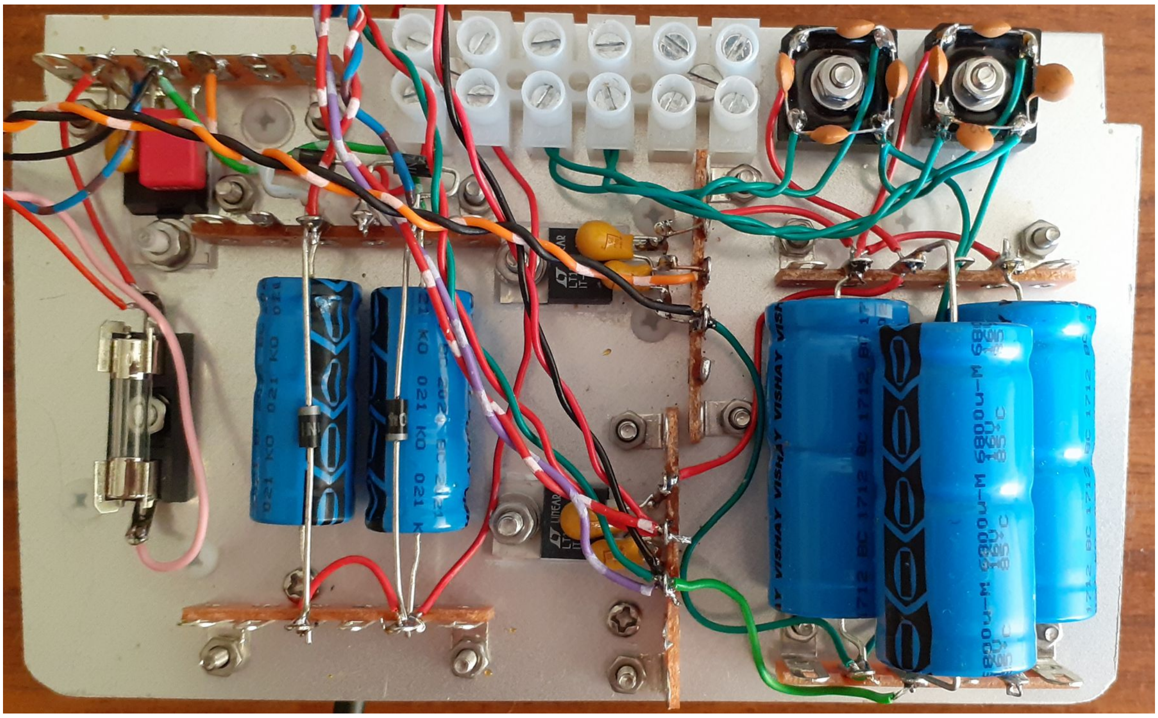

Figure 16a: Layout of the 5V and 12V power supply rectifiers and voltage regulators. Note the single connection between bridge D2 and D4 negatives (green wire, top right). This is the sole connection between 0V_Pluto and 0V_REF. Note that the location of the fuseholder for F3 (bottom left) is completely silly; I should have chosen a more accessible location for it!

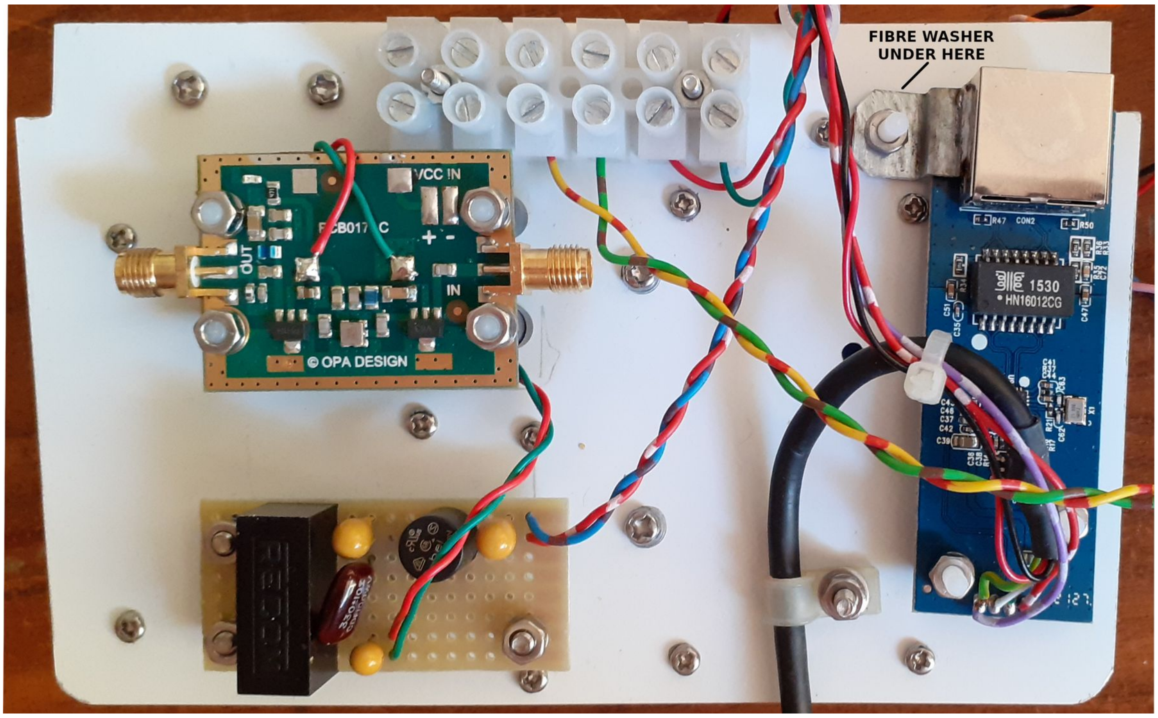

Figure 16b: Layout showing the isolated 5V switchmode power supply for the F1OPA driver amplifier (bottom left). The F1OPA driver amplifier and USB to Ethernet converter are also shown. Note: A fibre washer insulates the USB to Ethernet converter bracket from the chassis.

2.4.6 F1OPA driver amplifier

The ADALM Pluto can, by most accounts, provide about +2 to +5dBm out maximum.

The F1OPA amplifier is a great little gain stage which can give +20dBm output, has 30dB gain and has a bandpass filter for 2.4GHz. The gain is a bit too high but I can probably live with this; I might fit an attenuator on its input one day. Its output, +20dBm (100mW), is great for driving the DX-Patrol 12W power amplifier.

The F1OPA amplifier, as delivered, carries a small non-isolated DC-DC converter which takes 8 to 14VDC at about 1.2W, and provides 5V to the circuit. With the POTY transmitting antenna used initially, because the POTY antenna ground is electrically connected to the LNB ground, a ground loop would form (see figure 46). In order to break this ground loop, I removed this non-isolated DC-DC converter and replaced it with an off-board isolated DC-DC converter (the "isolated 5V switchmode power supply", see figures 14 and 16b). Note that removing the original DC-DC converter was not easy; it has four big pads. I got four soldering irons and a dearest acquaintance to help me, heated all four pads simultaneously and slid the original DC-DC converter off. With the Ice Cone v2.1 transmitting antenna this should no longer be necessary; the the unmodified F1OPA amplifier could be supplied directly from the 12V regulator U8 (see figure 14, deleting C19, F4, L2, C21, C29, U6 and C26).

2.4.7 USB to Ethernet converter

Since the ADALM Pluto was going to be installed outdoors, communication with it had to be over Ethernet. To connect the ADALM Pluto via Ethernet, I initially bought an RTL8153-based USB3.0 to Gigabit Ethernet converter. It worked fine but I managed to ruin it, so I replaced it with a USB2.0 to 100Mbps Ethernet converter based on a RTL8152, which works fine too.

I connected the converter's USB cable directly to the ADALM Pluto, and its Ethernet connection to the PC in the shack via the control box:

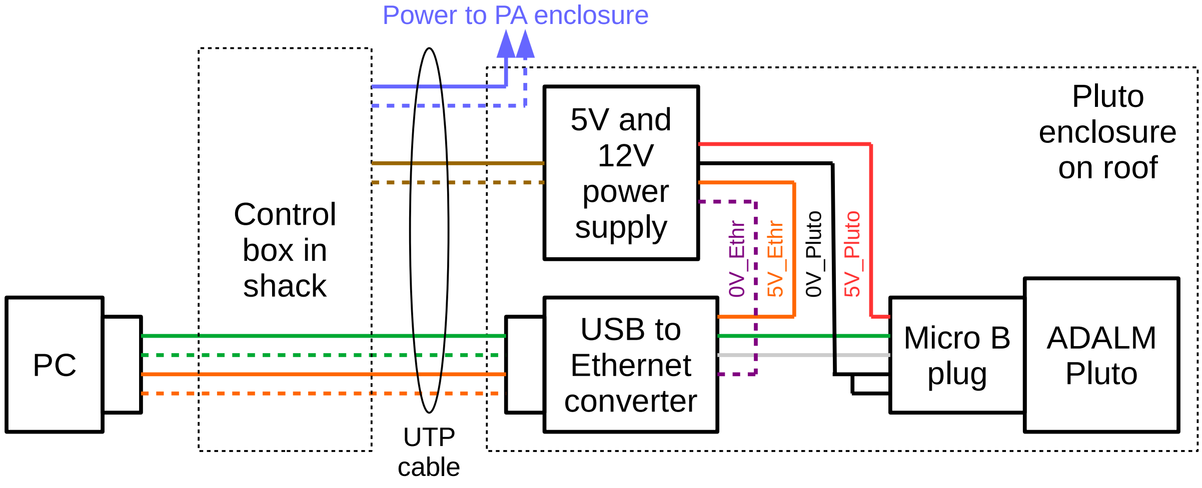

Figure 17: Direct connection of the USB to Ethernet converter to the ADALM Pluto. See figure 34 (left) for Micro B plug wiring. See figure 1 for overall interconnections.

2.4.8 Interconnections to the control box and PA enclosure

As shown in figure 1 and figures 3, 14 and 19, the Pluto enclosure connects to the control box for power and Ethernet through a single Cat 5 UTP cable. It also connects to the PA enclosure through a second Cat 5 UTP cable. An RJ45 plug and a pair of 6-way terminal posts (J17, J18) facilitate this connection:

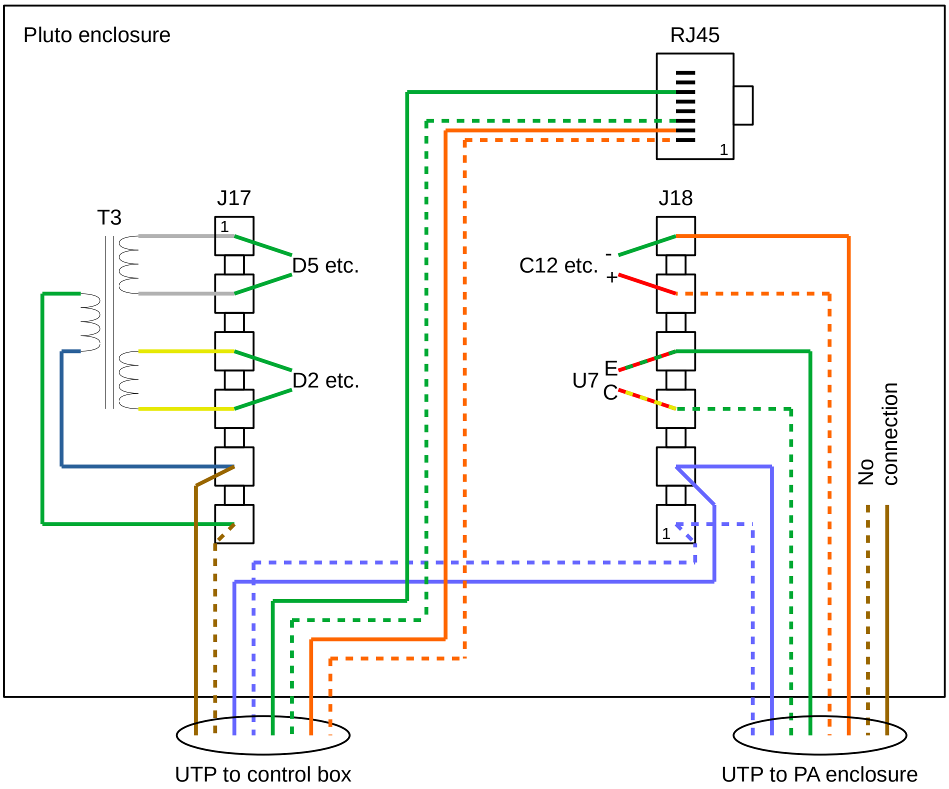

Figure 18: Interconnections from the Pluto enclosure to the control box and PA enclosure. See figure 6a for the location of terminal posts J17 and J18 and the RJ45 plug.

2.5 PA enclosure

The "PA enclosure" is a second diecast aluminium box which carries the DX Patrol power amplifier, the PA control board and the 28V switchmode power supply. This is driven by the F1OPA driver amplifier of the Pluto enclosure, and receives its control signals and power over six wires in a UTP cable from the Pluto enclosure.

2.5.1 Circuit diagram and layout

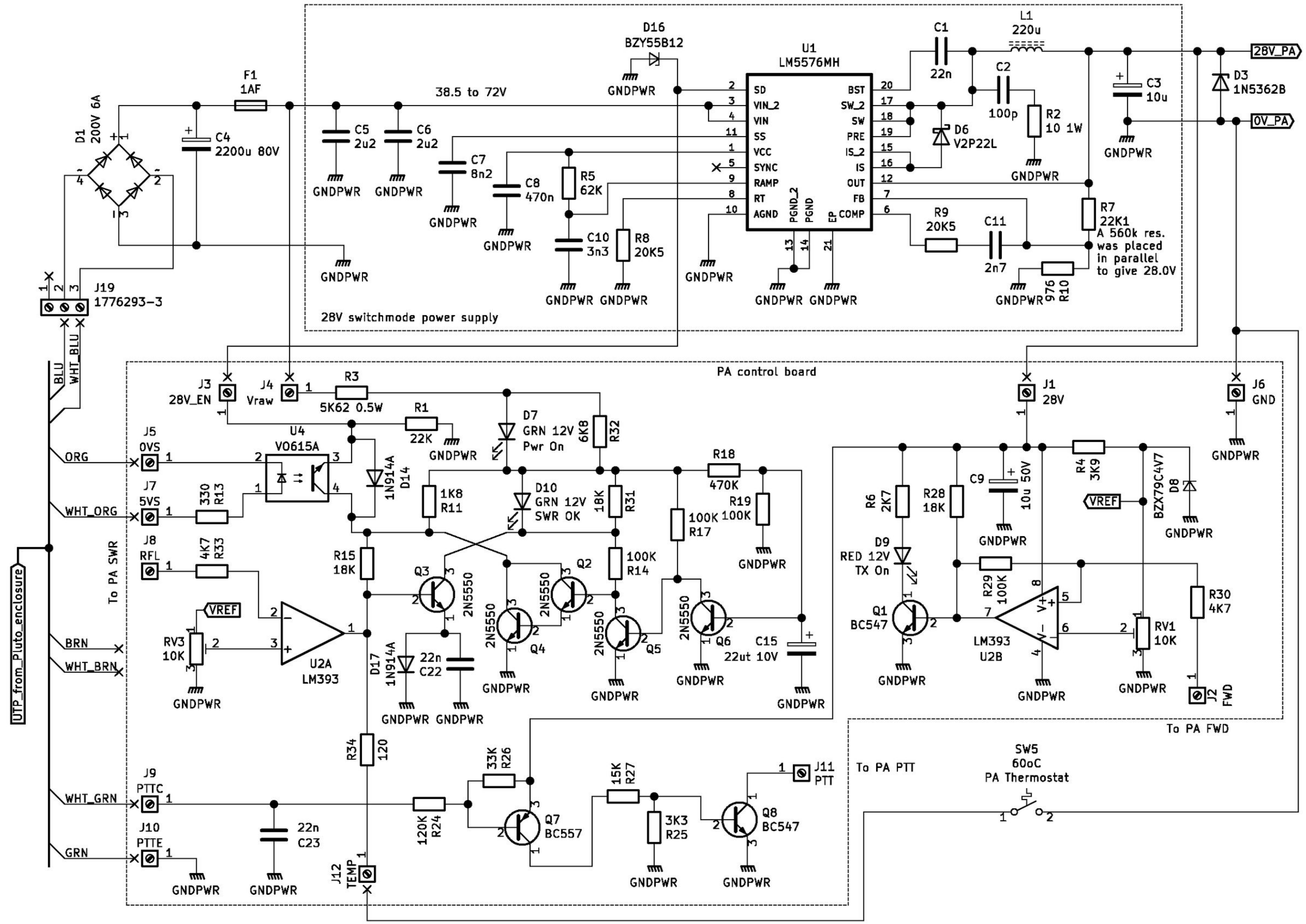

Figure 19: Schematic of the 28V switchmode power supply and PA control board. This is version P.

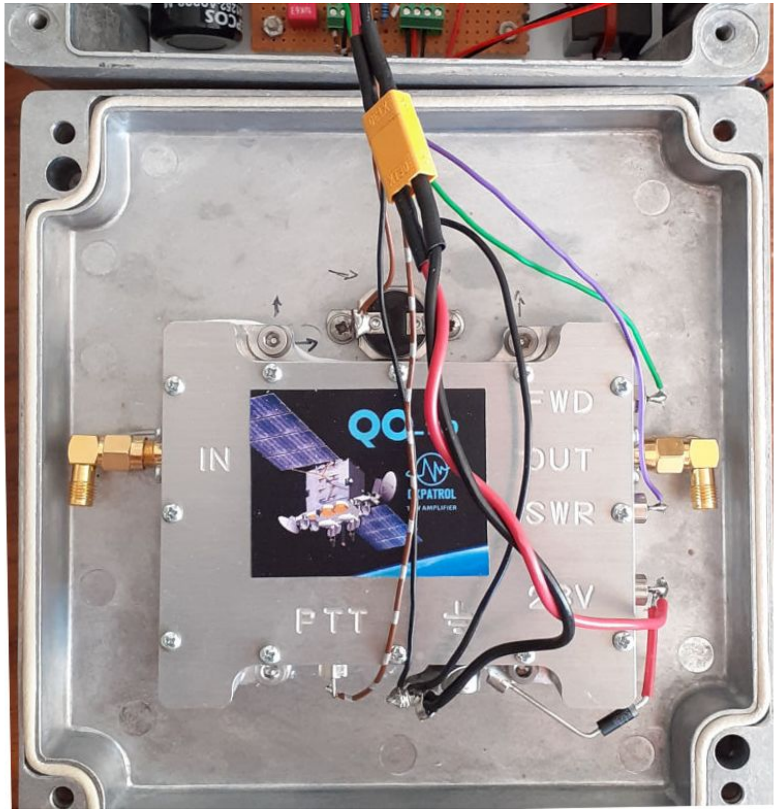

Figure 20: DX Patrol power amplifier and its connections. Thermally conductive paste is smeared under the amplifier. Thermostat SW5 is above the amplifier. D3 is on the bottom right.

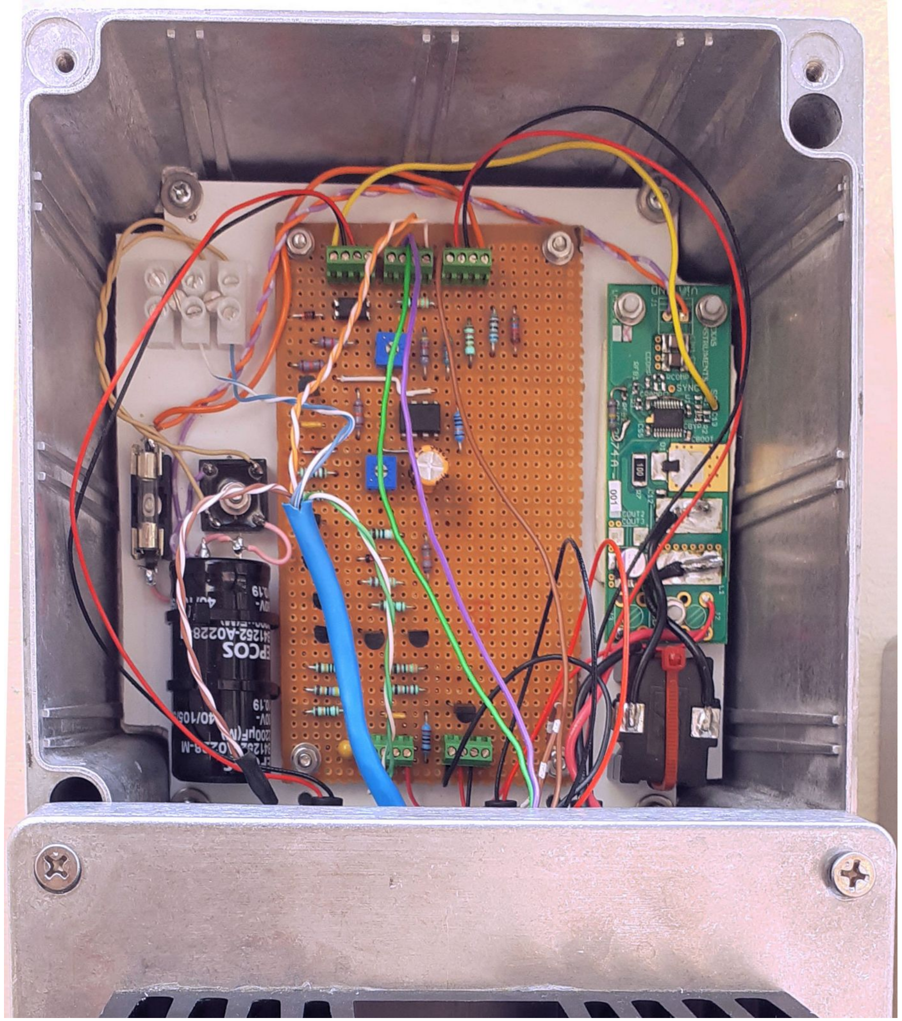

Figure 21: PA control board (centre) and the 28V switchmode power supply (right). L1 is too large and has to be mounted off the LM5576BLDT "Build-It" board. The wires from the DX Patrol power amplifier are long enough to allow the front cover to be slid downward and be screwed temporarily onto the box when opened.

