23 cm EME with ADALM PLUTO

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Analog Devices has been offering an SDR-transceiver with very interesting features ADALM PLUTO (Active Learning Module PLUTO SDR) [1]. It is intended primarily for students who, thanks to its open architecture, can program the transceiver for most modulations and coding used in communication systems and thus study the physical layer of these systems in the frequency range 325 to 3.8 GHz, with 12 bit ADC and DAC at bandwidths up to 20 MHz. There are a number of very good application programs for PLUTO, such as SATSAGEN spectrum analyzer and generator [2], and it is supported by MATLAB, Simulink and GNU Radio environments. The built-in AD9363 tuner can be easily switched to AD9364 mode with a frequency range of 70 MHz to 6 GHz. PLUTO's features were quickly discovered by users of the QO-100 stationary satellite and used for both narrowband and wideband transponder applications. In this context, F5OEO has written new firmware that addresses the use of the GPIO ports for PTT in addition to the TV modes for QO-100 [3]. Also, the DUBUS has already described the PLUTO extension for the 3 cm band [4]. In the original design, PLUTO is unusable for digital EME operation, mainly due to low frequency stability. Although the built-in 40 MHz TCXO has a very small jitter, the stability of ±25 ppm is insufficient for narrowband modes. For the current digital modes used in EME, synchronization by an external atomic oscillator is required so that the resulting frequency accuracy and stability is in the order of 10 Hz even in the microwave bands. Another shortcoming of the original design is the lack of shielding. For this reason, the PLUTO was built into an Al box and equipped with an external TCXO on an external plate with a relative stability of 0.5 ppm and, most importantly, the possibility of switching to GPSDO. There is also a PTT circuit and both USB ports (data and power, this time with USB mini-b connectors). A schematic of the board is shown in Figure 2 and Figure 1 is a double-sided PCB that can be downloaded as Eagle file [5]. Figure 3 shows a general view into aluminium box with the modified Adalm PLUTO. The small side plate shows the 40 MHz LPF at the output of the external TCXO, see schematic.

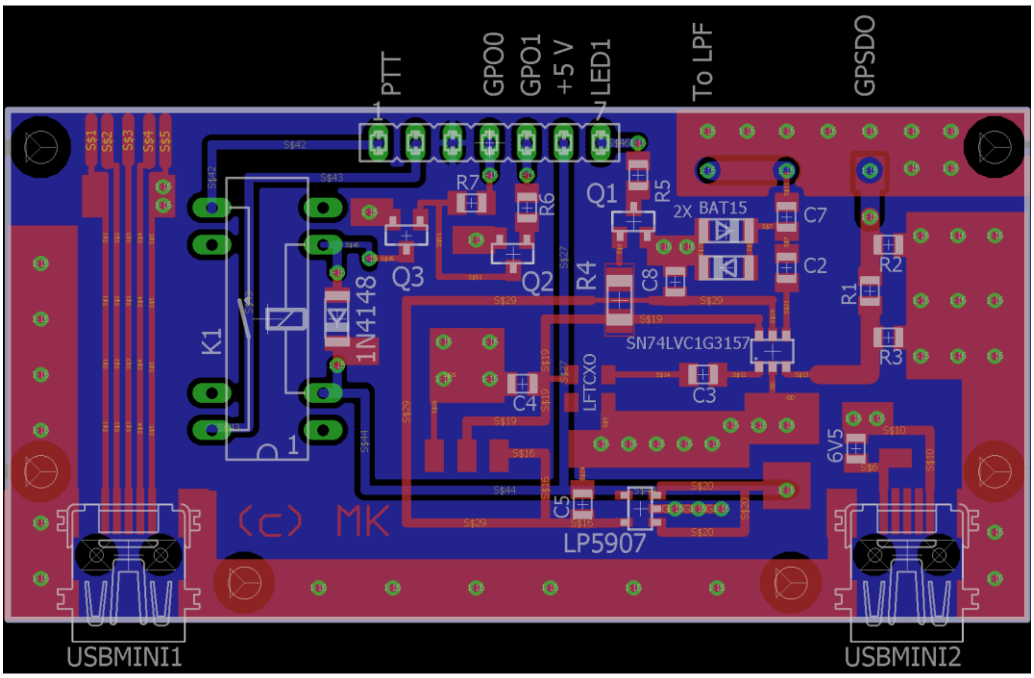

Fig. 1: PCB of external TCXO and PTT including USB Ports [5].