2.5.2 Parts list: PA enclosure

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Stathis.net	024399	Gainta	G139	Enclosure, Aluminium diecast IP65 158.5x158.5x101.5mm	PA enclosure		Box	37,05 €	1
ACDC shop.gr	35564		SK57-100SA	Heatsink, 100x120x50mm	PA enclosure		External heatsink	23,11 €	1
ACDC shop.gr	19029	AG Termopasty	TERMOGLUE-10	Compound, thermally conductive 10g tube	PA enclosure		Between heatsink and box, between box and power amplifier	4,43 €	0,5
Junkbox				Machine screw, hex socket cap stainless steel M4x20	PA enclosure		Supports power amplifier on heatsink	0,00 €	4
Junkbox				Spring lock washer, stainless steel M4	PA enclosure		Supports power amplifier on heatsink	0,00 €	4
Mouser	871-B41252A0228M000	EPCOS / TDK	B41252A0228M000	Capacitor, 2200µF 80V Aluminium electrolytic snap-in	PA enclosure		C4	2,84 €	1
Mouser	583-BR62	Rectron	BR62	Diode, bridge rectifier 200V 6A	PA enclosure		D1	1,07 €	1
Mouser	863-1N5362BRLG	onsemi	1N5362BRLG	Diode, Zener 28V 5W THT	PA enclosure		D3	0,42 €	1
Mouser	539-FL1M8CW-4-G12V	Mallory Sonalert	FL1M-8CW-4-G12V	Indicator, LED 12VDC green IP65	PA enclosure		D7, D10	2,53 €	2
Mouser	539-FL1M8CW-4-R12V	Mallory Sonalert	FL1M-8CW-4-R12V	Indicator, LED 12VDC red IP65 (see text)	PA enclosure		D9	2,53 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Gadgetpriority-Electronics Lda	113	DX Patrol		Amplifier, 12W 2.4GHz	PA enclosure		DX Patrol power amplifier	159,90 €	1
Shop910748016 Store (Aliexpress)				Adapter, SMA male to SMA female, right-angle	PA enclosure		DX Patrol power amplifier in, out	0,90 €	2
Junkbox	530-5SF1-R	Bel Fuse	5SF 1-R	Fuse, 1AF 5x20mm	PA enclosure		F1	0,49 €	1
Mouser	576-64700001003	Littelfuse	64700001003	Holder, fuse 5x20mm cable type	PA enclosure		F1	0,74 €	1
Mouser	571-1776293-3	TE Connectivity	1776293-3	Terminal block, barrier 8mm spacing 3 pole	PA enclosure		J19	2,17 €	1
Mouser	710-74437529203221	Würth Elektronik	74437529203221	Inductor, WE-HCF 2920, 220µH 8.8A 40mΩ	PA enclosure		L1	7,74 €	1
Grobotronics	39-00011823		XT30	Connector, male-female pair 2 contact polarized in-line	PA enclosure		On 28V_PA/ 0V_PA cable	1,60 €	1
ACDC shop.gr	19959	Honeywell	BT-F-060/H	Thermostat, normally open Topen 45°C Tclose 60°C	PA enclosure		SW5	12,28 €	1
Mouser	951-GPVOUS0.200AC-00	Bergquist Company	GPVOUS-0.200-AC	Pad, thermal transfer 0.200" thick	PA enclosure		Between U1 and chassis	4,42 €	1
Mouser	581-06031C223K4Z2A	Kyocera AVX	06031C223K4Z2A	Capacitor, 22nF 100V X7R 0603	PA enclosure	28V SMPS	C1	0,39 €	1
Mouser	581-06031A101K	Kyocera AVX	06031A101KAT2A	Capacitor, 100pF 100V C0G 0603	PA enclosure	28V SMPS	C2	0,10 €	1
Mouser	667-50SVPF10M	Panasonic	50SVPF10M	Capacitor, 10µF 50V Aluminium organic polymer 40mΩ SMD	PA enclosure	28V SMPS	C3	1,49 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	810-C3225X7R2A225K	TDK	C3225X7R2A225K230AB	Capacitor, 2.2uF 100V X7R 1210	PA enclosure	28V SMPS	C5, C6	0,69 €	2
Mouser	581-06035C822K	Kyocera AVX	06035C822KAT2A	Capacitor, 8.2nF X7R 0603	PA enclosure	28V SMPS	C7	0,19 €	1
Mouser	581-0603YC474KAT2A	Kyocera AVX	0603YC474KAT2A	Capacitor, 470nF 16V X7R 0603	PA enclosure	28V SMPS	C8	0,49 €	1
Mouser	581-06035A332JAT2A	Kyocera AVX	06035A332JAT2A	Capacitor, 3.3nF C0G 0603	PA enclosure	28V SMPS	C10	0,54 €	1
Mouser	581-06035A272JAT2A	Kyocera AVX	06035A272JAT2A	Capacitor, 2.7nF C0G 0603	PA enclosure	28V SMPS	C11	0,49 €	1
Mouser	78-V2P22LHM3/H	Vishay General Semiconductor	V2P22LHM3/H	Diode, Schottky 200V 2A SMD	PA enclosure	28V SMPS	D6	0,43 €	1
Mouser	821-BZY55B12-RYG	Taiwan Semiconductor	BZY55B12 RYG	Diode, Zener 12V 0.5W 0805	PA enclosure	28V SMPS	D16	0,41 €	1
Mouser	667-ERJ-S1TJ100U	Panasonic	ERJ-S1TJ100U	Resistor, 10Ω 1W 2512	PA enclosure	28V SMPS	R2	0,39 €	1
Mouser	667-ERJ-6ENF6202V	Panasonic	ERJ-6ENF6202V	Resistor, 62KΩ 0805	PA enclosure	28V SMPS	R5	0,10 €	1
Mouser	667-ERJ-3EKF2212V	Panasonic	ERJ-3EKF2212V	Resistor 22.1KΩ 1% 0603 (see text)	PA enclosure	28V SMPS	R7	0,10 €	1
Junkbox	594-5043ED560K0F	Vishay / BC Components	SFR2500005603FR500	Resistor, 560KΩ 1% THT (select on test)	PA enclosure	28V SMPS	In parallel with R7, select-on-test	0,20 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	667-ERJ-3EKF2052V	Panasonic	ERJ-3EKF2052V	Resistor 20.5KΩ 0603	PA enclosure	28V SMPS	R8, R9	0,10 €	2
Mouser	667-ERJ-3EKF9760V	Panasonic	ERJ-3EKF9760V	Resistor, 976Ω 1% 0603	PA enclosure	28V SMPS	R10	0,10 €	1
Mouser	926-LM5576BLDT/NOPB	Texas Instruments	LM5576BLDT/NOPB	PCB, semi-assembled LM5576, "build it board"	PA enclosure	28V SMPS	U1	26,60 €	1
Mouser	871-B41866C6106M000	EPCOS / TDK	B41866C6106M000	Capacitor, 10µF 50V Aluminium electrolytic THT	PA enclosure	PA ctl board	C9	0,56 €	1
Mouser	581-TAP226K010SCS	Kyocera AVX	TAP226K010SCS	Capacitor, 22µF Tantalum THT	PA enclosure	PA ctl board	C15	0,74 €	1
Mouser	581-SR211C223KARAP1	Kyocera AVX	SR211C223KARAP1	Capacitor, 22nF X7R THT	PA enclosure	PA ctl board	C22, C23	0,37 €	2
Mouser	571-282834-4	TE Connectivity	282834-4	Terminal block, PCB mount 0.1" spacing 4 terminal	PA enclosure	PA ctl board	D7, D9, D10, J1, J2, J3, J4, J5, J6, J7, J8, J9, J10, J11, J12	2,31 €	5
Stathis.net	014945	NXP	BZX79C4V7	Diode, Zener 4.7V 0.5W THT	PA enclosure	PA ctl board	D8	0,06 €	1
Mouser	512-1N914ATR	onsemi	1N914ATR	Diode, THT (see text)	PA enclosure	PA ctl board	D14, D17	0,34 €	2
Mouser	512-BC547CBU	onsemi	BC547CBU	Transistor, NPN	PA enclosure	PA ctl board	Q1, Q8	0,31 €	2
Mouser	512-2N5550TAR	onsemi	2N5550TAR	Transistor, NPN, high voltage (see text)	PA enclosure	PA ctl board	Q2, Q3, Q4, Q5, Q6	0,32 €	5
Mouser	512-BC557BTA	onsemi	BC557BTA	Transistor, PNP	PA enclosure	PA ctl board	Q7	0,32 €	1
Mouser	594-SFR2500002202FR5	Vishay / BC Components	SFR2500002202FR500	Resistor, 22KΩ THT	PA enclosure	PA ctl board	R1	0,20 €	1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	594-5053HD5K620F	Vishay / BC Components	SFR25H0005621FR500	Resistor, 5.6KΩ 1/2W THT	PA enclosure	PA ctl board	R3	0,23 €	1
Mouser	594-5043ED3K900F	Vishay	SFR2500003901FR500	Resistor, 3.9KΩ THT	PA enclosure	PA ctl board	R4	0,11 €	1
Junkbox		Vishay / BC Components	SFR2500002701FR500	Resistor, 2.7KΩ THT	PA enclosure	PA ctl board	R6		1
Junkbox		Vishay / BC Components	SFR2500001801FR500	Resistor, 1.8KΩ THT	PA enclosure	PA ctl board	R11		1
Mouser	594-5043ED330R0F	Vishay	SFR2500003300FR500	Resistor, 330Ω THT (see text)	PA enclosure	PA ctl board	R13	0,11 €	1
Mouser	594-5043ED100K0F	Vishay / BC Components	SFR2500001003FR500	Resistor, 100KΩ THT	PA enclosure	PA ctl board	R14, R17, R19, R29	0,13 €	4
Junkbox	594-5043ED18K00F	Vishay / BC Components	SFR2500001802FR500	Resistor, 18KΩ THT	PA enclosure	PA ctl board	R15, R28, R31	0,20 €	3
Mouser	594-5043ED470K0F	Vishay / BC Components	SFR2500004703FR500	Resistor, 470KΩ THT	PA enclosure	PA ctl board	R18	0,19 €	1
Mouser	594-5043ED120K0F	Vishay	SFR2500001203FR500	Resistor, 120KΩ THT	PA enclosure	PA ctl board	R24	0,11 €	1
Mouser	594-5043ED3K300F	Vishay	SFR2500003301FR500	Resistor, 3.3KΩ THT	PA enclosure	PA ctl board	R25	0,11 €	1
Mouser	594-5043ED33K00F	Vishay	SFR2500003302FR500	Resistor, 33KΩ THT	PA enclosure	PA ctl board	R26	0,11 €	1
Mouser	594-5043ED15K00F	Vishay	SFR2500001502FR500	Resistor, 15KΩ THT	PA enclosure	PA ctl board	R27	0,11 €	1
Junkbox	594-5043ED4K700F	Vishay / BC Components	SFR2500004701FR500	Resistor, 4.7KΩ THT	PA enclosure	PA ctl board	R30, R33	0,20 €	2
Junkbox		Vishay / BC Components	SFR2500006801FR500	Resistor, 6.8KΩ THT	PA enclosure	PA ctl board	R32		1

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
Mouser	594-5043ED120R0F	Vishay	SFR2500001200FR500	Resistor, 120Ω THT	PA enclosure	PA ctl board	R34	0,11 €	1
Mouser	652-3362P-1-103RLF	Bourns	3362P-1-103RLF	Potentiometer, trimmer 10KΩ	PA enclosure	PA ctl board	RV1, RV3	1,31 €	2
Mouser	595-LM393PE4	Texas Instruments	LM393PE4	IC, dual comparator (see text)	PA enclosure	PA ctl board	U2	0,37 €	1
Mouser	78-VO615A	Vishay	VO615A	IC, optocoupler (see text)	PA enclosure	PA ctl board	U4	0,37 €	1

Notes:

- D9, the red FL1M-8CW-4-R12V LED, is in the middle between the two green FL1M-8CW-4-G12V LEDs. The green LEDs are incredibly bright (8000mcd, I.A.W. their datasheet[5]) and swamp the red LED (1000mcd brightness[5]) when viewed from afar. Dimmer green LEDs or a brighter red LED would be preferable.
- On the 28V switchmode power supply, a 560kΩ resistor was soldered across R7 to fine-tune the power supply voltage. The value needed depends on component tolerances. The resistor should be selected experimentally; see section 2.5.3 below.
- On the PA control board, Q5, Q6 will never have high voltages on their collectors. I used 2N5550s for uniformity's sake, but the cheaper BC547s would have done the job just as well. Note that their pinout is different.
- U2 of the PA control board is an LM393. An LM293, with its wider temperature specification, would have been a better choice for outdoor use.
- R13, U4 and D14 are only needed if "Remote relay switching using the power lines in the Ethernet cable" (see section 7.3) is implemented. This is an unlikely scenario; R13, U4 and D14 can most probably just not be fitted, and a wire placed where D14 is instead.

5 https://mspindy.com/spec-sheets/FL1M-8CW-4.pdf.

2.5.3 28V switchmode power supply

This is based on a T.I./National Semiconductor LM5576BLDT/NOPB "build it" board, a nice bare board which contains a soldered-on IC. I have not found a layout diagram of the board, but I did find a picture for it (figure 22).

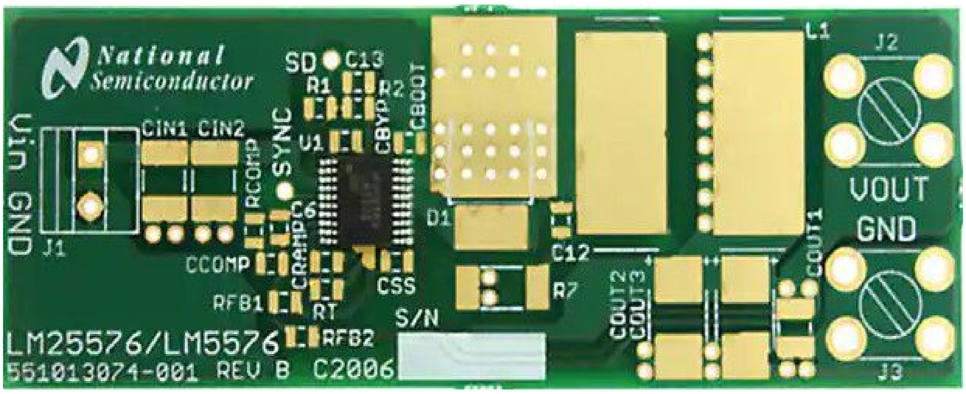

Figure 22: LM5576BLDT/NOPB "build it" board.

Designator in the schematic in figure 19	Designator on the LM5576BLDT/NOPB "build it" board	Designator in figure 36
C1	CBOOT	Cboot
C2	C12	Not shown
C3	COUT3	Cout
C5	CIN1	Cin
C6	CIN2	Cin
C7	CSS	Css
C8	CBYP	Cbyp
C10	CRAMP	Cramp
C11	CCOMP	Ccomp
D16	Unmarked	Not shown
R2	R7	Not shown
R5	No position	Rramp
R7*	RFB2*	Rfb2*
R8	RT	Rt
R9	RCOMP	Rcomp
R10	RFB1	Rfb1

* The 28V switchmode power supply as built gave an output voltage of 28.9V. I placed a 560kΩ resistor across R7 (RFB2) to bring the voltage down to 27.9V.

There are no pads for the ramp resistor R5, so it has been soldered onto C10 with a small wire connecting it to pin 1 of the IC. Also, inductor L1 is too large to fit on the pads, so it has been supported on the chassis and connected with thick wires.

Annoyngly, the board has no mounting holes so three have been drilled, one near the "National Semiconductor" logo, one near the "LM25576" writing and the third over the "VOUT" writing. Plastic screws have been used to insulate the board from the chassis.

A Bergquist GPVOUS-0.200-AC thermally-conductive "gap pad" has been placed between the rear of the board and the chassis to provide a path for cooling.

2.5.4 PA control board

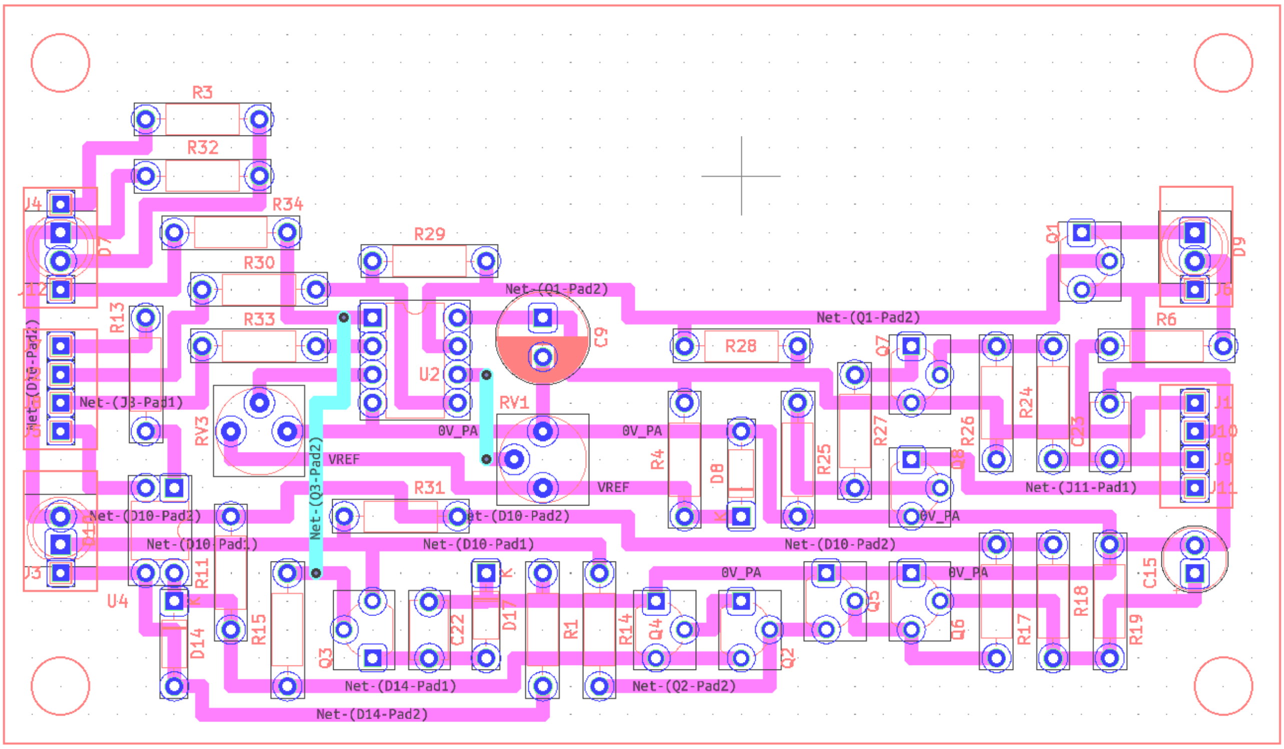

Figure 23: Layout of the PA control board, top view. This is version N. The board is 4.5" x 2.6".

A perforated board has been used as the PCB for the PA control board. It would have been better if the board were redesigned so that the wires which connect the PA enclosure to the Pluto enclosure actually came out the same side of the board. The long side of the board should also be made shorter; this would make it easier to connect the wires onto the screw-down terminals.

- If VSWR is too high, the PA control board trips the 28V power to the PA. RV3 sets the trip threshold; it is set so that power does not trip on SSB voice peaks. In my case, RV3 was set for about 3.2V on U2 pin 3 (see section 4.4.1 for rationale).
- RV1 sets the transmit level where the red "TX On" LED illuminates. I set RV1 for about 2.4V on U2 pin 6.

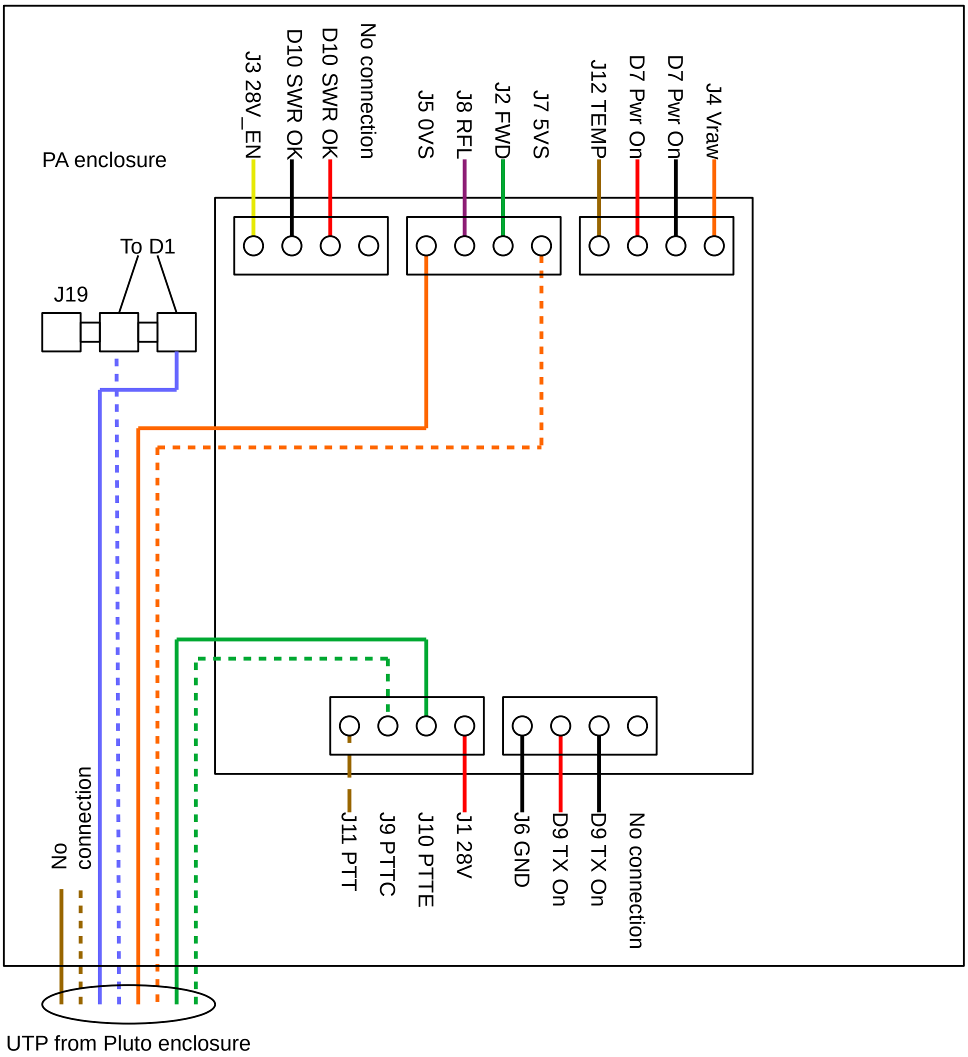

Figure 24: PA control board wiring.

2.6 Antenna

2.6.1 Parts list: Antenna

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
E-shop.gr	705170	Engel	Axil LH 1.05M	Satellite dish, 3ft. dia.	Antenna		Satellite dish	41,54 €	1
Nolle Engineering	121200	Nolle Engineering	121200	Ice Cone v2.1 antenna	Antenna		Ice Cone v2.1	126,79 €	1
Good Luck RF connector store (Aliexpress)				N type Male to SMA Female adapter	Antenna			1,37 €	1
Hardware shop		3M	Scotch® 23	Splicing tape, 19mm x 9m reel	Antenna			11,00 €	1
Junkbox				Pieces of perspex sheet, 2mm thick, 25x63mm	Antenna		Lift LNB support away from satellite dish arm	0,00 €	6
Passion Radio	QO100-LNB-BULLSEYE-978	Othernet	BE01	LNB, Othernet Bullseye	Antenna		LNB	24,90 €	1
Hardware shop		Vimatec	Vimaseal-PU S/A 30	Sealant, polyurethane 300ml cartridge	Antenna	LNB		5,83 €	1
Mouser	667-ERJ-6ENF75R0V	Panasonic	ERJ-6ENF75R0V	Resistor, 75Ω 0805	Antenna	LNB	R7	0,10 €	1

2.6.2 LNB

2.6.2.1 LNB selection

I initially chose a single-receptacle LNB which is more convenient since only one transmission line is needed to connect it to the rest of the electronics. I modified it so it would get its 25MHz reference through the same coaxial cable as its RF output and DC power feed and it did work well; see section 5 for details. However, all the diplexers and filtering needed in order to achieve this seemed horribly and unjustifiably complicated, so I finally resorted to using a dual-receptacle LNB, which was modified so that one of its two output receptacles would be used to bring in the 25MHz reference independently of its RF output and DC feed.

The dual-receptacle LNB is more convenient for the following reasons:

- In a single-receptacle LNB, the 25MHz reference clock and the 740MHz IF go up and down the same cable. Careful separation is required to ensure no intermodulation products arise; this means that the signals need to be well separated, and this complicates the diplexers needed. This is not really a problem at the reference source end, but it gets rather fraught at the LNB end where space is scarce and modifications difficult.
- I found that with the single-receptacle LNB, I couldn't use my "satellite finder" (a small analogue signal meter which goes in line with the LNB). I presume this is because it blocks the 25MHz going up from the frequency reference to the LNB.

Choosing a dual-receptacle LNB was difficult. There are lots of LNBs on the market ranging from the incredibly cheap to the somewhat fancy. I started off with the incredibly cheap variety but I found it disappointing. I finally settled on the Othernet Bullseye BE01 despite its relatively high price, for the following reasons:

- Many people use it and are happy with it.
- I believed the Othernet product would be consistent - I had an unpleasant experience when opening up an Amiko L107, only to find its internal design was entirely different from the one SV1BDS shows on the internet! See figure 47. This is pretty common with low-cost LNBs, apparently.
- It does not use a crystal but incorporates a separate 25MHz clipped-sine (sort-of squarewave) TCVCXO instead, so I thought it would be easy to modify it to use an external reference.
- Detailed specifications are available and are actually believable; for example the NF is quoted as 0.5dB compared to the commonly-quoted though not particularly likely 0.1dB.
- It seems to have been designed to be compatible with the QO-100 satellite[6].

The TCVCXO which is built into the Othernet Bullseye is actually very good indeed; I only chose to scrap it because the OCXO I use (U3 on the frequency reference PCB) is much more stable.

2.6.2.2 Opening the Othernet Bullseye

The LNB plastic body clips together. I unclipped the two halves of the plastic shell apart starting from the back - it is in fact possible to poke a screwdriver through the sides of the oval hole where the receptacles are, ever-so-slightly push the clips inward to release them, and then slowly work your way towards the front.

6 See http://www.pabr.org/radio/otherlnb/otherlnb.en.html.

The cast aluminium chassis lid has five T8 torx machine screws which come off easily once the white weatherproofing goo is removed. The lid then comes straight off (OK, you might need to cut the goo with a scalpel around the seam).

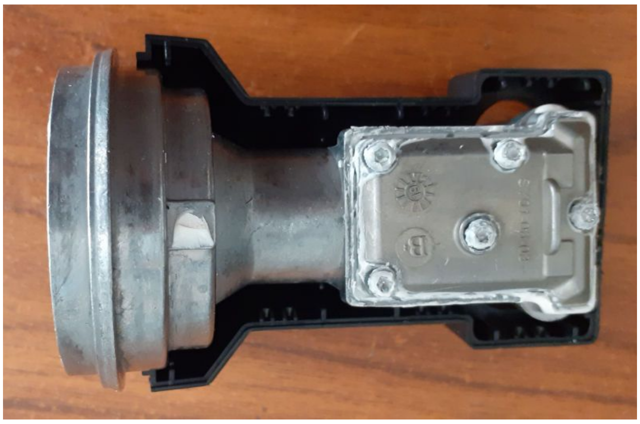

Figure 25: Othernet Bullseye with front cover removed (top left) and shell removed.

2.6.2.3 LNB modification for external clock

The original TCVCXO was removed by roasting its metal cover with a large soldering iron and just letting a little solder dribble onto the pads. Once it wobbled, I pulled it off with a pair of tweezers.

The track from the red F-type receptacle was cut (rather clumsily admittedly, see area circled in pink in figure 26). A wire was then connected between the track to the red F-type receptacle and the VCTCXO output pad. A 75Ω terminating resistor, R7, was then strapped between the pads where the VCTCXO Output and GND used to connect to.

> **WARNING!** The Othernet Bullseye LNB should never be operated without its external 25MHz clock. I discovered by accident that when external the clock is disconnected, current consumption rises to >200mA; how long the LNB can survive this, I do not know.

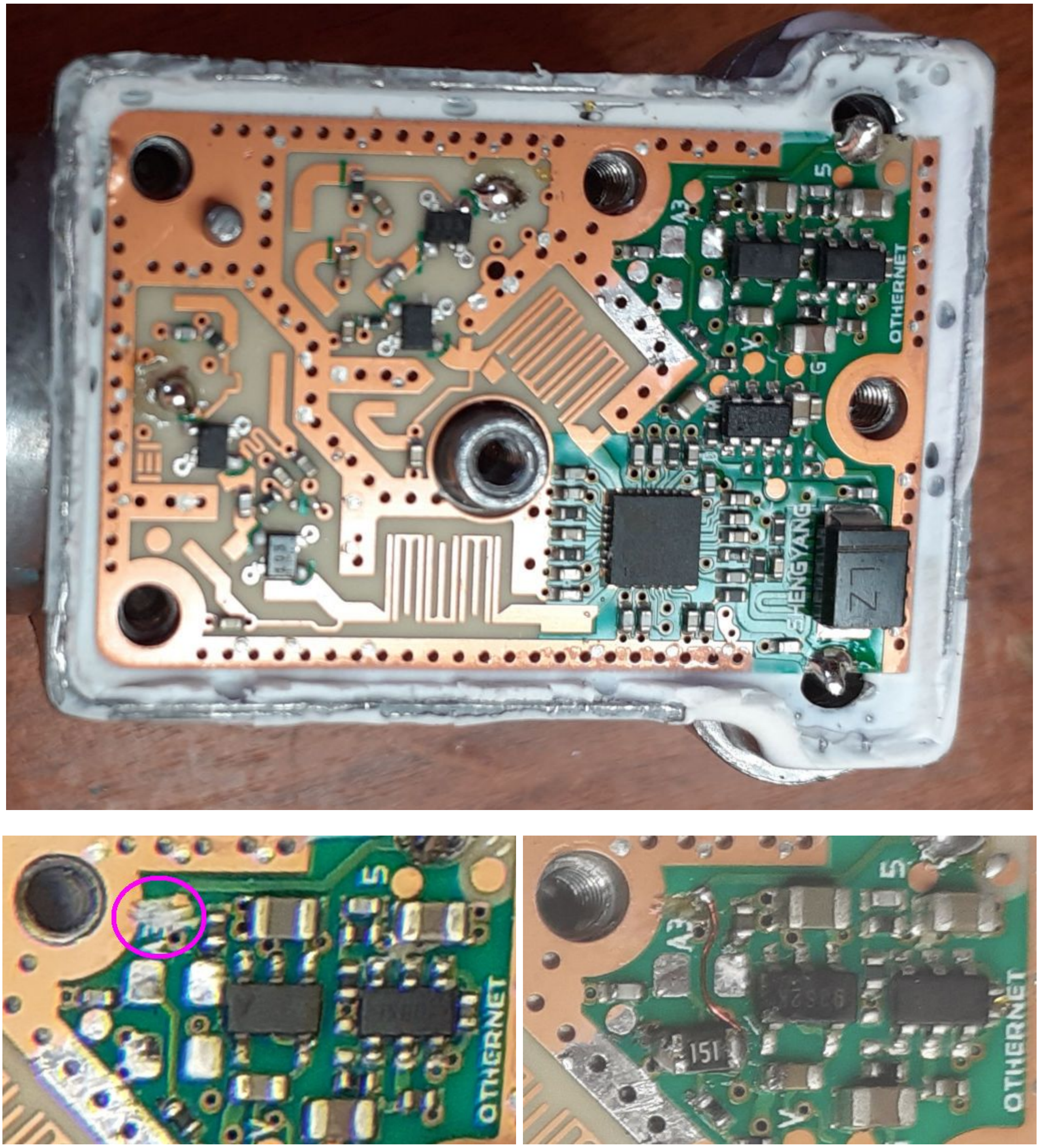

Figure 26: Othernet Bullseye with the VCTCXO removed (above) and the track from the red F-type receptacle cut (left, in circle). Jumper wire and R7 fitted (right).
Note that I forgot I had bought a 75Ω terminating resistor for R7, and actually used two 150Ω on top of one another instead...