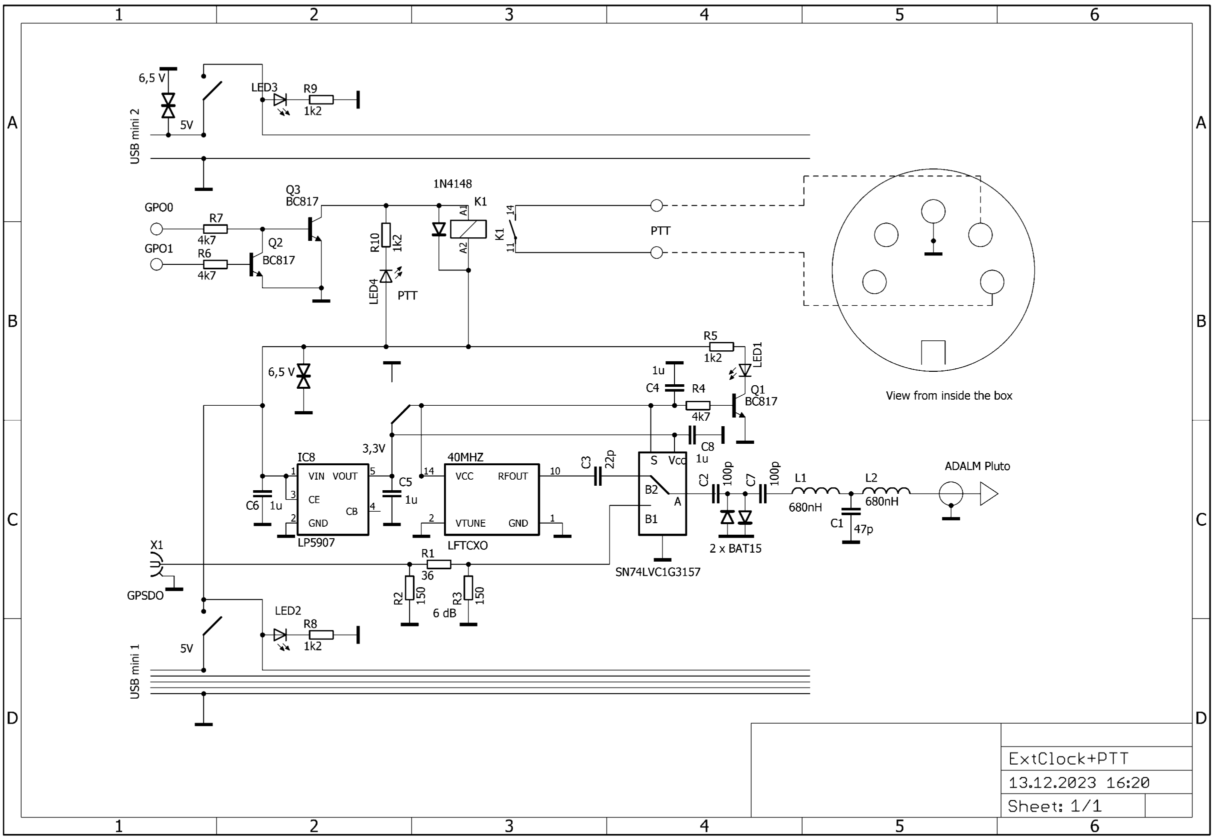

Fig. 2: Schematic of external TCXO and PTT circuits.