The lid was screwed back on to the LNB and sealant was reapplied all around the lid join and over the screws. The sealant used is a compound called Vimaseal PU[7], whose advantage is that it does not release corrosive acetic acid while curing. It is horribly sticky and gooey, but it does come off with isopropyl alcohol (or methylated spirits if you are a cheapskate like me).

The sealant was left to cure overnight.

7 https://vimatec.eu/wp-content/uploads/VIMASEAL-PU_en.pdf.

2.6.3 Transmitting antenna

2.6.3.1 Antenna selection

I had initially chosen a POTY antenna, because this was very popular when I started working on this project. However, I found waterproofing the arrangement to be a bit touch-and-go; furthermore, substantial mechanical modifications have to be made to the LNB to fit it onto the POTY antenna. So, when DC8PAT came up with the Ice Cone v2.1, I bought one right away! It is just unbelievably easy to put together and install, especially with the Othernet Bullseye BE01 LNB.

I have noticed no difference in performance between the POTY and the Ice Cone v2.1, but the latter is just so much easier to work with.

2.6.3.2 Ice Cone v2.1 assembly

There is very little to be said here, the antenna just slips over the LNB's body and is clamped onto the LNB by tightening a screw. In my arrangement I used an N-type to SMA adapter. The adapter and cable junction were weatherproofed using self-amalgamating Scotch® 23 splicing tape, which was then covered with a layer of PVC tape.

Installing the Ice Cone v2.1 over the LNB gave no significant difference in received levels: On the AMSAT-DL (DJ0ABR) QO-100 Linux SDR Transceiver software, the lower satellite beacon gives an SNR of 34dB before fitting the Ice Cone v2.1. After fitting the v2.1, this fluctuates from 33 to 34dB. Note however that one does get this degree of fluctuation from day to day anyway.

A problem I had is that the clearance at the LNB end of my antenna arm was not enough to fit the Ice Cone v2.1! The solution is shown in section 2.6.3.3 below.

2.6.3.3 Increasing the LNB vertical distance from the antenna arm

The Ice Cone v2.1 could not be mounted on the arm of the satellite dish I have, as its orange rear "crashed" into the arm. F5VMJ has come up with a clever solution[8] which I essentially copied (see figure 27):

- I put the satellite dish arm on a large sheet of paper and sketched out its outline with a pen.
- Then, I added six sheets of 2mm-thick plastic (i.e. 12mm in total) at the LNB support end of the arm.
- Finally, I bent the arm open slightly, so that the top of the stack of the plastic sheets is at the same position as the top of the LNB support was before.

So, the LNB is further from the arm, but still at the antenna focal point.

8 https://nolle.engineering/en/2023/05/15/satellite-dish-modification/

Figure 27: LNB end of the satellite dish arm, showing how the LNB support has been lifted with a stack of six sheets of perspex, increasing the clearance to allow for installation of the Ice Cone v2.1.

3 Software setup for the ADALM Pluto

3.1 Things I did which are probably unnecessary

The operations in this section are probably unnecessary for normal ham-radio operation. Most likely, one can jump directly to section 3.2.

3.1.1 Basic Linux installation

The following is from https://wiki.analog.com/university/tools/pluto/drivers/linux: "In order to access some USB functions without root privileges, it's recommended to install the PlutoSDR or ADALM2000 udev rules".

I did not do this: "Simply download 53-adi-plutosdr-usb.rules ... and copy into into the /etc/udev/rules.d/ folder. Afterwards reload rules or restart udev, using either udevadm control --reload-rules or sudo service udev restart".

I was worried about what the downloaded "53-adi-plutosdr-usb.rules" file might contain, so I did the following manually. I found that the 53-adi-plutosdr-usb.rules file contents:

```
# allow "plugdev" group read/write access to ADI M2K devices

SUBSYSTEM=="usb", ATTRS{idVendor}=="0456", ATTRS{idProduct}=="b672", MODE="0664", GROUP="plugdev"

SUBSYSTEM=="usb", ATTRS{idVendor}=="0456", ATTRS{idProduct}=="b675", MODE="0664", GROUP="plugdev"

# tell the ModemManager (part of the NetworkManager suite) that the device is not a modem,

# and don't send AT commands to it

SUBSYSTEM=="usb", ATTRS{idVendor}=="0456", ATTRS{idProduct}=="b672", ENV{ID_MM_DEVICE_IGNORE}="1"
```

I just copied the text above into /etc/udev/rules.d/ and rebooted.

3.1.2 Serial terminal emulation

The following is from https://wiki.analog.com/university/tools/pluto/drivers/linux:

dmesg: When plugging Pluto in (to the PC USB port) ..., you will see kernel messages of:

```
...
[ 3745.504184] cdc_acm 2-3:1.3: ttyACM0: USB ACM device
...
```

This shows that the serial port is ttyACM0.

You need to be member of the dialout group, which is done with

```
usermod -a -G dialout {my_user_name}
```

Then setup minicom (as root, minicom -s) for /dev/ttyACM0 and 115200 8N1, no handshake. In minicom setup, store settings as dfl.

Pressing [Enter] gives "Welcome to Pluto". Login is root, password is analog.

3.1.3 USB connection and SSH

The ADALM Pluto emulates a network interface on its USB port. When it is plugged into a PC's USB receptacle, the PC sees the ADALM Pluto as a virtual network port.

The following is from https://wiki.analog.com/university/tools/pluto/drivers/linux:

Connecting to the serial interface with minicom, log into the Adalm Pluto and find out its IP address:

```
# /sbin/ifconfig
...
usb0      Link encap:Ethernet  HWaddr 00:05:F7:37:40:5F
          inet addr:192.168.2.1  Bcast:0.0.0.0  Mask:255.255.255.0
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:10 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)
```

Then on the PC, find the name of the virtual network port (note that this is dynamic, and is only visible / available when the ADALM Pluto USB is connected to the PC):

```
> ip addr show
3: enx00e0222e0dc6: <BROADCAST,MULTICAST> mtu 1500 qdisc noop state DOWN group default qlen 1000
    link/ether 00:e0:22:2e:0d:c6 brd ff:ff:ff:ff:ff:ff
```

Then, add a 192.168.2.x subnet address to the PC virtual network port: vim /etc/network/interfaces on the PC, and add the following:

```
    auto enx00e0222e0dc6
    iface enx00e0222e0dc6 inet static
    address 192.168.2.2
    netmask 255.255.255.0
```

Reboot. The ip addr command on the PC will now shows the interface:

```
> ip addr
3: enx00e0222e0dc6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UNKNOWN group default qlen 1000
    link/ether 00:e0:22:2e:0d:c6 brd ff:ff:ff:ff:ff:ff
    inet 192.168.2.2/24 brd 192.168.2.255 scope global enx00e0222e0dc6
       valid_lft forever preferred_lft forever
    inet6 fe80::2e0:22ff:fe2e:dc6/64 scope link
       valid_lft forever preferred_lft forever
```

On the PC, create a file called ~/.ssh/config with the following text:

```
# This is the default ssh_config for the PlutoSDR
# This file should be located in ~/.ssh/config or /etc/ssh/ssh_config
# If you update the IP number, you need to do the same in this file
```

```
Host plutosdr
 HostName 192.168.2.1
 UserKnownHostsFile=/dev/null
 HostKeyAlias plutosdr
 StrictHostKeyChecking=no
 CheckHostIP no
 User root
 ChallengeResponseAuthentication no
# Do the same for zeroconf, so we don't end up with bad keys
Host pluto.local
        UserKnownHostsFile=/dev/null
        HostKeyAlias plutosdr
        StrictHostKeyChecking=no
        CheckHostIP no
        User root
        ChallengeResponseAuthentication no
```

You should now be able to SSH to the Pluto with the command ssh plutosdr. Password is analog.

3.1.4 IIO interface

The following is from https://wiki.analog.com/university/tools/pluto/drivers/linux.

On the PC,

```
apt-get install libiio-utils
```

Test on the PC:

```
iio_info -s
  Library version: 0.16 (git tag: v0.16)
  Compiled with backends: local xml ip usb serial
  No contexts found.
iio_info -u ip:192.168.2.1
```

returns various parameters.

3.2 Installing AMSAT-DL QO-100 Linux SDR Transceiver

The following is based on https://wiki.amsat-dl.org/doku.php?id=de:plutotrx:installation. Version 1.72 of the AMSAT-DL QO-100 Linux SDR Transceiver was installed.

Important: This uses the "mono" library (mono-devel and mono-complete). Early versions of the mono library suffer from a horrific memory leak. Upgrading the mono library didn't actually work - I had to uninstall the original mono installation and reinstall the new version from scratch. My Linux distribution had version 6.0.8, so I updated it as described in https://www.mono-project.com/download/stable/. The version loaded was 6.12.0.182, which worked fine.

The AMSAT-DL QO-100 Linux SDR Transceiver software requires the user to be a sudoer. Check whether you already belong to the sudo group (by issuing the "groups" command). If not, become a member of the sudo group: As root,

```
/sbin/usermod -aG sudo {my_username}
```

Log off and log back on again.

To run the installation, on the PC:

```
wget https://raw.githubusercontent.com/dj0abr/QO100_Transceiver/main/install
chmod 755 install
./install
```

If added above, remove sudo privileges using the command

```
gpasswd -d {my_username} sudo
```

Log off and log back on again. Then do:

```
cd QO100_Transceiver/Release
```

The ls command should display the following files (among others):

```
qo100trx.exe  startQO100trx  trxdriver
```

If one or more of these files are missing, something went wrong with the installation. If they are all there, you can start the program with the following command:

```
./startQO100trx
```

With the ADALM Pluto connected to the PC's USB receptacle, the software works fine.

For the gnome desktop (maybe others too), I created a desktop descriptor file named /home/{my_username}/.local/share/applications/qo100trx.desktop, based on the original install files. This allows me to start the application by clicking on the application icon. Note that "ai.ico" and "startQO100trx" may be in different locations on your set-up, so the paths will need to be modified accordingly.

```
[Desktop Entry]
Version=1.0
Name=QO100 transceiver
Comment=Start the Pluto QO100 Transceiver
Icon=/home/{my_username}/QO100_Transceiver/ai.ico
Exec=/usr/bin/xterm -e "cd /home/{my_username}/QO100_Transceiver/Release && ./startQO100trx"
Encoding=UTF-8
Type=Application
Terminal=false
```

3.3 Connecting the ADALM Pluto via Ethernet

While still in the experimental phase, the necessary hardware was set up as described in chapter 4.2 figure 32.

The ADALM Pluto's security features are somewhat lacking, and I didn't want it to be on the same subnet (192.168.2.x) as the rest of the devices on our home network. I therefore put the ADALM Pluto on a different subnet, 192.168.4.x.

3.3.1 ADALM Pluto setup

The ADALM Pluto was connected temporarily to the host PC directly via USB, and it appears as a USB flash drive. On this "USB flash drive", I edited config.txt with a text editor, and changed the ipaddr_eth to 192.168.4.76:

```
[NETWORK]
hostname = pluto
ipaddr = 192.168.2.1
ipaddr_host = 192.168.2.10
netmask = 255.255.255.0

[WLAN]
ssid_wlan =
pwd_wlan =
ipaddr_wlan =

[USB_ETHERNET]
ipaddr_eth = 192.168.4.76
netmask_eth = 255.255.255.0

[SYSTEM]
xo_correction =
udc_handle_suspend = 0
# USB Communication Device Class Compatibility Mode [rndis|ncm|ecm]
usb_ethernet_mode = 0

[ACTIONS]
diagnostic_report = 0
dfu = 0
reset = 0
calibrate = 0
```

The file was saved and the "USB flash drive" was then ejected through the file manager. I think this effectively restarts the Pluto, loading the new settings.

Note: Under Pluto's Linux operating system this is stored under /opt/config.txt and can (presumably) also be accessed there via ssh, using vi.

3.3.2 PC setup

3.3.2.1 Option 1: Using /etc/network/interfaces

My old PC uses /etc/network/interfaces to set up the network. I just added a second stanza to /etc/network/interfaces, on the same Ethernet interface as the existing stanza which is on a different subnet; the PC now also gets IP address 192.168.4.75:

```
vim /etc/network/interfaces

  auto enp63s0

    iface enp63s0 inet static
```

```
        address 192.168.4.75
        netmask 255.255.255.0
```

Reboot.

3.3.2.2 Option 2: using ConnMan

My newer PC (running Debian Linux with LXQt) uses ConnMan for network management. Connman will, apparently, not allow a second IP address to be assigned to an interface. How sad. So, I have to do this forcibly after every reboot by entering the following command (what a pain)...

```
sudo ip addr add 192.168.4.74/24 dev enp1s0f0
```

This makes the interface (enp1s0f0 on my PC) connect to both the local network and to the 192.168.4.x network the ADALM Pluto is on.

3.3.3 Testing

It is now possible to ping the ADALM pluto from the host PC using command

```
ping 192.168.4.76
```

I can now also ssh the ADALM Pluto from the host PC command line via Ethernet as follows:

```
ssh -l root 192.168.4.76
```

The password is analog.

The first time I ssh'd most commands were not available, but on second ssh most Linux commands were there (in spite of them not appearing under help).

On the PC, I can also now view the ADALM Pluto's web interface in a browser, under http://192.168.4.76.

The Amsat-DL QO-100 Linux software also works with the ADALM Pluto once the ADALM Pluto's address is set in the "Settings" panel (Pluto Addresse → Ethernet in figure 28).

3.4 Setting up the ADALM Pluto for 50MHz reference

3.4.1 DK1ML's instructions (not actually followed)

The following is from DK1ML's QRZ.com page. **These commands were not actually used at this point**, though I did use them later, see sections 3.5.1 and 3.5.2.

Login to the Pluto with Putty or some other ssh program. The standard IP address of the Pluto is 192.168.2.1

User: root / Pwd: analog

Set the range to 70 Mc until 6 GHz and 56 Mc bandwidth:

```
fw_setenv attr_name compatible
fw_setenv attr_val ad9364
```

reboot

The Pluto has a dual core CPU but only a license for one core, this command will activate both cpu cores:

```
fw_setenv maxcpus
pluto_reboot reset
```

The Pluto and the LNB are locked to a single Leo Bodnar GPSDO at 25 Mc. Here are the commands to modify the internal ref. frequency of the pluto from 40 Mc to 25 Mc:

```
fw_setenv adi_loadvals "fdt addr $"{fit_load_address}" && fdt get value fdt_choosen /configurations/$"{fit_config}"/ fdt && fdt get addr fdtaddr /images/$"{fdt_choosen}" data && fdt addr $"{fdtaddr}"; if test ! -n $"{ad936x_skip_ext_refclk}"; then if test -n $"{ad936x_custom_refclk}"; then fdt set /clocks/clock@0 clock-frequency $"{ad936x_custom_refclk}"; elif test -n $"{ad936x_ext_refclk}"; then fdt set /clocks/clock@0 clock-frequency $"{ad936x_ext_refclk}"; fi; fi; if test -n $"{model}"; then fdt set / model $"{model}"; fi; if test -n $"{attr_name}" && test -n $"{attr_val}"; then fdt set /amba/spi@e0006000/ad9361-phy@0 $"{attr_name}" $"{attr_val}"; fi"

fw_setenv ad936x_custom_refclk "<25000000>"
```

The first two sets of instructions are nice to have, but I didn't try them (yet). The third instruction will be necessary though, for use with the 50MHz clock from the frequency reference PCB.

3.4.2 Actual set-up

This is what I actually did: I connected to the ADALM Pluto remotely with SSH, using the following command on the PC

```
ssh -l root 192.168.4.76
```

With command fw_printenv, I found the ADALM Pluto has the following adi_loadvals environment variable (see Original_ADALM_pluto-fw_printenv_response.txt):

```
adi_loadvals=fdt addr ${fit_load_address} && fdt get value fdt_choosen /configurations/${fit_config}/ fdt && fdt get addr fdtaddr /images/${fdt_choosen} data && fdt addr ${fdtaddr}; if test -n ${ad936x_ext_refclk} && test ! -n ${ad936x_skip_ext_refclk}; then fdt set /clocks/clock@0 clock-frequency ${ad936x_ext_refclk}; fi; if test -n ${model}; then fdt set / model ${model}; fi; if test -n ${attr_name} && test -n ${attr_val}; then fdt set /amba/spi@e0006000/ad9361-phy@0 ${attr_name} ${attr_val}; fi
```

This differs from that given by DK1ML in the central section (the "if" tests) as to whether to set the clock frequencies. I shall use it as prescribed (but for 50MHz):

```
# fw_setenv adi_loadvals "fdt addr $"{fit_load_address}" && fdt get value
fdt_choosen /configurations/$"{fit_config}"/ fdt && fdt get addr fdtaddr
/images/$"{fdt_choosen}" data && fdt addr $"{fdtaddr}"; if test ! -n
$"{ad936x_skip_ext_refclk}"; then if test -n $"{ad936x_custom_refclk}"; then
fdt set /clocks/clock@0 clock-frequency $"{ad936x_custom_refclk}"; elif test
-n $"{ad936x_ext_refclk}"; then fdt set /clocks/clock@0 clock-frequency
$"{ad936x_ext_refclk}"; fi; fi; if test -n $"{model}"; then fdt set / model
$"{model}"; fi; if test -n $"{attr_name}" && test -n $"{attr_val}"; then fdt
set /amba/spi@e0006000/ad9361-phy@0 $"{attr_name}" $"{attr_val}"; fi"

# fw_setenv ad936x_custom_refclk "<50000000>"
```

3.5 Firmware modification for ADALM Pluto PTT output

DK1ML states that[9] "To switch GPO-Pins for PTT the Pluto DATV Beta Image from 05.02.2020 from F5OEO is required (also for narrowband SSB operation)". Now this is very scary.

I.A.W. https://wiki.batc.org.uk/Custom_DATV_Firmware_for_the_Pluto, "The Pluto must already have been modified for extended frequency range, and it is worth enabling the second processor".

After every step, I tested the ADALM Pluto by transmitting to the QO-100 satellite and listening to myself, to ensure everything still worked!

3.5.1 Extending the frequency range

Based on https://wiki.analog.com/university/tools/pluto/users/customizing, I connected to the Pluto via SSH (ssh -l root 192.168.4.76) and ran the following commands:

```
# fw_printenv attr_name
    Error: "attr_name" not defined
# fw_printenv attr_val
    Error: "attr_val" not defined
```

To widen the frequency range, the following were run:

```
# fw_setenv attr_name compatible
# fw_setenv attr_val ad9364
# reboot
```

Reconnect SSH and

```
# fw_setenv compatible ad9364
# reboot
```

3.5.2 Enabling the second CPU

I did this as described by PH4X in https://www.ph4x.com/pluto-sdr-hack-2nd-cpu-core. I connected to the Pluto via SSH (ssh -l root 192.168.4.76) and ran the following commands:

```
# cat /proc/cpuinfo
```

Shows one CPU (processor 0).

```
# fw_setenv maxcpus
# pluto_reboot reset
```

Reconnect SSH and

```
# cat /proc/cpuinfo
```

This now shows two CPUs (processor 0 and processor 1).

3.5.3 Updating the firmware

This has been done remotely (over Ethernet) based on the instructions in https://wiki.analog.com/university/tools/pluto/users/firmware ("Network Update" section).

The firmware was obtained from https://wiki.batc.org.uk/File:FIRM2101RC.zip, it is also available under http://firmware.hackhamradio.com/beta_for_the_brave and https://www.f5uii.net/wp-

9 https://forum.amsat-dl.org/index.php?thread/3372-pluto-mods-just-1-part-ptt-dc-mod-gpsdo-mod-ethernet-connect/.

content/uploads/2020/04/pluto-beta_for_the_brave-20200205-2104.zip. No checksums are provided on any of these sites, but the actual "pluto.frm" file thus downloaded is the same from all three sites, so I kind of think it is genuine. The SHA256 checksum of "pluto.frm" (according to my PC) is 0d517828cd34a4d7b24da5256bd37dde477d99365f69553fe8d56ae0bfc53c33.

I transferred this file from my Linux PC to Pluto's root directory giving the following command on the PC:

```
scp FIRM2101RC.zip root@192.168.4.76:/FIRM2101RC.zip
```

I then connected to the Pluto via SSH (ssh -l root 192.168.4.76) and ran the following commands:

```
# cd /
# unzip FIRM2101RC.zip
  Archive:  FIRM2101RC.zip
    inflating: pluto.frm
# rm FIRM2101RC.zip
# update_frm.sh ./pluto.frm
  427+1 records in
  427+1 records out
  Done
# reboot
```

Reconnect SSH. The login prompt shows version as

```
Welcome to:

______ _       _        _________________
| ___ \ |     | |      /  ___|  _  \ ___ \
| |_/ / |_   _| |_ ___ \ `--.| | | | |_/ /
|  __/| | | | | __/ _ \ `--. \ | | |    /
| |   | | |_| | || (_) /\__/ / |/ /| |\ \
\_|   |_|\__,_|\__\___/\____/|___/ \_| \_|

v0.31-4-g9ceb-dirty
http://wiki.analog.com/university/tools/pluto
```

3.6 Sound set-up for PC

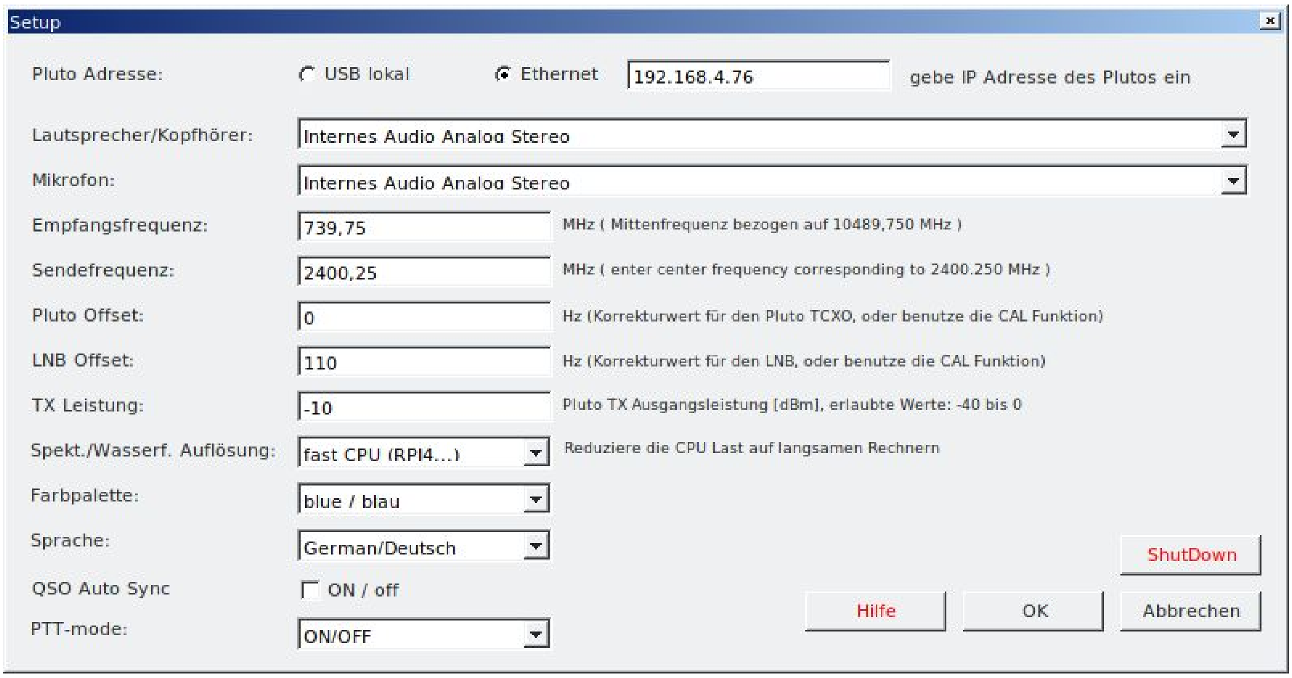

Figure 28: Settings for the AMSAT-DL QO-100 Linux SDR Transceiver (version 1.72).

3.6.1 Settings for voice

On AMSAT-DL QO-100 Linux SDR Transceiver mixer:

- Wiedergabe: SoundIoOutStream (QO-100) ein: Internes Audio Analog Stereo, 100% (0dB).
- **Aufnahme: SoundIoInStream (QO-100) von: Internes Audio Analog Stereo, 100% (0dB).**
- Ausgabegeräte: Internes Audio Analog Stereo Port: Headphones (eingesteckt), 100% (0dB).
- Eingabegeräte: Internes Audio Analog Stereo Port: Mikrofon (plugged in), 30% (-31.5dB). Check this with VU meter.
- Konfiguration: Internes Audio: Analog Stereo Duplex.

On AMSAT-DL QO-100 Linux SDR Transceiver:

- Compressor on.
- Audio: Bass boost off, mic gain can be raised to 5 to add more compression.

Microphone and headphones plugged into the front PC jacks.

3.6.2 Interfacing FLDIGI to AMSAT-DL QO-100 Linux SDR Transceiver

3.6.2.1 Two sound card solution

This was a little fiddly to set up, as it needs (digital) audio to cross feed between FLDIGI and the AMSAT-DL QO-100 Linux SDR Transceiver application.

Linux's pulse audio can "monitor" an audio stream from one application and use this as audio input to another application.

In my case things are simplified somewhat in that I have an HDMI screen connected to my PC which acts as a second sound card (although this is not actually necessary; see section 3.6.2.2). So, ultimately, my PC thinks it has two sound cards,

- "Internal analog Stereo" which is the actual sound card and
- "High definition audio controller" which is the HDMI screen.

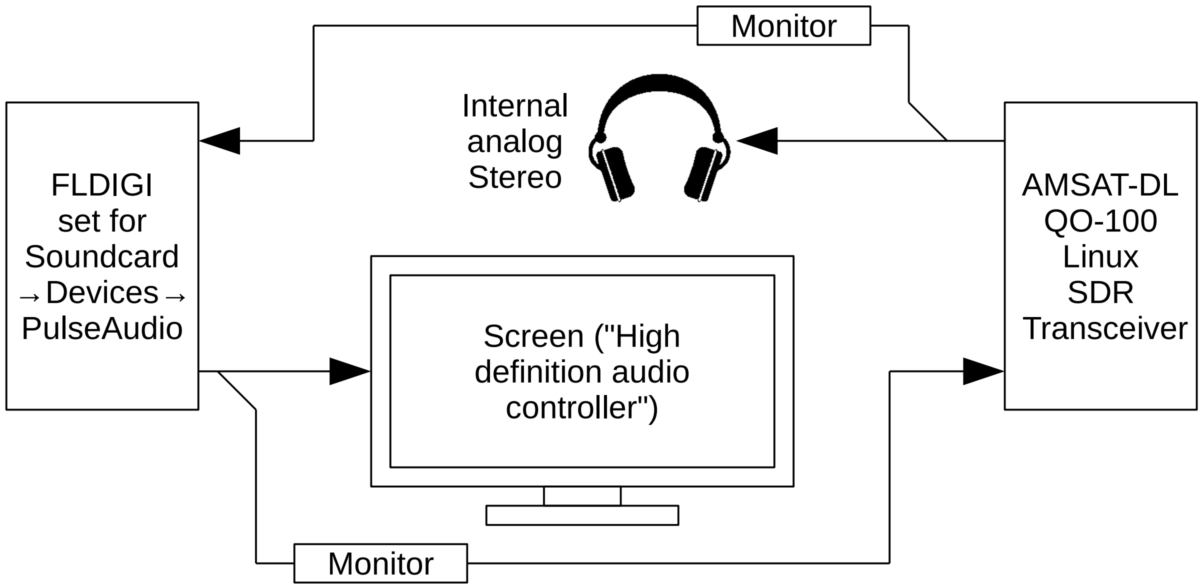

Figure 29: Routing of sound within the PC between FLDIGI and the AMSAT-DL QO-100 Linux SDR Transceiver. Two "sound cards" are used, the PC's internal sound card and that of the HDMI screen.

This is done with the following settings on the AMSAT-DL QO-100 Linux SDR Transceiver mixer:

- Wiedergabe: : playback (fldigi) ein: High Definition Audio Controller, 100% (0dB).
- Wiedergabe: SoundIoOutStream (QO-100) ein: Internes Audio Analog Stereo, 100% (0dB).
- Aufnahme: : capture (fldigi): von: Monitor of Internes Audio Analog Stereo, 153% (11dB).
- **Aufnahme: SoundIoInStream (QO-100) von: Monitor of High Definition Audio Controller, 20% (-42dB)[10].**
- Ausgabegeräte: High Definition Audio Controller Port: HDMI / DisplayPort 2 (eingesteckt), 100% (0dB).
- Ausgabegeräte: Internes Audio Analog Stereo Port: Headphones (eingesteckt), 100% (0dB).
- Eingabegeräte: Internes Audio Analog Stereo Port: Mikrofon (plugged in), 30% (-31.5dB).
- Konfiguration: High Definition Audio Controller: Digital Stereo (HDMI-2)-Ausgabe.
- Konfiguration: Internes Audio: Analog Stereo Duplex.

FLDIGI transmit level (bottom right): About -10dB[10] (for CW).

10 This setting keeps the transmit signal just below Layla, with the AMSAT-DL QO-100 Linux SDR Transceiver "TX Leistung" parameter is set to -10dB (see figure 28). All these adjustments are a bit of an experimental balancing act, needed to avoid overloading.

3.6.2.2 Single sound card solution

If there aren't two "sound cards" on the PC, it is possible to create a virtual sound sink for this purpose (I have tried, it works fine). Use the following script to create a virtual sound sink[11]:

```
#!/bin/bash
# Load virtual audio sink, if one isn't already loaded.
if ! (pactl list sinks 2>/dev/null | grep 'device.description =
"VirtualSink"' >/dev/null 2>&1); then
pactl load-module module-null-sink sink_name=virtsink
sink_properties=device.description=VirtualSink
fi
```

This script can, in fact, be incorporated in the startQO100trx script of the QO-100 Linux SDR Transceiver software.

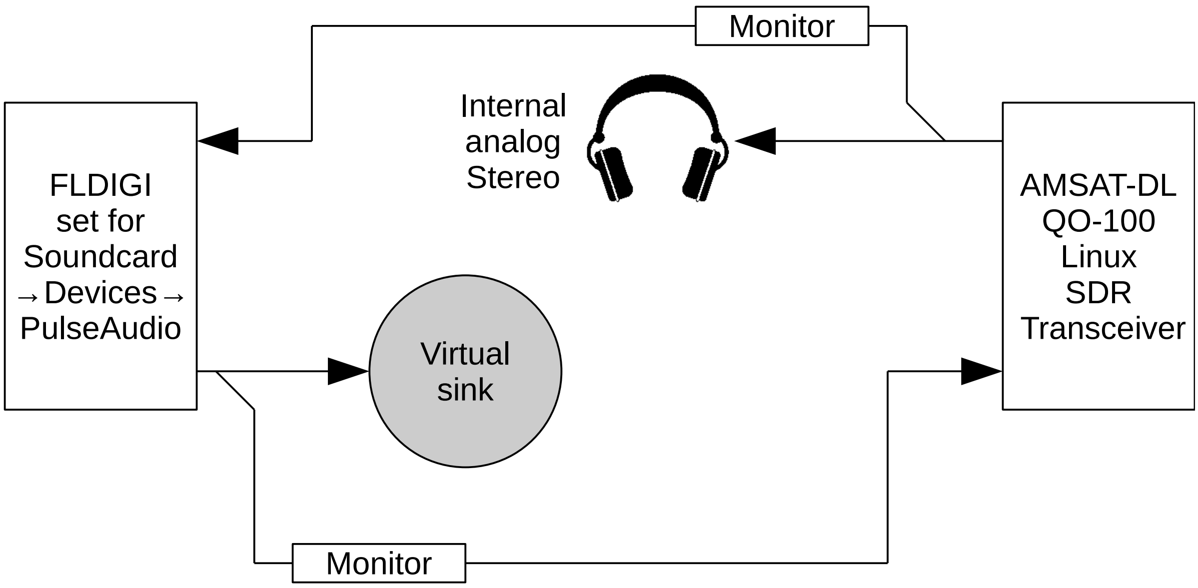

Figure 30: Routing of sound within the PC between FLDIGI and the AMSAT-DL QO-100 Linux SDR Transceiver, using a virtual sound sink.

Then adjust the AMSAT-DL QO-100 Linux SDR Transceiver mixer as follows:

- Wiedergabe: : playback (fldigi) ein: VirtualSink, 100% (0dB).
- Wiedergabe: SoundIoOutStream (QO-100) ein: Internes Audio Analog Stereo, 100% (0dB).
- Aufnahme: : capture (fldigi): von: Monitor of Internes Audio Analog Stereo, 153% (11dB).
- **Aufnahme: SoundIoInStream (QO-100) von: Monitor of VirtualSink, 30% (-32dB)[12].**
- Ausgabegeräte: VirtualSink, 100% (0dB).
- Ausgabegeräte: Internes Audio Analog Stereo Port: Headphones (eingesteckt), 100% (0dB).
- Eingabegeräte: Internes Audio Analog Stereo Port: Microphone, 30% (-31.5dB).
- Konfiguration: Internes Audio: Analog Stereo Duplex.

FLDIGI transmit level (bottom right): About -3dB (for CW).

11 Source: https://unix.stackexchange.com/questions/174379/how-can-i-create-a-virtual-output-in-pulseaudio.

12 This setting keeps just below Layla with FLDIGI transmit level set to -3dB, with the AMSAT-DL QO-100 Linux SDR Transceiver "TX Leistung" parameter is set to -10dB (see figure 28).

4 Appendix A: Circuit details

4.1 Clock generation and LNB modification

4.1.1 General design concept

An OCXO generates accurate, stable clocks for the ADALM Pluto and for the Othernet Bullseye LNB. I could start from 10MHz and multiply upwards (like SV1BDS' idea[13], see figure 31) or start at 100MHz and divide down (like DJ0ABR does[14]). I settled on the latter idea because it involves less analogue circuitry.

There are plenty of 100MHz OCXOs on the market. I chose the AOCJY3A-100MHz-F because it gives good accuracy and phase noise at a reasonable price.

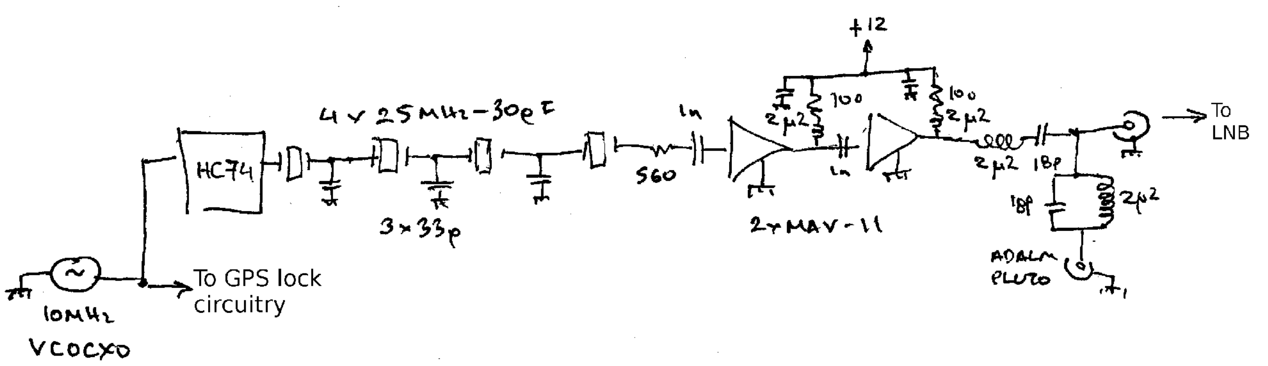

Figure 31: 10MHz to 25MHz multiplier designed by SV1BDS.

4.1.2 Voltage regulation for the OCXO "Control" pin

Abracon state (private communication) that the "Reference Voltage" pin of the OCXO provides a temperature-stable source, and suggest the use of a 10kΩ trimpot from this to drive the "Control" pin.

The sensitivity of the AOCJY3A-100.000MHZ-F OCXO's "Control" input is ±0.7ppm for 0 to 5V, i.e. 0.28ppm/V. I can only assume the OCXO's reference voltage is stable enough, otherwise Abracon would not recommend we use it. However, the resistance of the adjusting potentiometer must be very stable with temperature too! The Vishay 1280G series Y005610K0000K0L trimmer potentiometer has a temperature coefficient of 15ppm/ºC which, considering it is fed by about 5V, means it may drift 75µV/ºC. This corresponds to 0.28ppm/V·75µV/ºC=0.02ppb/ºC, which is acceptable when compared to the drift of the OCXO itself (±30ppb from -40 to 75ºC = 0.26ppb/ºC). Furthermore, it is the ratio of the upper and lower resistances of the potentiometer which matters; these resistances will (hopefully) drift in unison.

4.1.3 Clock for the ADALM Pluto

The unmodified ADALM Pluto has an internal crystal oscillator at 40MHz. 40MHz from an 100MHz source is rather difficult to generate. However, the Pluto will happily work with anything from 20 to 50MHz[15]; 50MHz it shall be.

13 https://forum.amsat-dl.org/index.php?thread/2745-my-qo100-setup/&pageNo=24.
14 http://projects.dj0abr.de/doku.php?id=de:sat:plutolnb.
15 See https://forum.amsat-dl.org/index.php?thread/3199-external-clock-for-adalm-pluto/.

See the schematic in figure 12. The ADALM Pluto needs an input of 1.3Vpp[16], which I will terminate into 50Ω. The 2:1 isolation transformer T1 will need 2.6Vpp into 200Ω. R1 gives a reasonable match to the transformer and brings the voltage to the correct level. In practice, I get a squarewave of around 1Vpp into 50Ω with over/undershoot to 1.5Vpp. It is difficult to measure with much accuracy really.

4.1.4 Clock for the Othernet Bullseye LNB

4.1.4.1 Measurements with the original Othernet Bullseye TCVCXO

My Othernet Bullseye's original TCVCXO[17] gave a clipped sine at 24.999940MHz. The clipped sine went from 0.6V low to 1.6V high (i.e. 1Vpp). This TCVCXO seemed to drive pin 4 of a small microcontroller(?) chip marked LE0V (levels: 0.6V low, 0.8V high) and pin 14 of the RT320M chip (levels: 0.8V low, 1.7V high). The 24.999940MHz signal output on the red F-type receptacle was about 40mVpp on 0.66VDC.

The DC component of the signals was not the same as that of the TCVCXO, which (hopefully) meant the VCTCXO output was AC coupled; it is therefore probably permissible to strap a 75Ω resistor between the VCTCXO Output and GND pads and just feed the TCVCXO pad from the red F-type receptacle. The required drive level is 1Vpp into 75Ω. Squarewave drive should be fine (the clipped sine looked squarish enough anyway).

Incidentally, the original TCVCXO had the following DC voltages on its pads (clocwise, starting from output pad):

- Output pad: As stated above
- GND pad: 0V
- Control voltage pad: 1.6V
- Vdd pad: 3.3V

4.1.4.2 25MHz clock generation for the Othernet Bullseye LNB

25MHz is generated by dividing down the 100MHz OCXO output. See figure 12: T2 transforms the coaxial cable's 75Ω to 300Ω and provides isolation which helps in the fight against ground loops. R6 attenuates the 25MHz signal from U1B, U1C to give about 2Vpp at the T2's primary; T2 then brings this down to the desired 1Vpp (1.4Vpp in practice). The resulting levels are:

Position	With original TCVCXO (per section 4.1.4.1)		With clock from frequency reference PCB	
	Logic low	Logic high	Logic low	Logic high
TCVCXO output pad	0.6V	1.6V	-0.7V	0.7V
Pin 4 of the microcontroller	0.6V	0.8V	0.6V	0.75V
Pin 14 of the RT320M chip	0.8V	1.7V	0.9V	1.7V

Not perfect, but good enough it would seem.

16 See https://ez.analog.com/adieducation/university-program/f/q-a/77922/will-it-be-possible-to-feed-in-a-reference-clock-to-the-adalm-pluto and AD9363 datasheet, https://www.analog.com/media/en/technical-documentation/data-sheets/AD9363.pdf.

17 Also see http://www.pabr.org/radio/otherlnb/otherlnb.en.html.

4.1.5 IF filter

I was having problems with occasional interference on receive; sometimes, the spectrum of all received signals would just splay out and there would be huge amounts of noise. In a QSO, DL6YCL suggested that this may be HSPA mobile 'phone interference, and he recommended I use a diplexer to get rid of this. I preferred a filter to a diplexer and tried making a filter myself but failed miserably; I don't have a network analyzer and, without one, it is not easy to make such a filter. So, I resorted to purchasing a ready-made TDS2143D-740M filter from TEMWell, which seems to do the job admirably. No more interference, thank you DL6YCL!

R4 and R5 form a lossy matching network from 50Ω to 75Ω and also provide a reasonable termination to the LNB at frequencies outside the passband of FL1. I was a bit concerned about the insertion loss of the arrangement (about 4dB for FL1 and 6dB for R4, R5), but the signal-to-noise ratio of the QO-100 lower beacon is the same[8] with and without FL1-R4-R5 so loss is most likely not an issue, well, at least not with this set-up.

4.2 Connecting the ADALM Pluto via Ethernet

Since the ADALM Pluto is going to be installed outdoors, communication with it has to be over Ethernet. To connect the ADALM Pluto via Ethernet, I initially bought the following:

- A Powertech CAB-U035 "Converter USB 3.0 σε Gigabit Ethernet LAN", RTL8153, Public #MRK1222174
- A Y-cable with a USB "A" female and a USB "B" male and female connectors (https://www.ebay.de/itm/USB-OTG-Y-Adapterkabel-mit-Stromeinspeisung-A-Buchse-Micro-B-Stecker-Buchse/112349822778?ssPageName=STRK%3AMEBIDX%3AIT&_trksid=p2057872.m2749.l2649). This is necessary, as in order to function properly[18],[19] the ADALM Pluto needs to be powered from its USB port, not from its power receptacle.

The Pluto was then connected to Ethernet as follows:

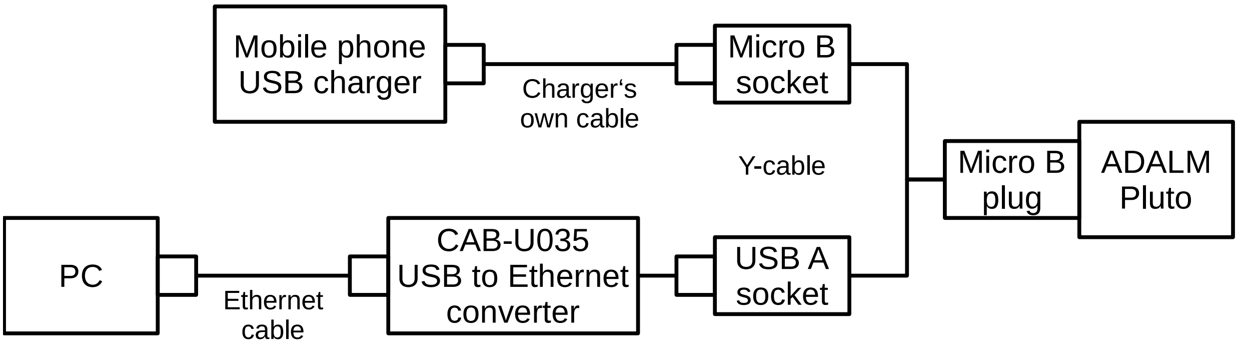

Figure 32: ADALM Pluto experimental connection to PC via USB to Ethernet converter and Y-cable.

Thus, the mobile 'phone USB charger powered both the ADALM Pluto and the USB to Ethernet converter directly. This worked fine, with software set-up as shown in section 3.3.

The problem with this arrangement was that all the converters, wires and what-have-you were very large physically. So, I decided to take the CAB-U035 USB to Ethernet converter apart, and make direct connections to the necessary parts.

The CAB-U035 USB to Ethernet converter came apart by prying its case open with a screwdriver pushed into the top part of the Ethernet socket. Its box has studs, not clips, so it is pulled open. The USB 3.0 connections were as follows:

18 See https://g3yjr.wordpress.com/2020/12/01/connecting-the-adalm-pluto-using-ethernet/ and https://www.dd1us.de/Downloads/Connecting the ADALM Pluto to the Local Area Network v5.pdf.

19 DK1ML states (https://forum.amsat-dl.org/index.php?thread/3372-pluto-mods-just-1-part-ptt-dc-mod-gpsdo-mod-ethernet-connect/) that an Icy Box IB-AC510 adapter can be used without a Y-cable, maybe due to its lower consumption (it is a USB 2.0 to Ethernet 10-100 device). I could not get hold of one of these, they seem to be obsolete.

Wire colour	Connection	Comment
Plain	GND	
PNK	RXP	Shielded pair
VIO	RXN	
YEL	TXN	Shielded pair
BLU	TXP	
BLK	GND	
WHT	DM	
GRN	DP	
RED	VCC	

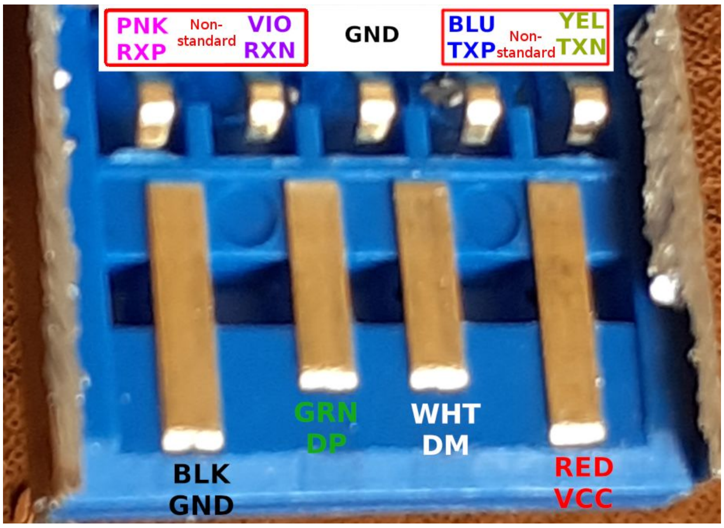

Figure 33: CAB-U035 USB to Ethernet converter USB3.0 connections. Note that the top differential pairs (RXP-RXN, TXP-TXN) have the opposite polarity to the standard. This doesn't really matter as they are not used in this application anyway[20].

When connected to the USB Y-cable, the connections were as follows:

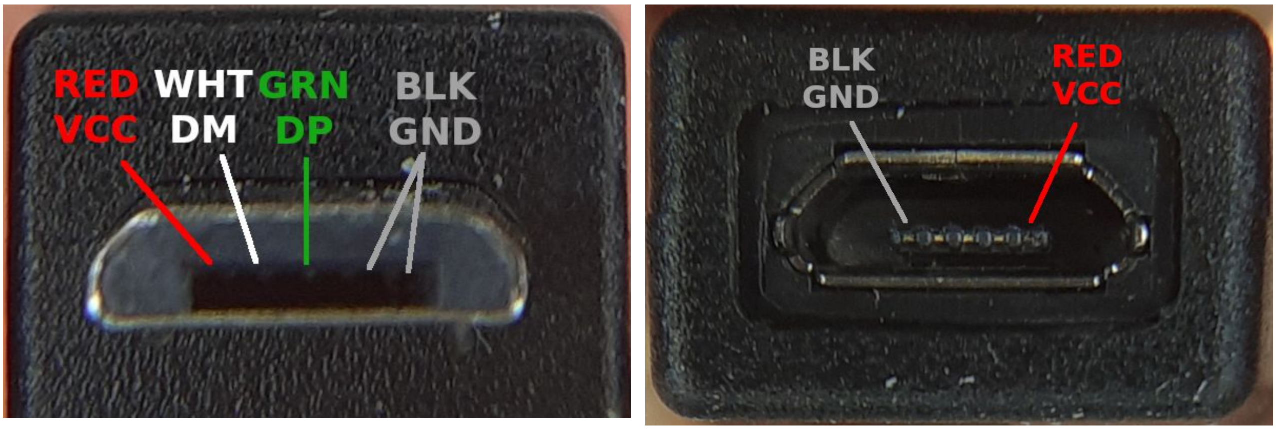

Figure 34: Y-cable USB micro-B connector connections.

Note that the fourth pin (to the right of the green DP pin) is the "USB On-The-Go ID" pin. It is grounded, to inform the ADALM Pluto that the Pluto is to be an OTG host[21].

So, I got rid of all this paraphernalia and just connected to the CAB-U035 USB to Ethernet converter with a shielded pair with DP, DM from the ADALM Pluto, and 5V_Pluto / 0V_Pluto from the power supply (see figure 17).

20 As mentioned in section 2.4.7, I managed to ruin this the USB3.0 Ethernet converter, and replaced it with a USB2.0 converter. The latter does not have these wires anyway.

21 For a somewhat unclear explanation, see https://electronics.stackexchange.com/questions/35462/why-does-micro-usb-2-0-have-5-pins-when-the-a-type-only-has-4.

4.3 Power supply

Power is supplied via 15m of Ethernet cable, whose resistance (one pair) is about 1.5Ω (0.1Ω/m). I initially thought I would use 34VRMS (48Vpp) on the Ethernet cable, since 48VDC is commonly used for POE. However, with a rough simulation I ran for the 28V section rectifier (see section 4.3.1.1), I found the voltages would have been a little marginal. So, I decided to go for 48VRMS over the Ethernet cable.

4.3.1 28V switchmode power supply for the PA

The DX Patrol AMP2 power amplifier can draw 1.5A at 28VDC. This is 42W.

4.3.1.1 Rectifier

I used https://www.falstad.com/circuit/index.html to simulate the power chain (see figure 35). The 1.5Ω resistor is the resistance of 15m of UTP (0.1Ω/m). The circuit is saved in 28VRegulatorRectifier.txt[22], you can just paste it into the simulator under Datei → Von Text importieren.

4.3.1.1.1 50W transformer attempt

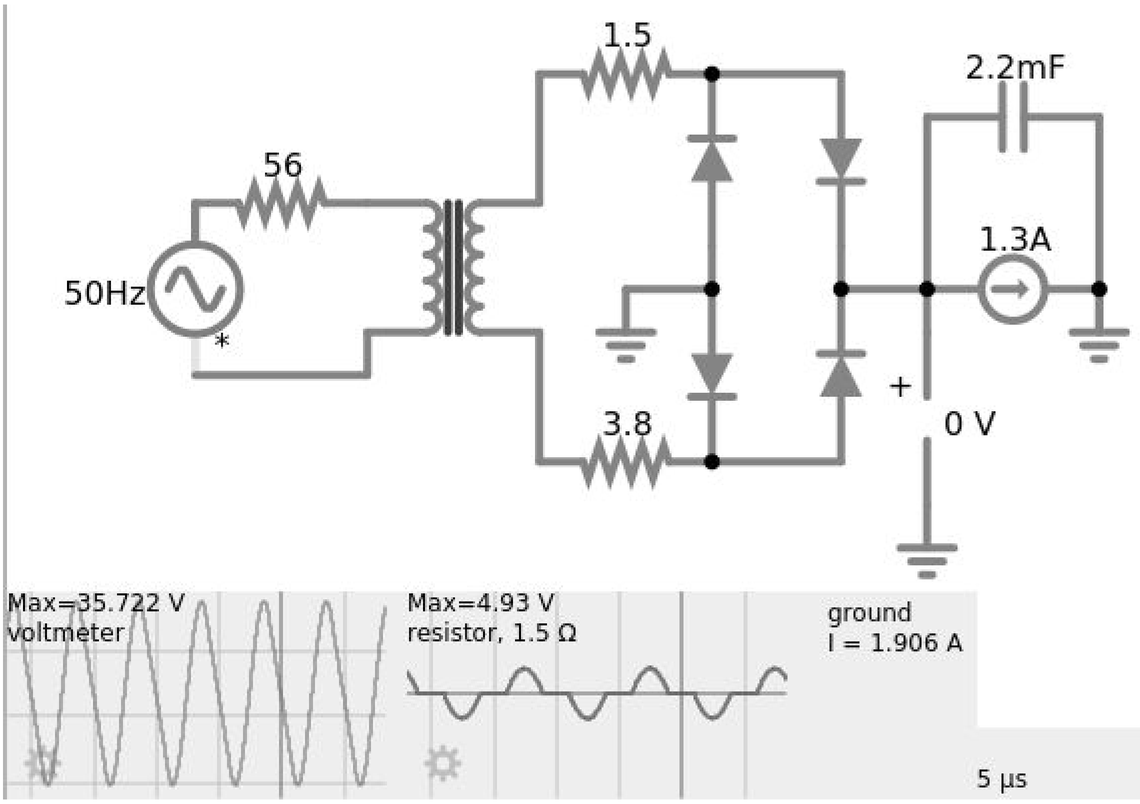

Figure 35: Rectifier simulation with a 50W toroidal transformer. Bottom left: Output voltage. Bottom centre: voltage drop across 1.5Ω cable resistance. Not shown here: The diode voltage drop is around 0.9V peak, which is realistic.

22 The actual transformer loss resistances in this file are for the 80W transformer; see section 4.3.1.1.2.

The transformer was a difficult beast to simulate, I assumed it behaves like a standard 50W toroidal transformer made by Talema and tried to simulate it based on this[23]; see Talema_50W_toroidal_transformer.ods, which shows that:

- Primary equivalent resistance (230V primary) is 49Ω · 115% = 56Ω.
- Secondary equivalent resistance is V²/700 · 115%. For a 48VAC secondary, this is 3.8Ω.

Minimum (full-load) voltage: Let us say mains can go down by 10%, so it could be 296Vpp. The load current will be around I_{IN}=42W/40V/(90% switchmode regulator efficiency)=1.2A. With I_{IN}=1.2A and a 1000µF filter capacitor, the rectifier output according to the simulator is from 32.7 to 38.2V (ripple). This is a bit low. Increasing the capacitor to 2200µF reduces the ripple and the voltage too; this becomes 34.4 to 37V. Re-iterating, since the voltage is actually around 35.7V, I_{IN}=42W/35.7V/(90% efficiency)=1.3A. The simulator gives just 33 to 35.7V at the capacitor. This is pretty measly. Furthermore, the simulation shows it takes a good 100msec for the voltage to reach 35.7V.

Maximum (no-load) voltage: Let us now say mains can go up by 10%, so it could be 358Vpp. Setting the load current to 10mA and the capacitor initial voltage to 70V ("voltage on reset"), gives a final voltage across the capacitor of around 72V.

This is all a little marginal. It might be wiser to use a larger transformer with better regulation.

4.3.1.1.2 80W transformer

Using the same assumptions as for the 50W transformer, I have now taken the values from a Talema 80W toroidal and tried to simulate it based on this[24]; see Talema_80W_toroidal_transformer.ods, which shows that:

- Primary equivalent resistance (230V primary) is 28Ω · 120% = 34Ω.
- Secondary equivalent resistance is V²/1000 · 120%. For a 48VAC secondary, this is 2.8Ω.

Minimum (full-load) voltage: Let us say mains can go down by 10%, so it could be 296Vpp. The load current will be around I_{IN}=42W/40V/(90% switchmode regulator efficiency)=1.2A. With I_{IN}=1.2A and a 2200µF filter capacitor, the rectifier output according to the simulator is from 38.5 to 41.3V (ripple). This is much healthier than what I had with the 50W transformer. Diode drops are around 870mV at 3.5A peak.

Maximum (no-load) voltage: Let us now say mains can go up by 10%, so it could be 358Vpp. Setting the load current to 10mA and the capacitor initial voltage to 65V ("voltage on reset"), gives a final voltage across the capacitor of around 72V again.

4.3.1.2 28V switchmode regulator

I used Texas Instruments' Webench (http://webench.ti.com/) to "design" the regulator. the parameters I gave it are Vin=38.5 to 72V, Vout=28V 1.5A, balanced design. The LM5576 regulator was chosen because Mouser offer a "build it board" for it (LM5576BLDT/NOPB).

23 Source: http://www.talema.it/trf/trfpdf/0050P1_0209.pdf
24 Source: http://www.talema.it/trf/trfpdf/0080P1_0209.pdf

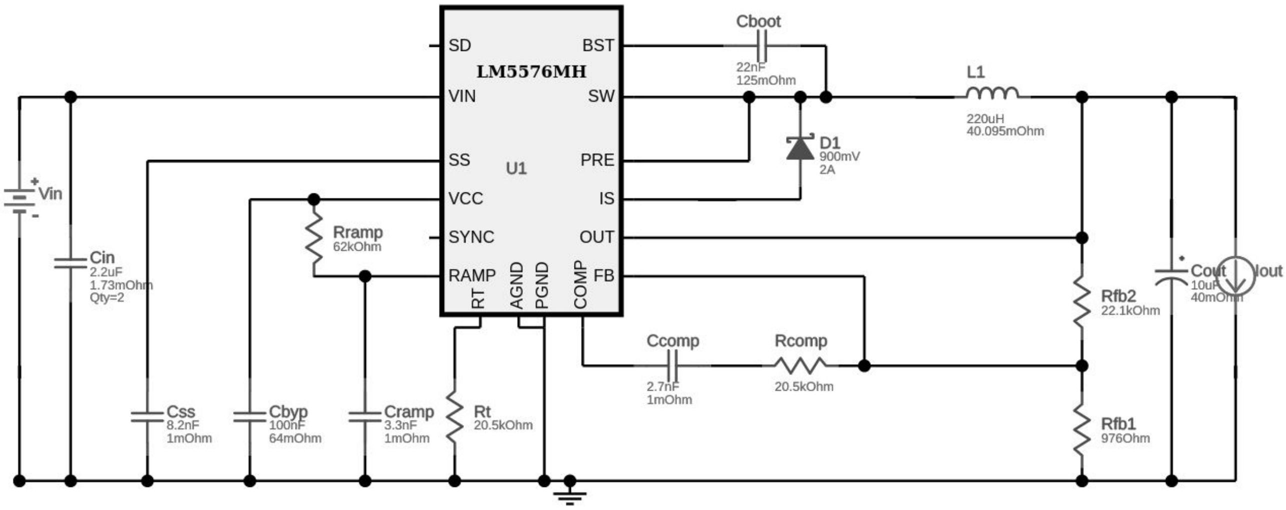

Figure 36: LM5576 28V switchmode regulator. A snubber (100pF and 10Ω in series), not shown, connects between the SW pin of the IC and ground.

The results are in WBOperatingValuesDesign5.csv. According to Webench, this supply runs at about 300kHz and gives an efficiency of 98% and an output ripple of about 7mV. The components are listed in WBBOMDesign5.csv.

In practice, on the output of the IC, on the SW pin, under 1A load I get a beautifully clean squarewave with about 50% duty cycle. The IC gets quite warm to the touch, and so does the coil funnily enough. With 8mA load the output is still regulated at 28.0V. The IC seems to skip cycles; on the SW pin I get one narrow pulse, one positive half-sine alternating. The half-sine may be the LC circuit ringing, I don't know.

4.3.2 5V and 12V power supply for the Pluto enclosure

It will be better to use linear regulators here where possible, to avoid noise problems. This power supply needs to provide:

- 12V at 100mA for the Othernet Bullseye LNB. This is the measured value on which all calculations here have been made; I unfortunately found that the current can be as high as 120mA when the LNB gets warm, but I discovered this too late and haven't included it in the calculations here.
- 12V at 80mA for the F1OPA driver amplifier (see section 4.3.4),
- 5V at 500mA (?) for the ADALM Pluto,
- 5V at 600mA for the OCXO on the Reference PCB,
- 5V at around 100mA for all other ICs etc. on the Reference PCB,
- 5V at around 100mA for a future GPS receiver and Arduino (again on the Reference PCB),
- 48VAC at 1.5VA (31mA) for each of the two RT424548 relay coils[25].

The total power is thus about 2W from the 12V supply and 6.5W from the 5V supply.

What makes things a little fiddly is that the 5V and 12V supplies must have separate grounds (see section 4.5).

4.3.2.1 Rectifier

The idea is to use a 230V to 48V transformer to drive the UTP cable from the control box in the shack to the Pluto enclosure, and then have a custom-made 48V primary transformer to power the 12V and 5V regulators.

I initially decided to use a 50W transformer in the control box, but the regulation was horrific (just as in the 28V switchmode power supply case, sections 4.3.1.1.1, 4.3.1.1.2). So I selected an 80W transformer in the control box and a smaller 50W transformer in the Pluto enclosure where space is limited.

The transformers are assumed to behave like Talema 50W/80W toroidals. Simulation is as in the 28V switchmode power supply case (see sections 4.3.1.1.1, 4.3.1.1.2).

For the control box transformer,

- Primary equivalent resistance (230V primary) is 28Ω · 120% = 34Ω.
- Secondary equivalent resistance is $V^2/1000 \cdot 120\%$. For a 48VAC secondary, this is 2.8Ω.

For the Pluto enclosure transformer,

- Primary equivalent resistance (48V primary) $R \approx V^2/700 \cdot 115\%$. For a 48VAC winding, this is 3.8Ω.
- Secondary equivalent resistance is $V^2/700 \cdot 115\%$.

I used https://www.falstad.com/circuit/index.html to simulate the power chain (see figure 37). The 1.5Ω resistor is the resistance of 15m of UTP (0.1Ω/m). The two 1.5kΩ resistors are the two RT424548 relay coils[25]. The circuit is saved in 5V12VDoubler.txt.

---

25 These are not part of the QO-100 transceiver project, they are part of a separate switching arrangement. See section 7.3 for details.

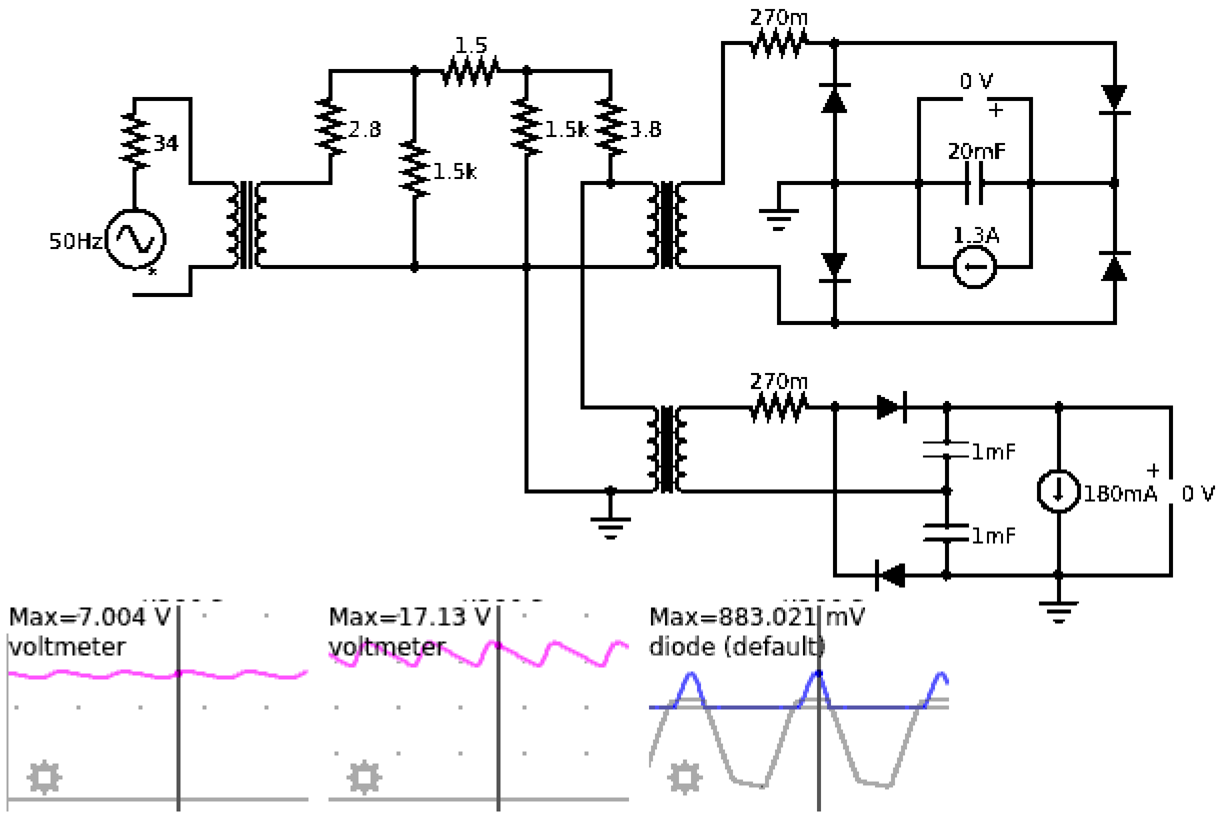

Figure 37: Circuit simulation for the 5V and 12V power supply transformers and rectifiers. The transformer on the left is that in the control box while the two transformers on the right simulate the transformer in the Pluto enclosure. Bottom left: 5V supply output. Bottom centre: 12V supply output. Bottom right: Voltage and current across a bridge rectifier diode. This is for a Pluto enclosure transformer turns ratio of 2·0.1875=0.375.

Minimum (full-load) voltage: Let us say mains can go down by 10%, so it could be 296Vpp. The simulator gives the following results:

Pluto enclosure transformer turns ratio	Pluto enclosure transformer secondary voltage, V/2	Secondary resistance per secondary half, V²/700·115%/2	12V rail doubler capacitor (each), µF	12V rail trough voltage	5V rail filter capacitor, µF	5V rail trough voltage
0.417	10	0.33	1000	16.54	20000	7.35
0.4	9.6	0.30	1000	15.9	20000	7.08
0.375	9	0.27	1000	14.4	4400	6.15
0.375	9	0.27	2200	16.14	9400	6.44
0.375	**9**	**0.27**	**2200**	**16.20**	**20000**	**6.62**
0.375	9	0.27	4700	16.56	20000	6.61
0.375	9	0.27	1000	14.6	20000	6.64
0.333	8	0.21	1000	12.6	20000	5.91

With the turns ratio of 0.375 (two 9V secondaries), the 12V supply ripples between 16.2 and 17.3V. This is fine.

The 5V supply ripples between about 6.6 and 7V. This is marginal, I would have liked some more, but I had already ordered the transformer. Because of the large capacitance, the 5V bridge rectifier current rises to a whopping 4A at the peaks; for this reason it was decided to use two bridge rectifiers and split the 5V supply in two halves, to reduce the diode voltage drops. The simulator predicts a diode drop of about 880mV, which isn't unrealistic.

Maximum (no-load) voltage: Let us now say mains can go up by 10% from nominal, so it could be 358Vpp. Setting the current sunk[26] to 10mA on the 12V rail and 20mA on the 5V rail and removing the two 1.5kΩ relay loads, the 12V rail reaches 26.0V while the 5V rail reaches 12.3V.

4.3.2.2 Test results

A prototype was built, using resistors to emulate the loads. A variac varied the mains voltage. The following components were used (o/c: open circuit). Note that in some cases, the loads were somewhat heavier than the actual consumption of the units the power supply will have to feed in practice.

	Full load test	No-load test
Resistors emulating the RT424548 relay coils[25] across secondary of the 230V-48V transformer and primary of the 48V-9V&9V transformer	1.5kΩ	o/c
Resistor emulating 15m of UTP (0.1Ω/m), connected from the secondary of the 230V-48V transformer to the primary of the 48V-9V&9V transformer	1.5Ω	1.5Ω
Resistor emulating 5V, 500mA ADALM Pluto load	10Ω	o/c
Resistor emulating 5V, 800mA load of other consumers	6Ω	o/c
Resistor emulating 12V, 180mA LNB and F1OPA driver amplifier loads	64Ω	o/c

The smoothing capacitors used were: 5300µF for the 5V, 500mA section, 12000µF for the 5V, 800mA section and 2x2200µF for the 12V, 180mA section. The voltage regulators were built as proposed. The results were encouraging, in fact, for the 5V supplies they were much better than predicted (see section 4.3.2.1):

	Full load test	No-load test
Mains voltage set to...	$207V_{RMS}$	$253V_{RMS}$
230V-48V transformer secondary voltage	$43.4V_{RMS}$	$55.0V_{RMS}$
48V-9V&9V transformer primary voltage	$43.0V_{RMS}$	$55.0V_{RMS}$
5V, 500mA supply rectifier output to regulator	7.86V peak, 7.46V trough	13.2V
5V, 800mA supply rectifier output to regulator	7.95V peak, 7.35V trough	13.1V
12V, 180mA supply rectifier output to regulator	18.5V peak, 17.3V trough	27.7V

26 Note that this is a remnant from the days when I used LT1086-ADJ regulators, which use an external voltage divider drawing about 10mA. I no longer use these regulators, but the values are not unrealisitc anyway.

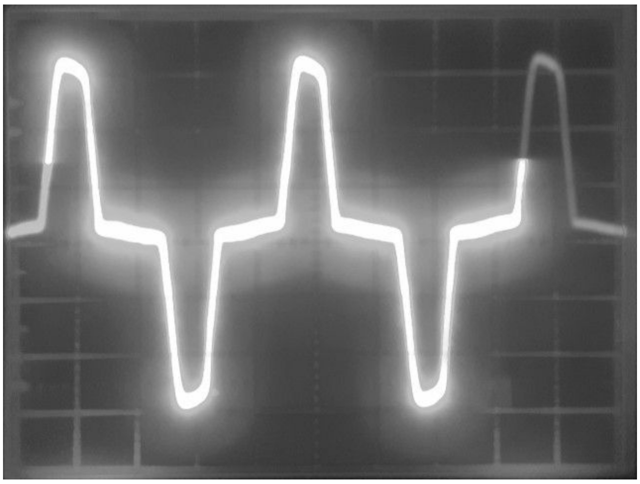

Figure 38: Voltage drop across 1.5Ω resistor emulating 15m of UTP, on 0.5V/div, with full load. This can be viewed as the current into the primary of the 48V-9V&9V transformer, at 0.33A/div.

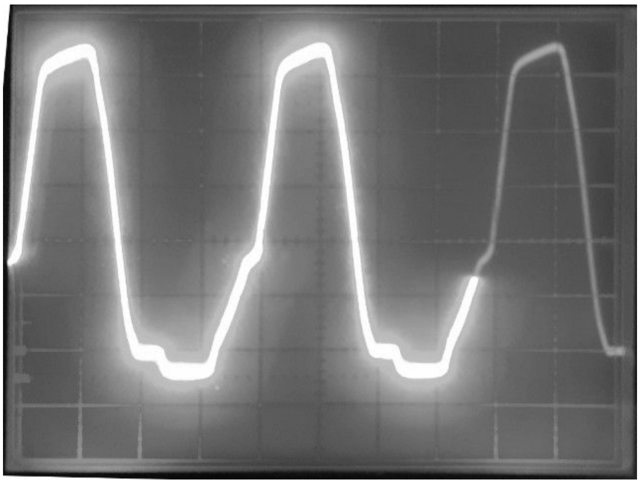

Figure 39: Voltage drop across one of the 5V, 800mA supply bridge diodes, at 2V/div. 5V 800mA supply under full load, others no load, $230V_{RMS}$ mains input.
0V is at the second graticule from bottom. The diode voltage drop is about 0.8V.

4.3.2.3 Linear voltage regulators

4.3.2.3.1 Voltage regulation IC selection

I initially chose LD1086-ADJ LDOs which feature excellent ripple rejection. However, despite the use of the recommended capacitors, these probably had stability problems (details in section 4.3.2.3.2). I think this has to do with the layout; tag strips do not lend themselves to short wires!

So, LT1086-5 fixed LDOs were finally used for the 5V supplies and a conventional 7812 for the 12V supply. These have the advantage that their ground pin comes straight out of the case, so it is possible to solder the decoupling capacitors directly on the IC leads, thus avoiding the long lead lengths associated with tag strip construction.

- 12V regulator: I.A.W. section 4.3.2.1, the input voltage to this will be from 16.2V (lowest ripple bottom) to 27.7V (actual measurement, section 4.3.2.2). This is ideal for the 7812, nothing special is needed.
- 5V regulators: I.A.W. section 4.3.2.1, their input voltage could be as low as 6.6V (lowest ripple bottom), and reach a maximum of 13.2V (actual measurement, section 4.3.2.2). At the lowest voltage, the LT1086-5 will probably be holding up by the skin of its teeth, but there isn't much I can do about this... There are better LDOs, like for example the LM2940 which has a guaranteed drop-out of just 1V. However it has a very strict output capacitor specification for stability at light loads (22µF at 0.1 to 1Ω ESR) which is extremely difficult to meet.

4.3.2.3.2 Instability and hum problems

I initially used LD1086-ADJ LDOs for U3, U5 and U8. When I put the whole thing together, I had horrific hum problems both on receive and transmit. There was no perceptible background hum and SSB voice didn't sound so bad, but CW signals were audibly modulated by hum. This must have been PM sidebands on the OCXO.

With my trusty Tektronix 465B oscilloscope, I found the world was crawling with 100MHz modulated by 100Hz. What I think must have been happening is that the whopping 100MHz signal on the OCXO power pin was getting into the output transistors of the LD1086-ADJ regulators, driving them doolally and making them let the hum through.

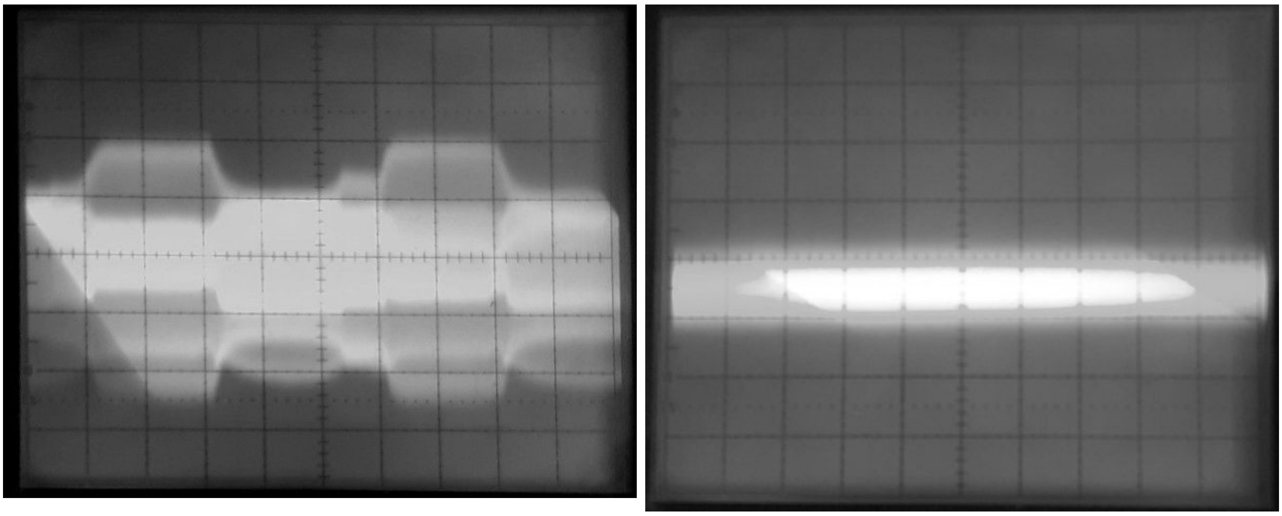

Figure 40: Left: Noise on the 12V_LNB rail before changes to the power supply. 20mV/div 2ms/div. Note that the noise was pretty much the same on all supplies.
Right: Noise on the 5V_REF rail after changes to the power supply. 20mV/div, 1ms/div

This is what I did:

- On the 5V and 12V power supply, I placed Tantalum capacitors from the regulator inputs to nearby ground. I also shortened the pins of the regulator output decoupling capacitors (these were 150µF electrolytics at the time).
- On the 5V and 12V power supply again, I fitted capacitors C30 to C37 across bridge rectifiers D2 and D4 (see figure 14).
- On the frequency reference PCB, I added the filter components L1, L2 and C7, C8 on the 5V_REF and 0V_REF lines (see figure 12).

Interestingly, it was the last two changes which made the most difference. After these changes, there is no perceptible hum.

4.3.3 Inrush current protection

Toroidal transformers are notorious for their huge inrush currents. I decided to include NTC thermistor TH1 in the control box to prevent this from constantly blowing the power fuse or ruining the power switch.

The simulation run in section 4.3.1.1.2 for the 28V switchmode power supply for the PA shows[27] it draws around 390mA_{RMS} from the mains. The simulation run in section 4.3.2.1 for the 5V and 12V power supply for the Pluto enclosure shows it draws around 210mA_{RMS} from the mains. The transformers themselves will dissipate around 10W each for magnetic losses[28]. So, the total consumption under full load will be around $390mA_{RMS}+210mA_{RMS}+30W/230V_{RMS}=730mA_{RMS}$.

27 The Falstad simulator does not have an RMS measuring function as far as I know. The "measurement" has been made by manually working out a point-for-point root-mean-square from the waveforms provided.

28 http://www.talema.it/trf/trfpdf/0080P1_0209.pdf shows the specification of a typical 80W toroidal transformer.

The smallest thermistor I found at Mouser's is the B57153S0330M. This has a maximum rating of 1.3A, 1.4W. Since current draw will be low during receiving periods, bypass switch SW4 is used to keep the thermistor from creating unnecessary losses.

4.3.4 Isolated 5V switchmode power supply (for the F1OPA driver amplifier)

With the POTY transmitting antenna used initially, the POTY antenna ground was electrically connected to the LNB ground. The same power supply supplied the F1OPA driver amplifier and the LNB, so a ground loop would form (see figure 46). In order to break this ground loop, it was necessary to use an isolated 5V switchmode power supply to power the F1OPA driver amplifier.

With the Ice Cone v2.1 transmitting antenna this should no longer be necessary; it should be possible to power the unmodified F1OPA driver amplifier directly from 12V regulator U8. The description of the isolated 5V switchmode power supply which follows is probably redundant.

The F1OPA driver amplifier (P/N OPA_PA20DBM_2G4) already has a small non-isolated DC-DC converter on board, so I decided to replace that with an isolated 5V switchmode power supply.

I.A.W. its specifications[29], the F1OPA amplifier with its on-board non-isolated DC-DC converter draws 1.2W. According to designer F1OPA (private communication), the on-board non-isolated DC-DC converter provides 5V, so I decided to find a small isolated 5V switchmode regulator capable of providing 5V at 2 or 3W. I decided to feed this off the unregulated rail before the linear 12V regulator U8, to avoid placing unnecessary stress on the 12V regulator. The unregulated rail's voltage (see section 4.3.2.1) goes from 16.2 to 26.0V, so the isolated 5V switchmode regulator will have to be capable of handling this.

Mouser sell a bewildering range of such isolated 5V switchmode regulators. From all these, I chose[30] the Recom RS3-2405SZ/H2[31] because it is small, not overly expensive, has relatively low output ripple and shows a filter on its datasheet to make it compliant with EN55032 class B (conducted emissions). A good alternative may be the Traco Power TDR 2-2411WI.

The F1OPA amplifier with on-board non-isolated DC-DC converter draws 1.2W. Assuming its original non-isolated DC-DC converter was 85% efficient, this means that the amplifier itself draws around 1W at 5V.

The Recom RS3-2405SZ/H2 I chose has a minimum efficiency of 76%, which means the input power could be 1W/76%=1.32W. Driving this from the 12V supply smoothing capacitors, I.A.W. section 4.3.2.1, the minimum average input voltage will be (16.2V+17.3V)/2=16.75V, so the input current will be 1.32W/16.75V=79mA. Recom recommend[31] a fuse of two to three times the maximum input current, so I think a 200mA fuse will do fine. Note that the Recom RS3-2405SZ/H2 has a peculiar trait: At around 2-3V input, it draws a huge amount of current and blows the fuse! This is not normally a problem since the input rapidly exceeds / falls below 2-3V on power-up / power-down, but I did get caught out when slowly increasing the voltage while testing.

29 https://www.passion-radio.com/index.php?controller=attachment&id_attachment=500.
30 Isolated_SMPS_selection_for_F1OPA_driver_amplifier.ods.
31 Datasheet: https://g.recomcdn.com/media/Datasheet/pdf/.fatj5IpW/.t1305551dee110dff2189/Datasheet-28/RS3.pdf.

4.4 Power amplifier control board

4.4.1 Tx On indicator and VSWR cut-out

The DX-Patrol 12W 2400MHz Power Amplifier has two analogue outputs. According to its manual[32], one gives 0 to 4V (FWD) and the other 1.5V to 4V (RFL). In practice I found that when transmitting with enough power to just not trigger Layla,

- on CW the FWD output gives about 3.15V and RFL gives about 1.1V.
- on SSB the FWD output can rise to almost 6V(!) while RFL can reach 3V.

These are fed into an LM393 dual comparator to light respective LEDs; see figure 19.

I thought it would be a good idea to create a latch which will detect RFL and switch off the 28V regulator using the LM5576 regulator's "SD" pin. Because of the high voltages involved, this has been implemented with a transistor bistable. A green "SWR OK" LED, D10, shows that RFL hasn't tripped. I could have used a red "VSWR" LED instead, but this would not be easy to distinguish from afar from the (also red) "Tx On" LED D9.

Power for the VSWR detector section is in series with the "Power On" LED D7. This saves the 5mA or so of current which would be drawn if the "SWR OK" LED were driven separately.

4.4.1.1 Normal condition: Q3 on

See figure 19. When the circuit is first powered up, C15 is empty and keeps Q6 off. This switches Q5 on, forcing the Q2-Q4 pair off and thus Q3 on (assuming U2A isn't holding it off). This arrangement is the "power-on reset".

I used prefabricated LED assemblies because of their water-tightness. Only 12V parts were in stock. Their datasheet[33] only specifies their maximum current, so I had to give them a try to see what actually gives. The results are shown in figure 41.

32 https://dxpatrol.pt/wp-content/uploads/2022/06/AMP2.pdf.
33 https://mspindy.com/spec-sheets/FL1M-8CW-4.pdf.

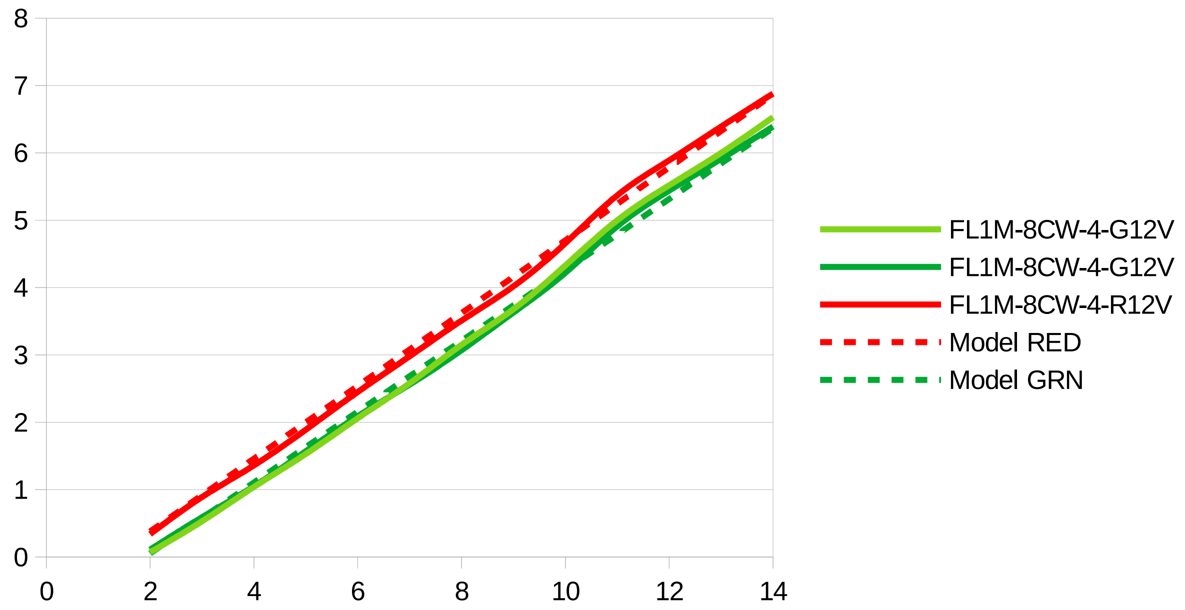

Figure 41: Measured LED V-I characteristics[34]. The red line is for the red LED, while the two (almost indistinguishable) green lines are for the two green LEDs I have. Note that this is not necessarily universal; different batches of LEDs could well have different characteristics, as the manufacturer only specifies[33] maximum current.
Horizontal axis: Voltage, V. Vertical axis: Current, mA.
The red LED has been "modeled" as a 1.3V source with a 1.85kΩ series resistor.
The green LED has been "modeled" as a 1.9V source with a 1.9kΩ series resistor.

The circuit is modeled as follows, again using https://www.falstad.com/circuit/index.html (circuit saved in Falstad_Q3_on.txt):

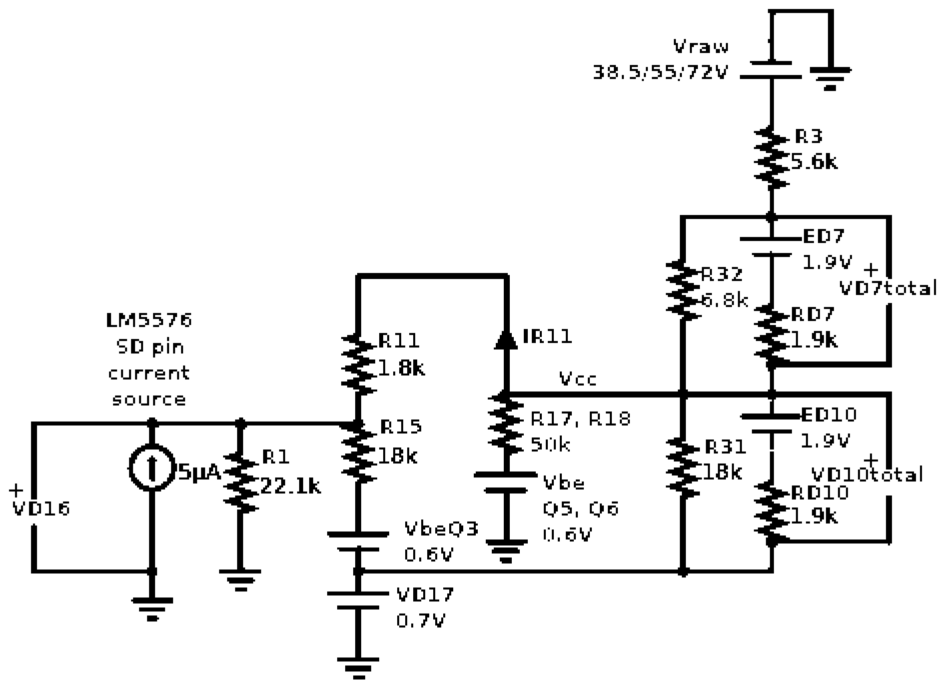

Figure 42: Approximate equivalent circuit, Q3 on. Note that R18 has changed since.

34 Source: LED_V-I_curve.ods.

The results for different rectifier voltages (Vraw) are:

Vraw	38.5	55	72	V
ID7	2.972	4.482	6.037	mA
VD7total	7.546	10.415	13.371	V
ID10	2.894	4.374	5.899	mA
VD10total	7.399	10.211	13.108	V
IR11	0.626	0.865	1.113	mA
Vcc	8.099	10.911	13.808	V
VD16	6.973	9.353	11.805	V

VD16 is applied to the SD ("enable") pin of the LM5576. It is very comfortably within the 1.225 to 14V limits specified. It is also unlikely to activate D16 (not that it would matter if it did).

Note that D14 and D16 were fitted after I blew up U1 and U4 (in that order) by forgetting to connect the ground to J6. Oops...

R18, R19 and C15 give the time constant for the power-on reset. The threshold is the 0.6V Vbe of Q6. Depending on the choice of R19, this will be reached faster or slower (or never). If too large an R19 is used, a larger (more expensive) capacitor is needed to give a long time delay. If too small an R19 is used, the voltage might never quite reach 0.6V (leaving the circuit permanently in reset). The capacitor charging current is about 15µA while its own leakage is unlikely to be an issue[35].

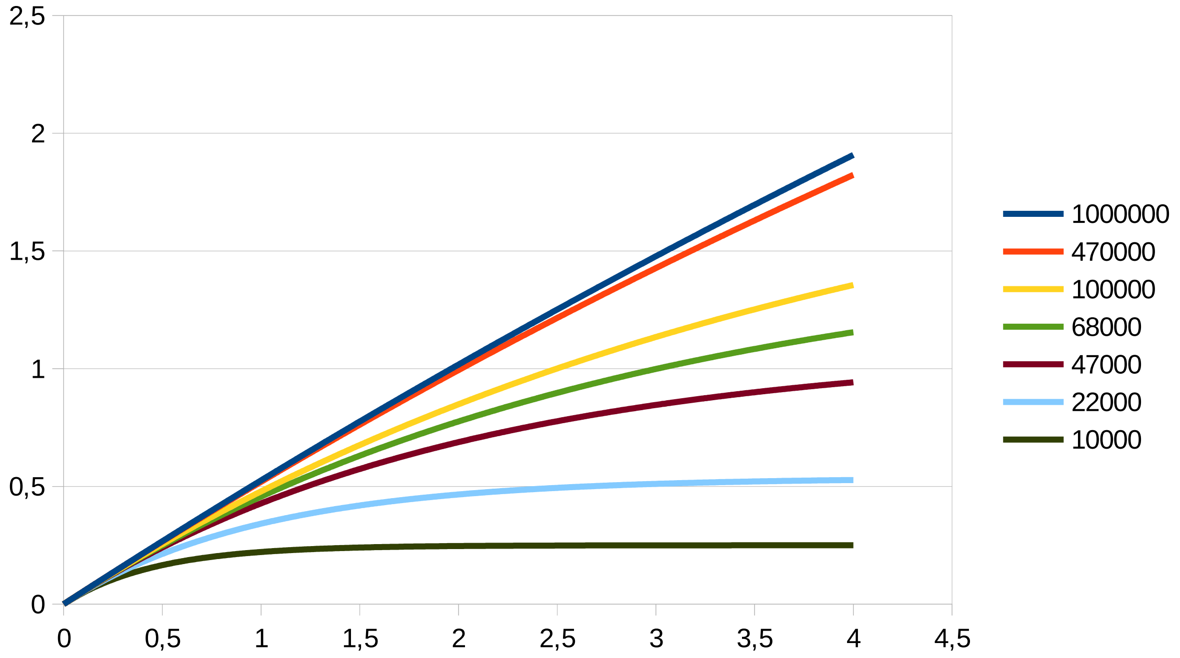

Figure 43: Q6 Vbe, V (vertical) vs. time, sec (horizontal), with different values of R19[36]. Vcc (the voltage feeding R18) has been taken to be 8.099V, which is the lowest expected value (see table above). The leakage current of C15 has not been taken into account.

35 I.A.W. datasheet https://datasheets.kyocera-avx.com/tap.pdf for C15 (a TAP226K010SCS), this is 1.7µA max.
36 Source: Reset_RC.ods.

4.4.1.2 VSWR alarm: Q4 on

In this situation, Q2's base is powered through LED D10. The reason for using a Darlington pair here is that the base current has to be low, to prevent D10 from illuminating. Still, in practice I found I had to add R31 (it was not fitted initially) to stop D10 illuminating.

The slight problem with using the Darlington pair is that Q4's collector doesn't quite go down to 0V. This is why D17 has been added to the emitter of Q3, to make sure it turns off.

The circuit is modeled as shown in figure 44, again using https://www.falstad.com/circuit/index.html (circuit saved in Falstad_Q4_on.txt).

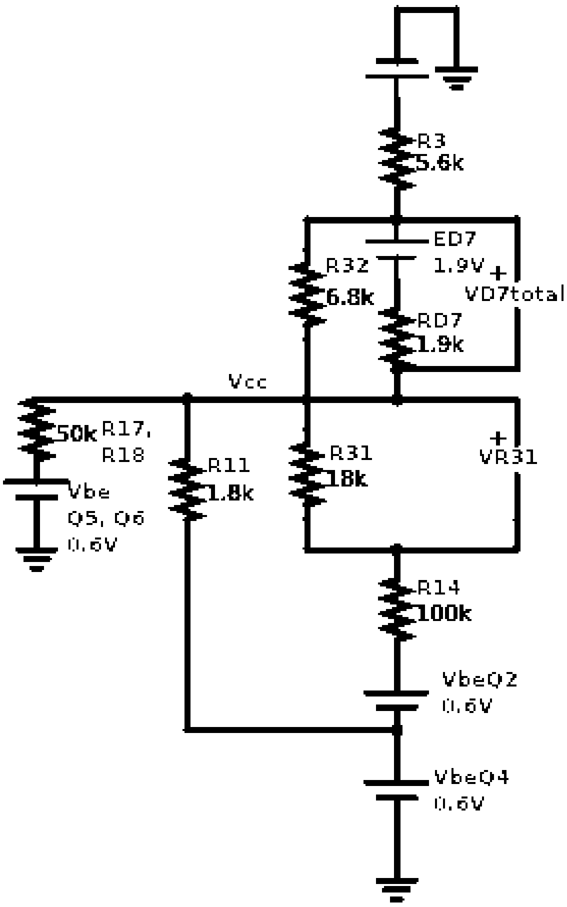

Figure 44: Approximate equivalent circuit, Q4 on. Note that R18 has changed since.

The results for different rectifier voltages (Vraw) are:

Vraw	38,5	55	72	V
ID7	3.016	4.482	5.993	mA
VD7total	7.631	10.416	13.286	V
VD10=VR31	0.990	1.481	1.985	V
Vcc	7.695	10.906	14.215	V

I checked an FL1M-8CW-4-G12V LED assembly, it does not illuminate perceptibly at voltages below 2V. VR31 reaching 1.985V might just make it light a little.

4.4.1.3 Special case: Q3, Q4 off

This is an improbable situation but I suppose it might happen during power-on reset. Nothing would hold Vcc down and this could damage the LM5576, since its SD input would soar to beyond the absolute maximum 14V permitted.

D16 limits the voltage to safe values. At Vraw = 72V, the current into D16 (pessimistically ignoring IR15, IR1 and IR14, IR17, IR18) would be approximately ID16 = (Vraw-VD16) /

(R3+(RD7//R32)+R11) = (72V-12V)/(5.6kΩ+(1.9kΩ//6.8kΩ)+1.8kΩ) = 6.7mA. D16 would therefore dissipate 12V·6.7mA = 80mW, which is well within its ratings.

D16, a BZY55B12, has a maximum voltage of 12.24V at 5mA and its differential resistance at 5mA is 20Ω maximum (lower at higher currents, presumably). So the actual voltage across it at 6.7mA could reach 12.24V+(6.7mA-5mA)·20Ω = 12.27V. Fine.

4.4.2 PTT from ADALM Pluto

DK1ML states that[37] "The PTT output only requires an LTV-354T optocoupler which is soldered directly to the two pins GPO0 and GPO1 without a series resistor, no further transistors are required".

I.A.W. its schematic[38], the ADALM Pluto drives GPO0 and GPO1 directly from the AD9363's GPO0 and GPO1 pins. VDD_GPO which powers these pins is powered by a fairly measly 1.3V (see sheet 9 of the ADALM Pluto schematic[38]). It is actually supplied via "E3", which appears to be a ferrite bead or something similar with a resistance of about 100Ω.

It is impossible to gauge what the current through the optocoupler LEDs will be. Furthermore, it is likely to vary a lot with temperature as the temperature coefficients come into play.

I guess (perhaps incorrectly) that the 100Ω resistance of the "E3" ferrite bead will dominate on the ADALM Pluto and set the optocoupler LED current[39] to between, say, 5mA (+75ºC, 0.85V across the LED) and 1.5mA (-25ºC, 1.15V across the LED).

Optocoupler LTV-354T (U7 in figure 14) could[39] have a CTR as low as 20% at 1mA. So, the current through its phototransistor could be as low as 300µA.

According to CT1FFU[40], the DXPatrol PA PTT line draws about 17mA. Transistor Q8 drives this PA PTT line (see figure 19). To saturate reliably, Q8 will need a base current of 1.7mA, but from optocoupler U7 we might only have just 300µA; hence the use of transistor Q7.

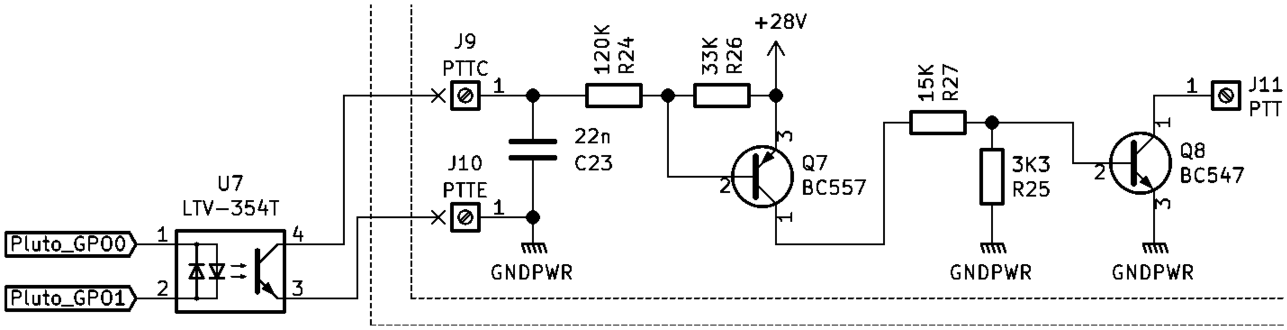

Figure 45: PTT drive circuit. From figures 14 and 19.

37 https://forum.amsat-dl.org/index.php?thread/3372-pluto-mods-just-1-part-ptt-dc-mod-gpsdo-mod-ethernet-connect/.
38 https://wiki.analog.com/_media/university/tools/pluto/hacking/plutosdr_schematic_revb.pdf.
39 I.A.W. the LTV-354T optocoupler datasheet, https://eu.mouser.com/datasheet/2/239/LTV-354T Series-1308-1175585.pdf.
40 I.A.W. personal communication with CT1FFU, the DXPatrol PA has an internal optocoupler on its PA PTT line. This optocoupler is powered from +5V with a 220Ω resistor. This is likely to draw around (5V-1.2V)/220Ω=17mA.

4.5 Ground loops

One of the major pains and bains in this kind of project is avoiding ground loops. Transformer coupling has been used in most places for this. The grounding scheme has been implemented as shown in figure 46.

- The 12V rail grounds (0V_LNB with 0V to the 5V SMPS) and
- the 5V rail grounds (0V_REF, 0V_Pluto, 0V_Ethr, 0VS)

are kept separate. Their only common point (unavoidable with the current set-up) is at the antenna.

Ethernet itself poses no problems, as it is transformer coupled anyway.

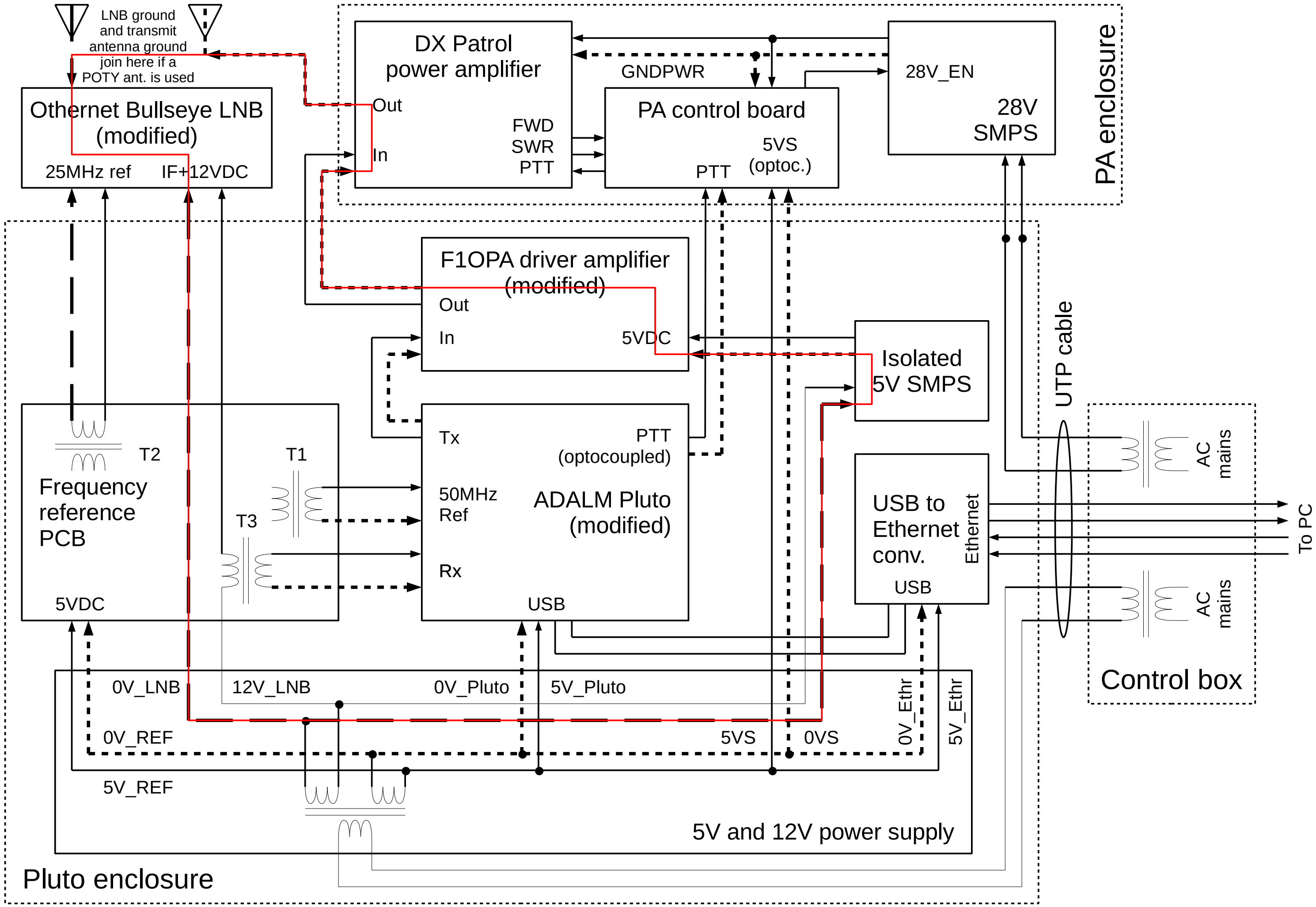

Figure 46: Integration of the various components showing how ground is connected to avoid ground loops. For simplicity, rectifiers and linear voltage regulators are not shown. The red line shows the ground loop which would form if a POTY transmit antenna were used without the isolated 5V switchmode power supply. Note that with the Ice Cone v2.1 antenna, this is no longer an issue.

5 Appendix B: On the use of a single-receptacle LNB

As stated in section 2.6.2.1, I originally planned to use a single-receptacle LNB. This required the 25MHz reference to be sent through the same coaxial cable as its RF output and DC feed. This imposed some pretty austere restrictions:

- The 25MHz signal had to have very low harmonic content, as harmonics could appear as LNB IF output. SV1BDS[13] recommends the use of a crystal ladder filter for this.
- A rather complex triplexer was needed at the LNB to separate the 25MHz signal, 740MHz LNB IF output and DC feed.

I had decided on an Amiko L107 LNB which is very cheap and had successfully been modified by George, SV1BDS. Unfortunately, as it turned out, although we both ostensibly bought the same LNB, mine was different to his; I dare say inferior, since it lacks the stripline filter. Still, it worked...

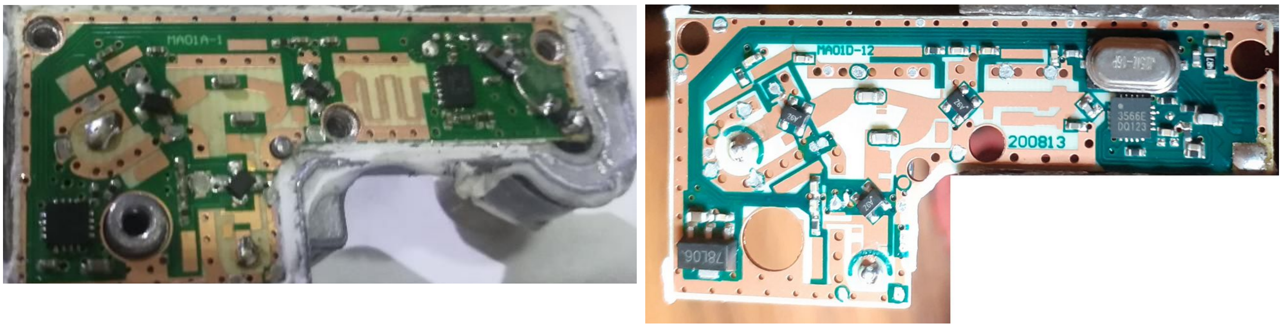

Figure 47: Innards of SV1BDS' Amiko L107 LNB (left)[41] and of the one I bought (right).

5.1 25MHz crystal ladder filter

The idea of using a crystal ladder filter came from SV1BDS's work[45]; see figure 31.

Common-or-garden crystals can only handle 1mW. With a maximum crystal series resistance of 35Ω, P=I²R losses give:

$$I=\sqrt{P/R}=\sqrt{1\,mW/35\,\Omega}=5\,mA_{RMS}$$

See figure 55. For a 5V squarewave from U1B and U1C, the first Fourier term is 0.64, i.e. 5V · 0.64 = 3.2Vpp = 1.13V_{RMS}. For 5mA_{RMS} from 1.13V_{RMS}, the total series resistance must be no lower than 1.3V / 5mA = 230Ω. With R6 = 270Ω in series, even if the output is short-circuited, no harm will come to the crystals.

According to PY2RN (see section 5.3), we want around about 0dBm on X1 (the "corner pin") of the Amiko L107 LNB's RDA3566E chip. Assuming he was considering a 50Ω system, 0dBm is 223mV_{RMS}.

The transmission line impedance is 75Ω. Feeding the system with a 2:1 transformer T2, at the input of T2 the impedance is 300Ω (lovely) and the voltage to the transformer will need be at least 2 · 223mV_{RMS} = 446mV_{RMS}. Assuming the four crystals each have a series resistance of 35Ω, the 1.13V_{RMS} from U1B and U1C will be dropped to 1.13V_{RMS}·300Ω/(270Ω+4·35Ω+300Ω) = 477mV_{RMS}. Just right. In practice the crystal resistance is unlikely to be quite this high, but the input of the LNB's RDA3566E won't be all that fussy (hopefully).

41 Source: https://forum.amsat-dl.org/cms/index.php?attachment/3717-l107-jpg.

The discussion above is, unfortunately, purely academic; the losses of the subsequent triplexer are so bad (see sections 5.2.2 and 5.2.4) that output level calculations are sadly irrelevant.

5.2 Triplexer

The triplexer was a complicated little beast. It fed +12V at 80mA into the Amiko L107 LNB, also passed the 25MHz clock while separating out the 740MHz IF for routing to the ADALM Pluto.

5.2.1 DC feed

See figure 55.

LNB side: No sensible-value coils have resonant frequencies anywhere near 740MHz. The Amiko L107 LNB uses a narrow meandering microstrip as an RF choke to isolate the IF from the power feed, and I used this. L2, A Taiyo Yuden CBMF1608T4R7M 4.7µH 0603 coil has a minimum resonant frequency of 45MHz, so it acted as a good isolator for the 25MHz clock, at least; its reactance at 25MHz is around 700Ω. The LNB had a 4.7Ω 1206 size resistor in this position which was substituted by L2. L2's DC resistance is just 0.24Ω. R4 and R5, two 8.2Ω 0603s, emulated the original 4.7Ω resistor in the LNB.

Frequency reference PCB side: After having broken a few SMD coils due to wiring moving while attaching / detaching the F-type plug, I decided to use a 5.6µH axial leaded choke I had at hand (L1). I found this has a resonant frequency of 48MHz, so (extremely roughly) it can be modeled as a 5.6µH inductor in parallel with 2pF. I could parallel-resonate that with a small coil for 740MHz, but decided it wasn't worth the effort...

5.2.2 25MHz series resonant circuits

I arbitrarily chose a tuned circuit coil Q of around 5 (note that this turned out not to be a particularly smart idea). With a series resistance of 2·75Ω=150Ω, the coil reactance had to be 750Ω. So, I used Taiyo Yuden CBMF1608T4R7M 4.7µH coils for L3 and L7. 4.7µH resonates at 25MHz with 8.6pF (minus stray capacitances).

In practice, I found this LC circuit was unbelievably lossy - it lost about 14dB, with the series resistance being around 500Ω at resonance! Freaky... The problem was clearly with the coil, see figures 48 and 49.

To improve matters, I replaced the Taiyo Yuden CBMF1608T4R7M coils L3 and L7 with coils made with 33 turns on an Amidon T37-2 core. The wire used was probably 38SWG (around 0.15mm diameter); see figure 50. Tweaking was necessary; I started with 36 turns and started taking the turns off one at a time to get to the peak. 11mm of wire is required per turn, so I always left 11mm spare in case I needed to put the turn back on!

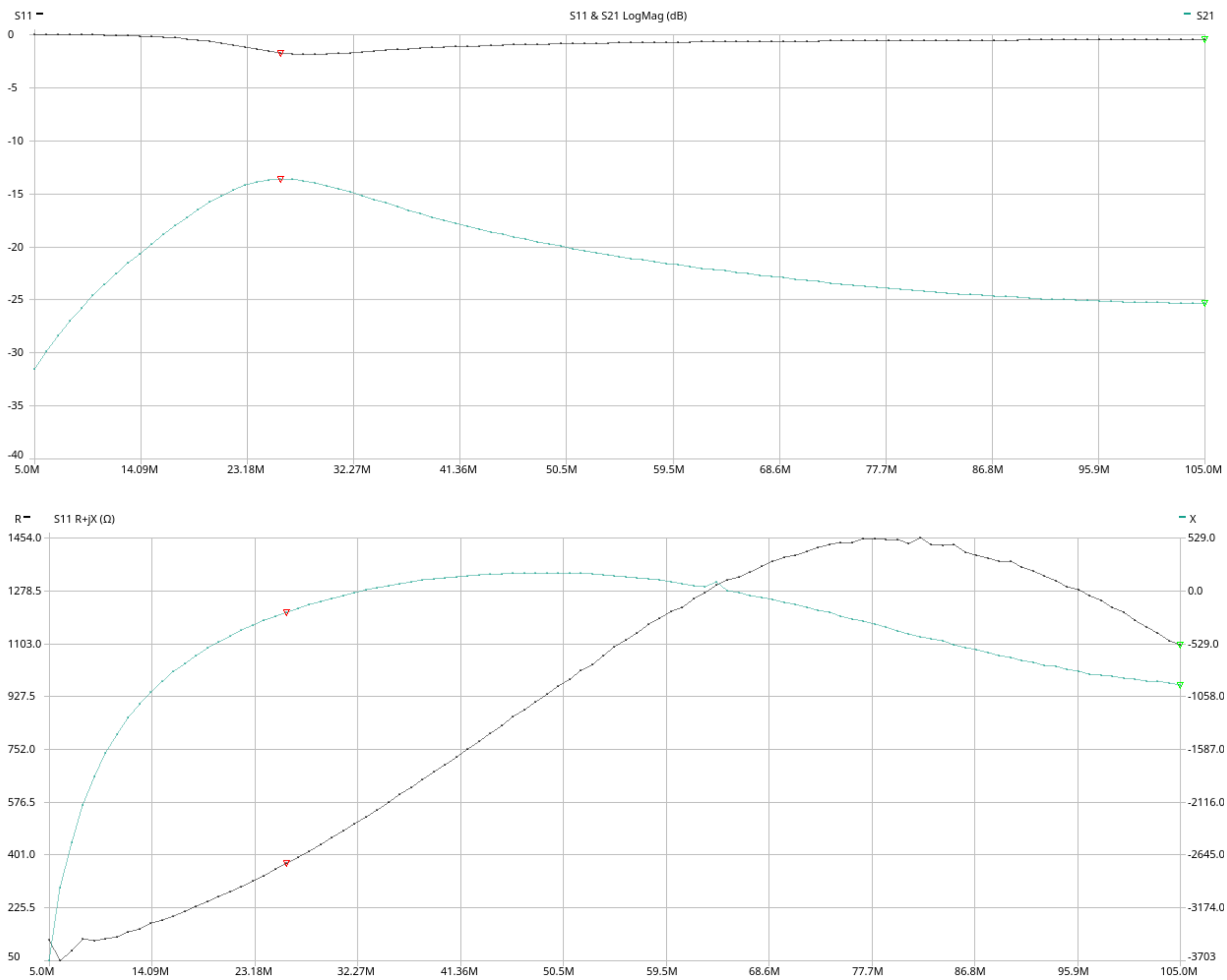

Figure 48: S11 and S21 (above, 50Ω) and input R+jX (below) of the 25MHz series resonant circuit made with a Taiyo Yuden CBMF1608T4R7M 4.7µH coil and an AVX 08051A8R2JAT 8.2pF capacitor.

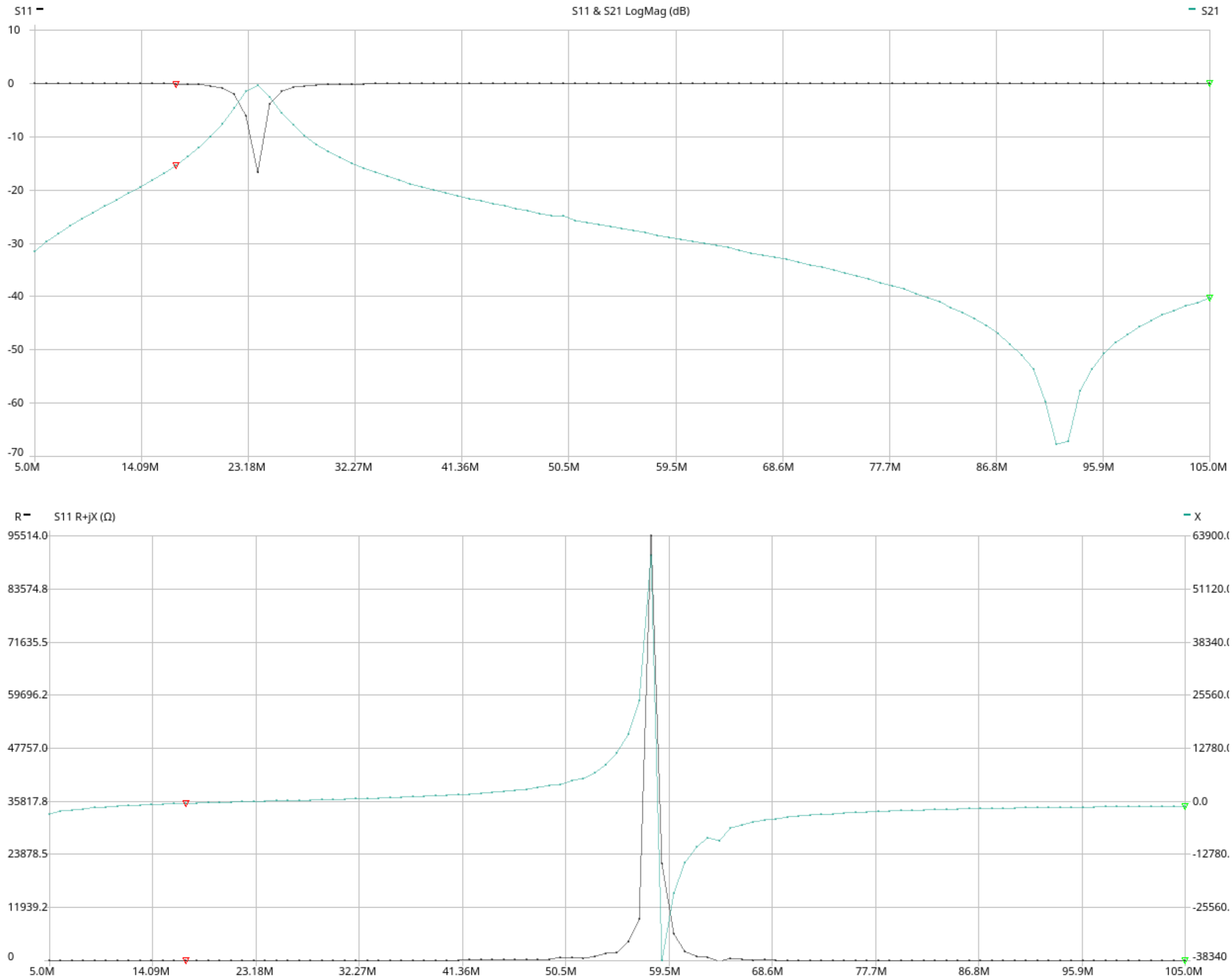

Figure 49: S11 and S21 (above, 50Ω) and input R+jX (below) of the 25MHz series resonant circuit made with an airwound coil, 20 turns of 0.5mm wire closewound, ½" diameter, and an AVX 08051A8R2JAT 8.2pF capacitor.

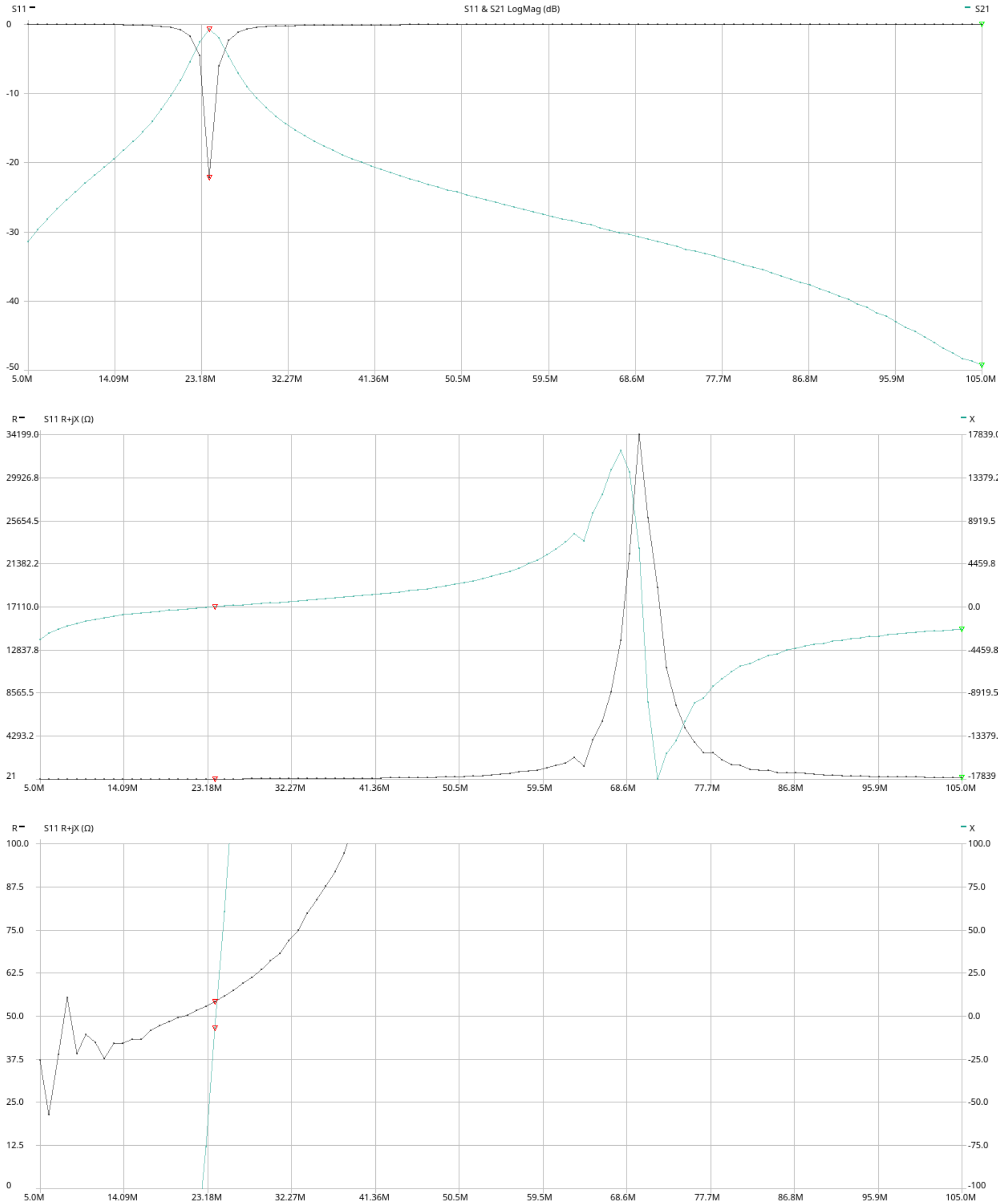

Figure 50: S11 and S21 (above, 50Ω) and input R+jX (mid and below) of the 25MHz series resonant circuit made with a coil with 33 turns on an Amidon T37-2 core, and an AVX 08051A8R2JAT 8.2pF capacitor.

Toroidal coils do not fit in the LNB. I kept the Taiyo Yuden CBMF1608T4R7M coils in the LNB series-resonant circuit, but paralleled two of them up (L4, L9). Even so, the losses of L4, L9 are horrific; a much better solution is needed, really.

5.2.3 25MHz parallel resonant circuits

I tried the same Taiyo Yuden CBMF1608T4R7M 4.7µH coil for the parallel resonant circuits L5 with C14 and L6 with C15. This worked pretty well giving a nice, broad dip:

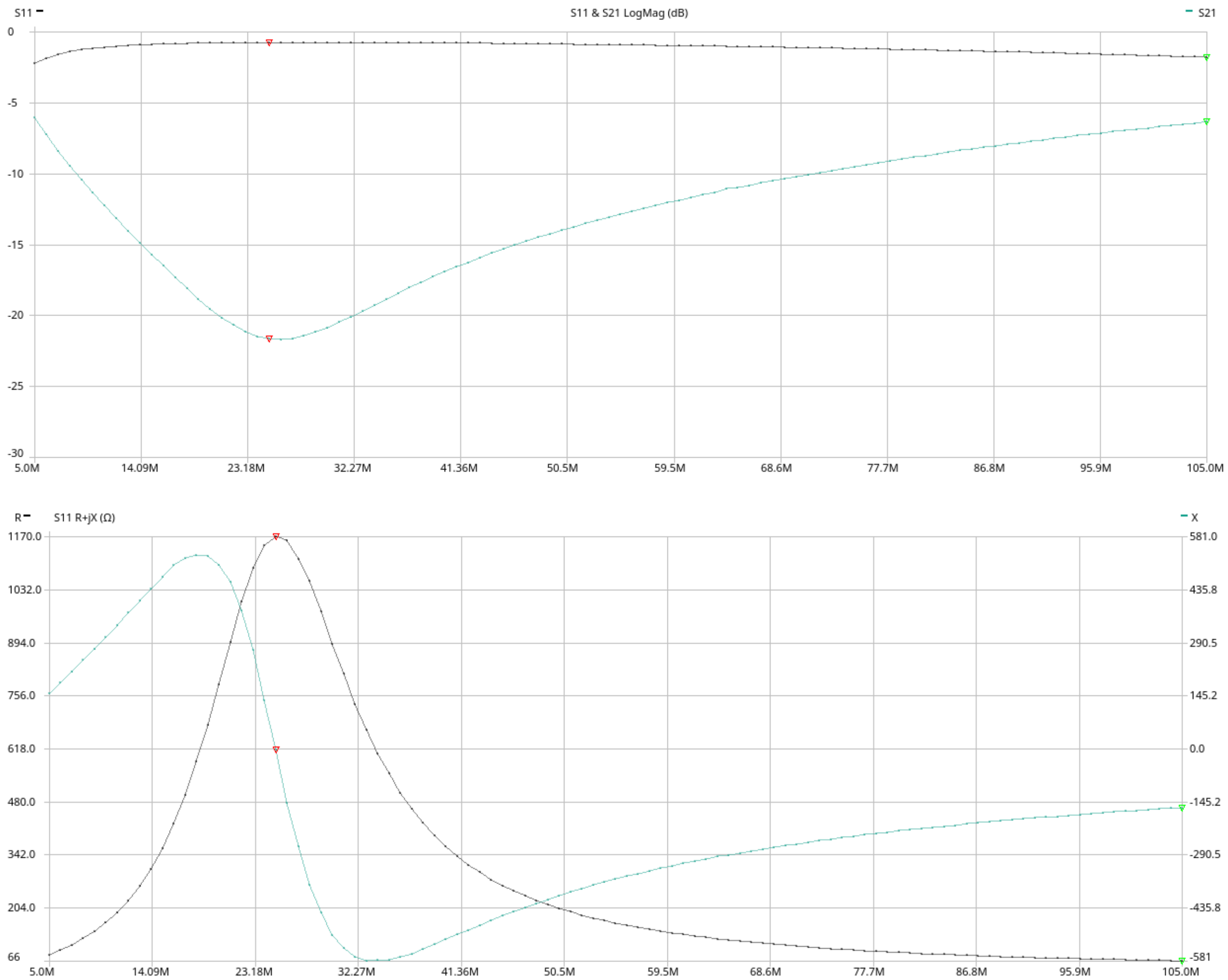

Figure 51: S11 and S21 (above, 50Ω) and input R+jX (below) of the 25MHz parallel resonant circuit made with a Taiyo Yuden CBMF1608T4R7M 4.7µH coil and an AVX 08051A8R2JAT 8.2pF capacitor.

5.2.4 Triplexer results

See figure 55. The resulting arrangement with the triplexer gave 900mVpp (320mV$_{RMS}$) of 25MHz on SK2 into 50Ω (I didn't have a decent 75Ω load to test it with). Connecting the ADALM Pluto output (P2) to a 50Ω load made no difference to the output on SK2, showing the isolation is pretty good.

Without the shunt trap (L7, C18), the 25MHz output on the ADALM pluto output (P2) was around 35mVpp. The trap brought this down to about 10mVpp. The response of the circuit from F-connector SK2 to SMA connector P2 is shown in figure 52.

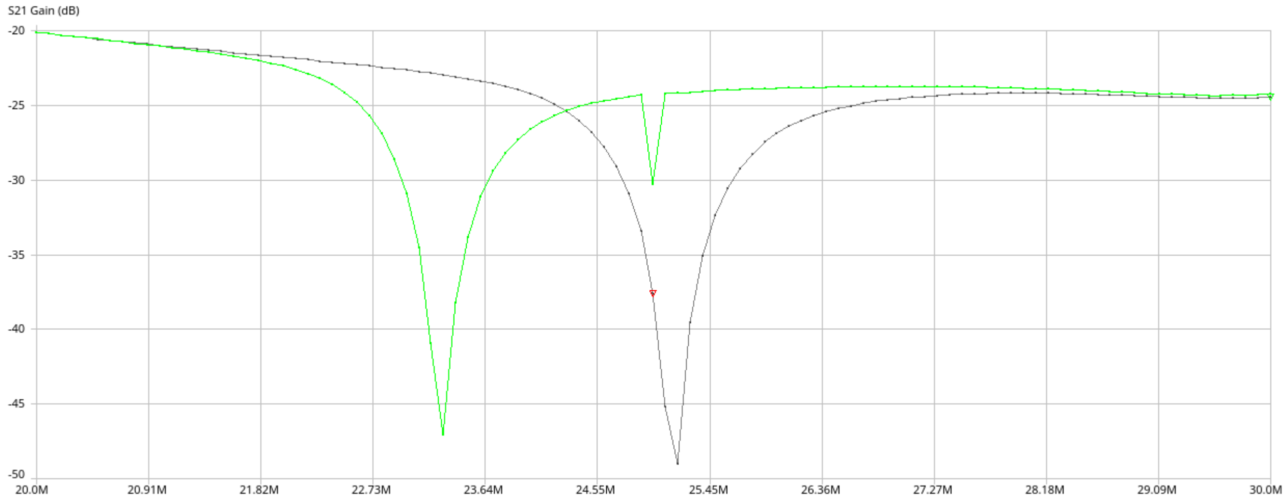

Figure 52: S21 of the triplexer, feeding the F-type receptacle SK2 and taking the output from the SMA plug to the ADALM Pluto (P2). Green: With 35 turns on L7 (Amidon T37-2 core); observe the "suckout" from the crystals at 25MHz. Grey: With 33 turns on L7 (correct tuning).
I also tried a scan to 800MHz but my NanoVNA could not really provide a sensible measurement.

5.3 Amiko L107 LNB modification for external clock

Instructions from SV1BDS[42]:

- The bottom part (where the connector is) has openings for the clips. So, pry the upper part outwards with a screwdriver (see figure 53).
- Remove the torx screws, unsolder the output connector and pull PCB upwards.
- The antenna tube has two monopoles, one horizontal, one vertical. The PCB needs to be twisted slightly to disengage these.

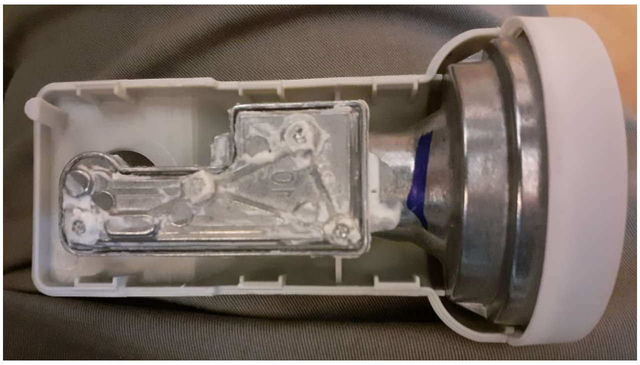

Figure 53: Amiko L107 with the plastic cover removed.

42 Personal communication.

- This is what SV1BDS did: He removed the 25MHz crystal (through-hole) and fed the signal as shown in the picture in figure 47, left[43]. He used 18pF and 2.2µH in series to diplex 25MHz onto the same coaxial connector as the main signal.

The following is from an article[44] by PY2RN (see figure 54): "Both X1 and X2 pins will work, input at the corner pin (of the OS) is the low sensitive but better performance, -6 to +6 dBm input, the second pin is the sensitive input (-30 to +_6 dBm) but more phase noise".

I initially tried pin X1, as it seemed more promising. Drive was from the circuit shown in figure 55, but without R7 and C9. Note that I had removed the small capacitor from the RDA3566E's pin X1 to ground. I got 800mVpp signal on pin X1 (centered on about 800mVDC) which ought to be plenty (800mVpp into 50Ω is +2dBm). However, I got no signal out from the LNB.

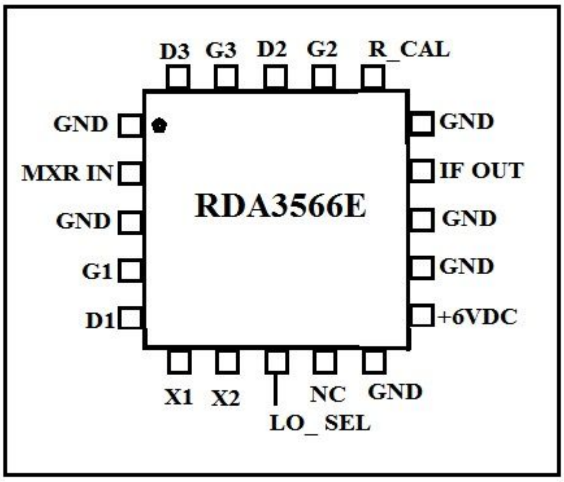

Figure 54: LNB IC pinout.

So, I moved the drive to pin X2. I did not refit the small capacitor earthing pin X1, and I removed the small capacitor earthing pin X2. The LNB sprung to life! Great.

5.4 Schematics and component layout

The final schematic is shown in figure 55. Component layouts are shown in figures 56, 57 and 58.

43 This was based on an article by OZ2OE, https://vushf.dk/4588-2/, which has been updated since.
44 https://forum.amsat-dl.org/index.php?thread/3030-lnb-with-25-mhz-dds-input-goes-bad/&pageNo=1.

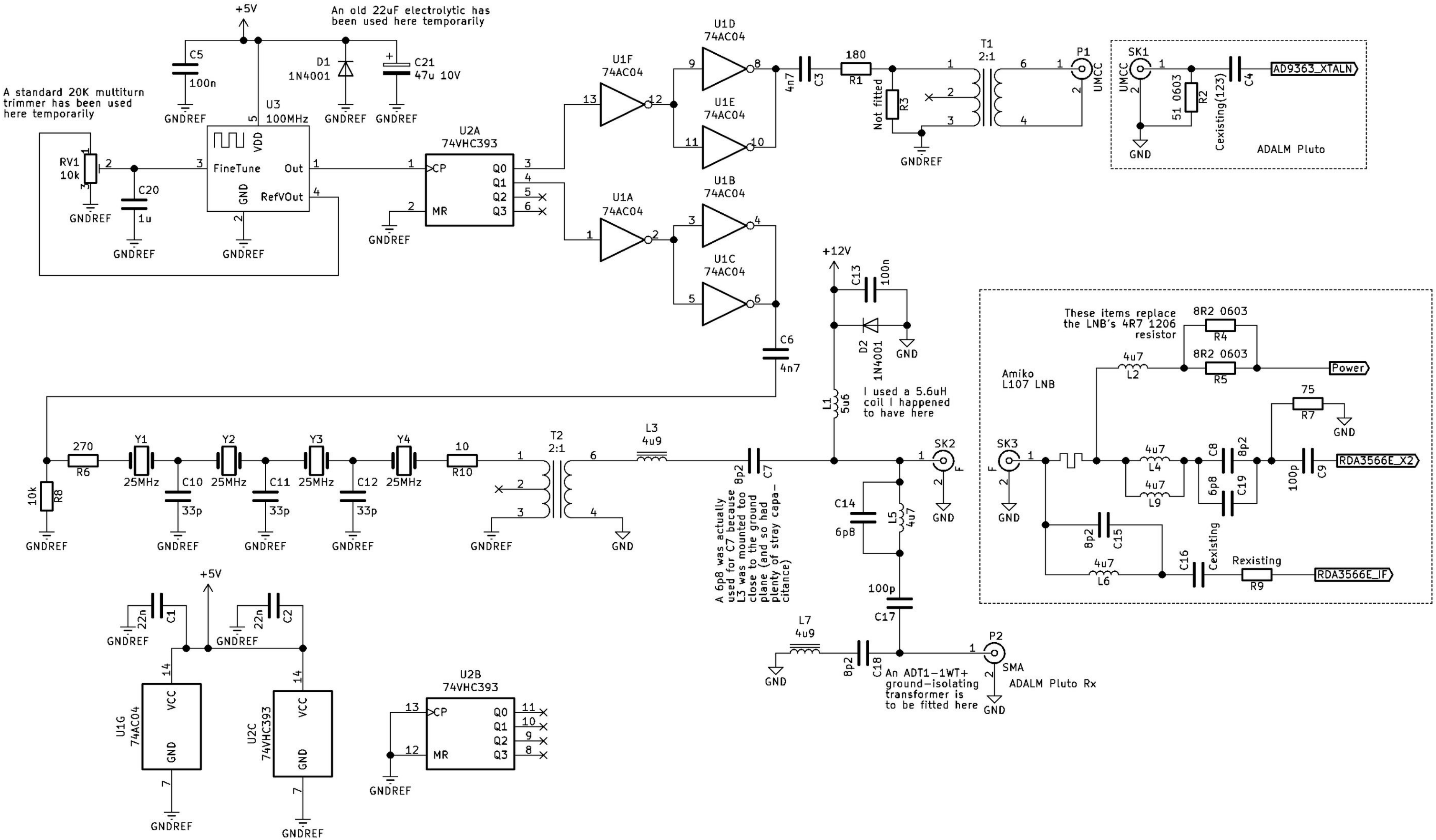

Figure 55: Schematic of the frequency reference PCB for the Amiko L107 single-receptacle LNB. This is version D.

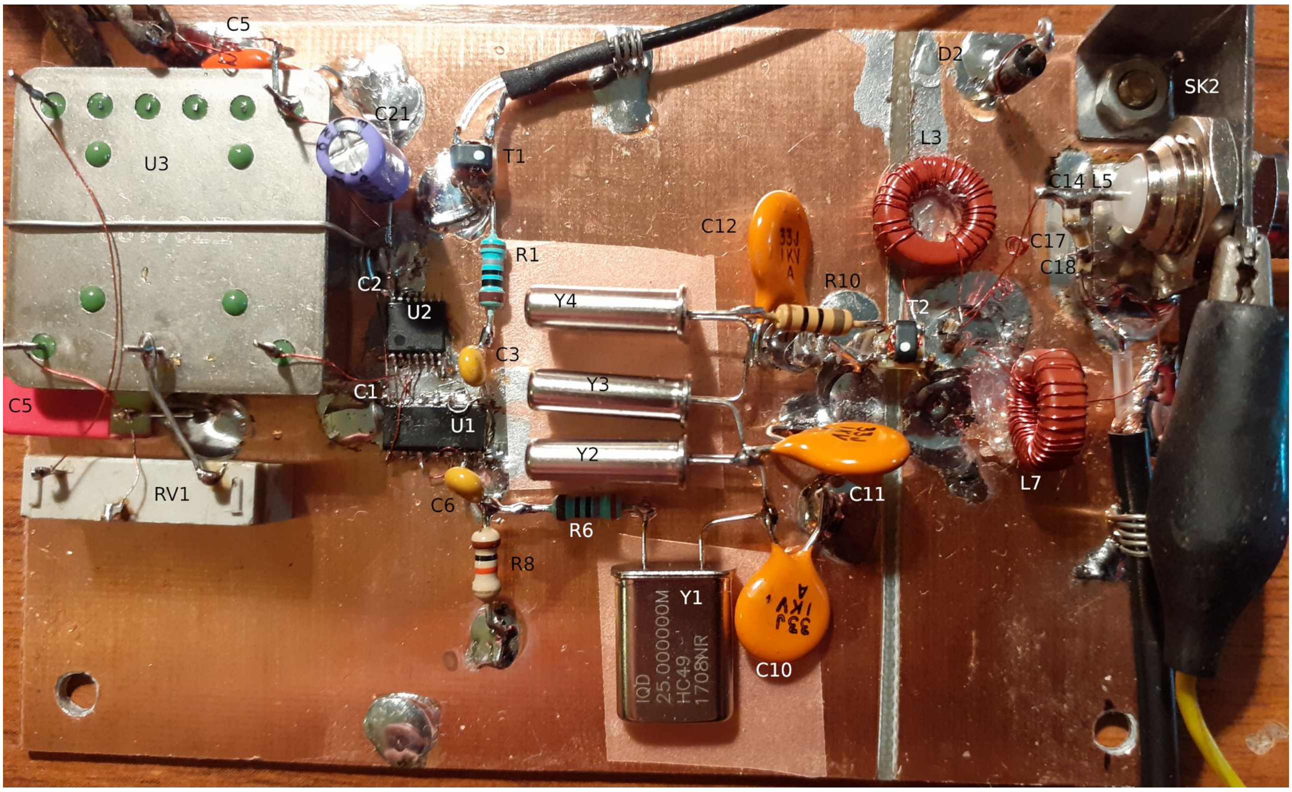

Figure 56: Layout of the frequency reference PCB for the for the Amiko L107 single-receptacle LNB. Note that this is a somewhat earlier incarnation which does not include C7, C13, L1.

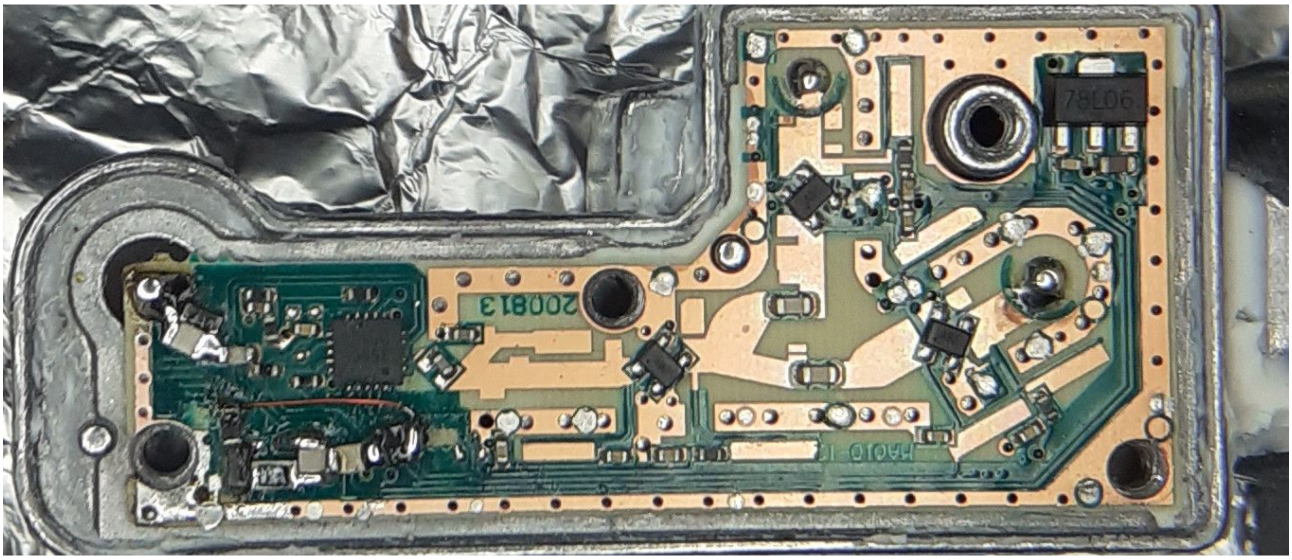

Figure 57: Modified Amiko L107 LNB. See figure 58 for details.

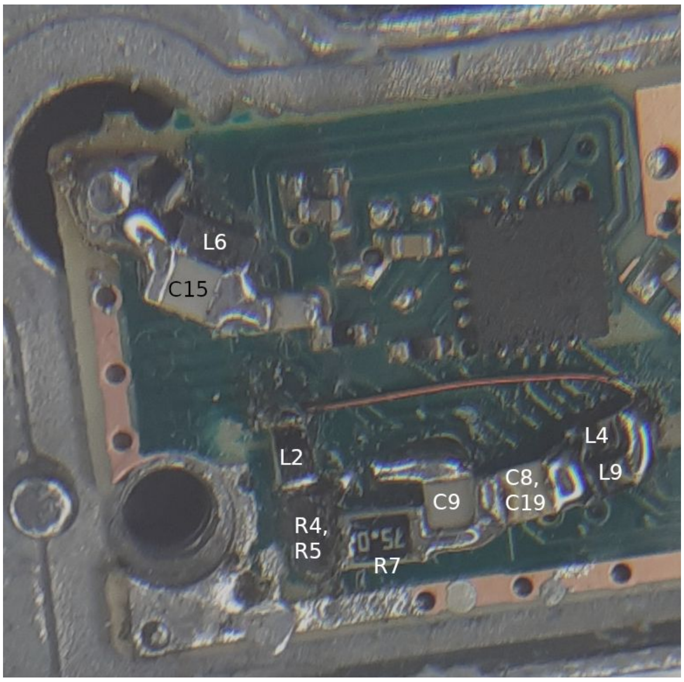

Figure 58: Amiko L107 modifications. Note that the track was cut under L6, C15. The meander line was cut under L2 and removed; the last meander was removed. The original 25MHz crystal and its two capacitors were removed; R7 solders onto the ground pad of one of the removed crystal capacitors.

5.5 Results

I powered the LNB with a simple diplexer (a 5.6µH coil and an 10nF coupling capacitor), and measured the LNB's impedance at its F-type receptacle SK3 with the nanoVNA. Note that the 5.6µH coil and10nF capacitor were included during nanoVNA calibration, so they have been calibrated out.

Arrangement (see figure 55)	Impedance measured on SK3	25MHz level at RDA3566E X2
L4, L9, C8, C19, C9 not fitted, R7 connected directly to L2 meander end (no power applied)	61.5+j4Ω	Not measured
R7 not fitted, C8, C19 connected directly to RDA3566E X2	350-j159Ω	700mVpp on about 700mVDC
All components fitted	200-j70Ω	300mVpp on about 600mVDC

The results imply that the 75Ω termination by R7 was ineffective, due to the huge losses in the series tuned circuit (L4, L9, C8, C19). The impedance at SK3 was an appalling match to the 75Ω transmission line.

Note that with all components fitted, I had about 1.5Vpp 25MHz signal on SK2, which was at the driving end of the (around 14m long) 75Ω transmission line used during these tests. The voltage might have been this high because we were on a VSWR antinode of the 14m long transmission line; the actual voltage with a resistive termination (admittedly 50Ω, see section 5.2.4) was 900mVpp.

Interestingly, the LNB worked fine none-the-less...

6 Appendix B: On the use of a POTY transmitting antenna

I initially used a POTY transmitting antenna, and results were great. I finally chose an Ice Cone v2.1 transmitting antenna, for the reasons given in section 2.6.3.1. This section shows how the POTY transmitting antenna was installed.

6.1 Antenna parts list with POTY transmitting antenna

Vendor	Vendor P/N	Manufacturer	MPN	Description	Level 1	Level 2	Ref. designator	Price ea.	Qty.
E-shop.gr	705170	Engel	Axil LH 1.05M	Satellite dish, 3ft. dia.	Antenna		Satellite dish	41,54 €	1
Passion Radio	QO100-ANT-POTY-KIT-762	PE1CKK		Antenna, POTY	Antenna		POTY antenna	41,90 €	1
eshop.mymarket.gr	901255	Shantou Enjoyland Plastic Industrial	YP1028A	Plastic food container	Antenna		POTY antenna cover	5,69 €	1
Shop910748016 Store (Aliexpress)				Adapter, SMA male to SMA female, right-angle	Antenna		POTY antenna connection	0,90 €	1
Passion Radio	QO100-BAGUE3-207217-22MM-1029			Reduction ring, 40/22mm for POTY antenna	Antenna		POTY antenna support onto satellite dish	3,95 €	1
Passion Radio	QO100-LNB-BULLSEYE-978	Othernet	BE01	LNB, Othernet Bullseye	Antenna		LNB	24,90 €	1
Hardware shop		Vimatec	Vimaseal-PU S/A 30	Sealant, polyurethane 300ml cartridge	Antenna	LNB		5,83 €	1
Mouser	667-ERJ-6ENF75R0V	Panasonic	ERJ-6ENF75R0V	Resistor, 75Ω 0805	Antenna	LNB	R7	0,10 €	1

6.2 POTY antenna

The POTY antenna I used is a kit by PE1CKK. It is very easy to put together and seems to work fine. This was assembled in accordance with the instructions which came with it. The black plastic 40/22mm POTY antenna reduction ring was then slipped onto the POTY antenna copper pipe, and was pushed all the way down towards the antenna disk. A damp cloth was wrapped around the pipe near the reduction ring, to keep it from melting. Then, a 22mm copper pipe joint was soldered onto the POTY antenna copper pipe for the LNB's throat to go into; this can be seen in figure 60, lower left.

Figure 59: Modifications made to the plastic food container.

A problem I hadn't anticipated with the POTY antenna (though it is obvious if you think of it) is that rainwater gets trapped between its two plates and detunes it. It was raining one evening and PA VSWR kept on tripping - this suddenly made me aware of the issue! PA2V suggested I use a plastic pot to house it in, after checking that the pot doesn't heat up in the microwave oven. I bought a sealable plastic food container from the supermarket, which did the job just fine. Some chopping and hacking was obviously needed to get the container around the POTY antenna (see figure 59), but it was a very simple operation all-in-all.

I am under the impression that the addition of the container brought the signal-to-noise ratio of the QO-100 lower beacon[45] down by about 1dB , though this is difficult to judge accurately. It doesn't seem to have made any difference on transmit.

45 About 33-34dB on the AMSAT-DL (DJ0ABR) QO-100 Linux SDR Transceiver software.

6.3 LNB modification for mounting on POTY antenna

A lint-free cloth was dampened and packed into the LNB's throat, to stop any aluminium filings and chips from entering. The LNB was covered with a cloth. Then, the LNB's antenna flare was cut off and the throat filed down so that it would fit snugly into the 22mm copper pipe joint soldered onto the POTY antenna tube (see section 6.2). Once done, everything was cleaned with isopropyl alcohol and the LNB was secured into the pipe joint with a little polyurethane sealant (not that it needs it, really). This was left to cure overnight.

Finally, the LNB's black plastic shell halves were refitted and the flare was filled with polyurethane sealant (Vimaseal PU[7]). This was given one whole week to cure.

Note that once the sealant has set, it is very difficult to take the LNB apart again. It is worth double-checking that all the electronics work fine before filling with sealant!

Figure 60: Fitting the LNB into the 22mm POTY pipe joint.
Above left: Filing down the LNB's throat. Note how the LNB is covered with a cloth and has its throat blocked with a lint-free cloth. Below left: LNB throat fitting snugly into the 22mm copper pipe joint. Right: Completed antenna with the polyurethane sealant left to cure.

7 Appendix C: Untested ideas

This section contains various ideas I have which I haven't actually put into practice. Should anyone do try them out, please do let me know how it went!

7.1 ADALM Pluto power-on delay circuit

As mentioned in section 2.4.3.6, the ADALM Pluto will sometimes refuse to start. I guess the reason is that the 5V_Pluto supply rises slowly (see figure 61) and this messes up the Pluto's power supply sequencing. Figure 61 shows that the 5V_Pluto supply should be stable after about 200msec under full load (faster if the Pluto is off). We could delay the application of power to the ADALM Pluto for, say, 200msec and then switch it on suddenly so that the Pluto gets a fast rising edge on its 5V supply. A delay circuit which might work is shown in figure 62 below. The two-transistor "thyristor" part has been simulated using https://www.falstad.com/circuit/index.html and seems to work fine; the circuit can be found under Thyristor.txt.

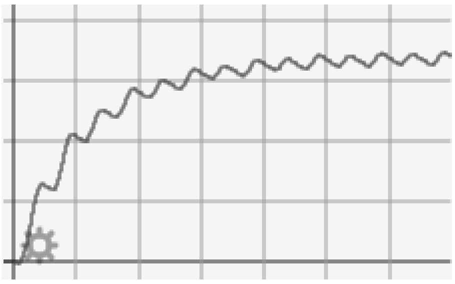

Figure 61: Start-up detail of the simulated output voltage of the 5V and 12V power supply transformers and rectifiers (same simulation as in section 4.3.2.1). 2V/div, 20ms/div.

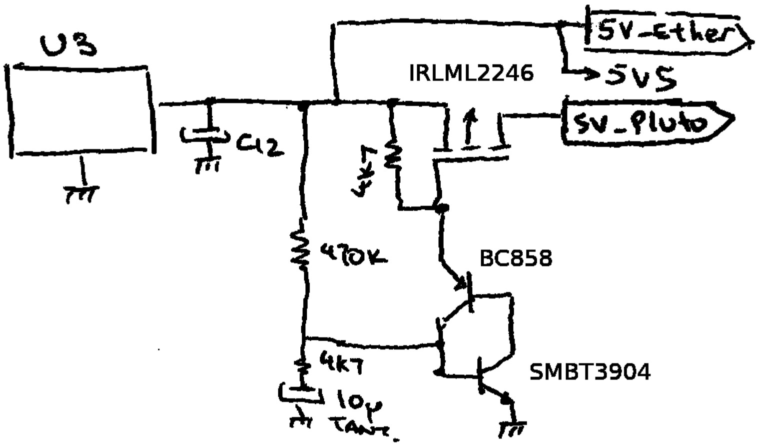

Figure 62: Suggested ADALM Pluto power-on delay circuit.

The reason for putting the delay circuit after the 5V regulator (U3 in figure 14) rather than before the regulator, is that I want to minimize the transient current the power supply will have to source when the delay circuit switches on; if the delay circuit were fitted before regulator U3, decoupling capacitors C14 and C12 (figure 14) would have to charge, and that would make the rise time longer.

7.2 Division of the clock down to 10MHz

It would be nice to be able to divide the 50MHz clock down to 10MHz e.g. for the "Lars" GPSDO[46] or for use as a lab reference. Reliably dividing the 50MHz clock by 5 is not entirely trivial.

Strangely, it is difficult to find a counter which will reliably divide-by-5 at 50MHz. The 74FCT163 will do it, but I don't like it's TTL logic levels. The only sensible solution I found was to use a 74AC163 with a rather peculiar counting sequence:

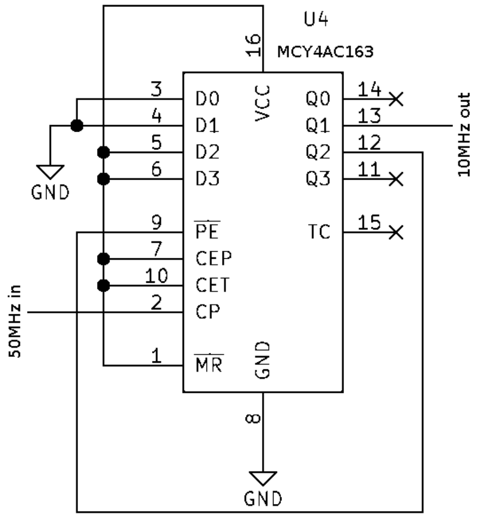

Figure 63: MC74AC163 divide-by-5 circuit with a reasonable duty cycle output.

Cycle	!PE	Q3	Q2	Q1	Q0	Time, ns
0→1	1	1	1	0	0	0→20
1→2	1	1	1	0	1	20→40
2→3	1	1	1	1	0	40→60
3→4	1	1	1	1	1	60→80
4→5	0	0	0	0	0	80→100
5→6	1	1	1	0	0	100→120

So, Q2 can drive !PE nicely and Q1 can be the divider's output. The output will be high for 40ns and low for 60ns.

The difficulty lies with the CD74AC163 itself; I. A. W. the Texas Instruments datasheet, it needs a setup time before CLK for !Load of 5.3nsec, while the propagation time of CLK to Q can be as high as 15ns. The total is 20.3ns, so the CD74AC163 might not be able to do 50MHz.

The On Semiconductor datasheet for the MC74AC163 paints a somewhat rosier picture: it shows a setup time of 8.5ns, but a propagation delay of just 10ns. The total is 18.5ns. Better.

Interestingly, ST microelectronics' datasheet gives different numbers yet again! Strange...

46 By Lars Walenius, Rest in Peace. See e.g. https://www.qsl.net/zl1bpu/PROJ/NGPSDO/Lars Arduino based GPSDO Controller page 1-7.pdf.

7.3 Remote relay switching using the power lines in the Ethernet cable

I have a requirement which is not related to this project in any way: I have a single coaxial cable going from the shack up to the roof. I cannot install a second cable, so I want to switch this coaxial cable between my HF and VHF transceivers and antennas. I think I can use the QO-100 project's Ethernet cable for this purpose. The idea is the following:

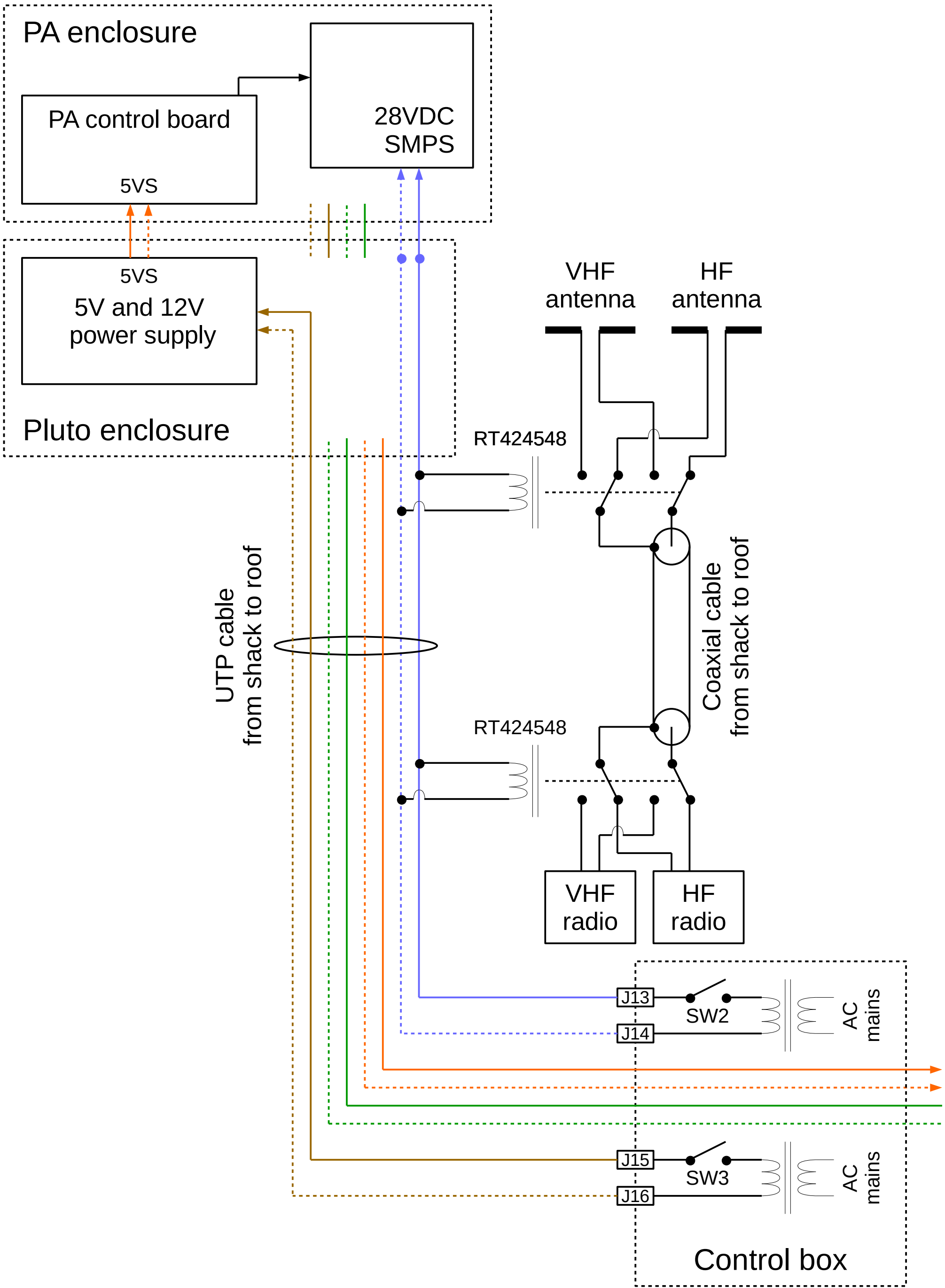

Figure 64: An idea for using the power lines in the Ethernet cable for switching antennas not related to the QO-100 transceiver project.

There are the following combinations of SW2 (the control box Transmit switch which powers the PA enclosure) and SW3 (the control box Receive switch which powers the Pluto enclosure):

SW2	SW3	QO-100 Transceiver status	HF transceiver status	VHF transceiver status
Off	Off	Off	Connected to antenna	Not connected to antenna
Off	On	Receive only	Connected to antenna	Not connected to antenna
On	Off	Off*	Not connected to antenna	Connected to antenna
On	On	Transceive	Not connected to antenna	Connected to antenna

This should allow me to use my HF and VHF transceivers over the single coaxial cable I have going up to the roof. The third combination (marked *) is of some interest: Switching SW2 on applies power to the PA enclosure. However, with SW3 off, the Pluto enclosure is not powered so 5VS (see figure 14) is not powered. This means that optocoupler U4 in the PA enclosure (figure 19) remains off, so the 28V switchmode supply for the PA remains inactive.

Clearly, substantial decoupling of the relay coils from the UTP cable will be required to ensure RF from the HF or VHF transceiver doesn't find its way into the QO-100 transceiver. Capacitors won't help much, I believe, as there isn't much of a ground return to speak of anywhere. Series chokes and ferrites are more likely to be effective.

I don't know whether the Schrack RT424548 relays chosen will prove meaty enough for switching. In my case probably yes, as my HF transceiver is a barefood 100 Watter and the VHF rig puts out just 3W.