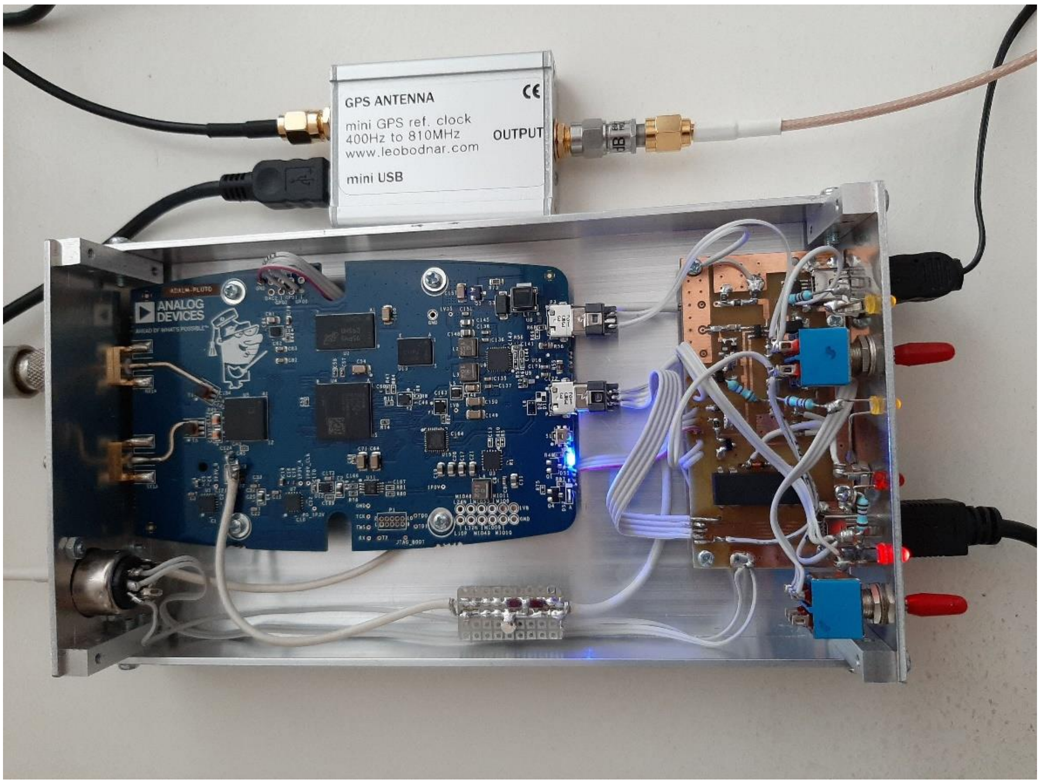

Fig. 3: ADALM PLUTO with external TCXO, PTT and 40 MHz LPF in AL box.

Front-Ends

As already mentioned after switching to AD9364 mode, the frequency range of the SDR is 70 MHz - 6 GHz. However, there are no filters at the receiver input or transmitter output. For use as Rx and Tx for certain amateur band, these filters need to be added. In my case, I built them into the same cabinet as the Adalm PLUTO and they are on the same board with the sequencer. The schematic is shown in Fig. 4. In both branches there are two-stage amplifiers with PGA 103+, between which there is a four-pole bandpass tuned to the center frequency of 1296 MHz. The simulated and measured transfer function is shown in Figs. 5 and 6. The receiver branch has one more resonant circuit at the input. The PCB of the Front-Ends is shown in Fig. 7. It is a double-sided PCB on 1.5 mm thick FR4 material and the PCB can also be downloaded as Eagle file or Gerber data [5] . The gain in both branches is about 20 dB. The output power of the transmitting branch of 22 dBm is sufficient to excite another amplifier up to 10 W. This is fitted with a Mitsubishi M57762 module and with the appropriate heatsink is mounted to the cap of the Front-Ends unit. The amplifier is assembly with both Al boxes into a single unit, as can be seen in Fig. 8.

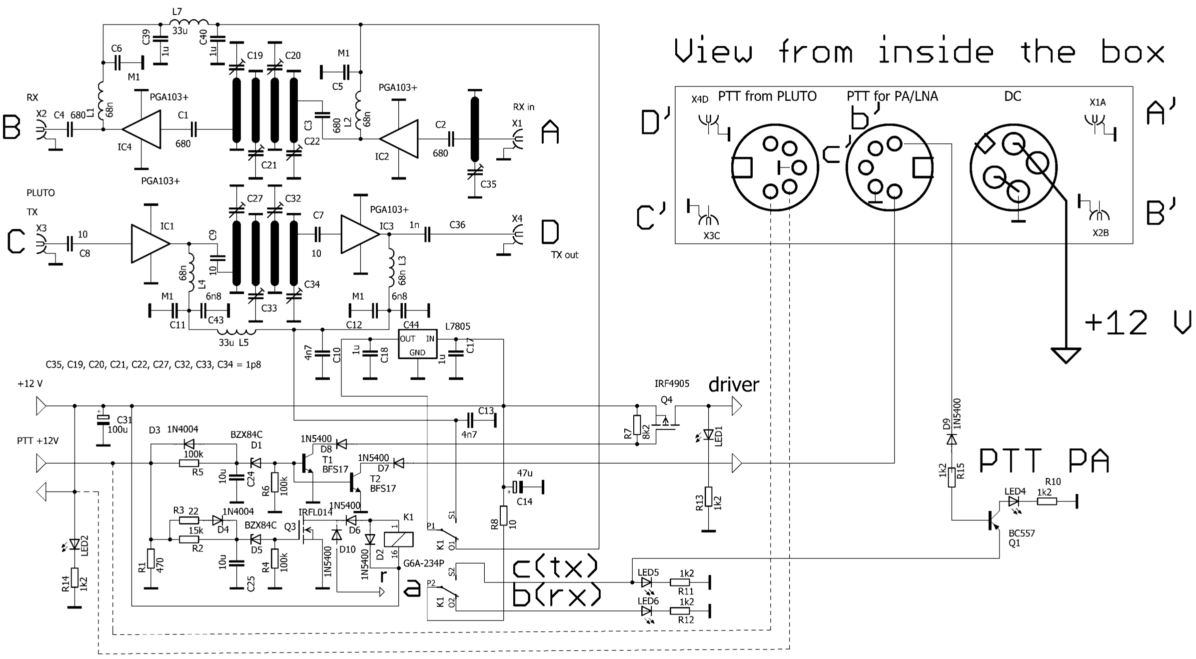

Fig. 4: Front-Ends schematic – sequencer including.

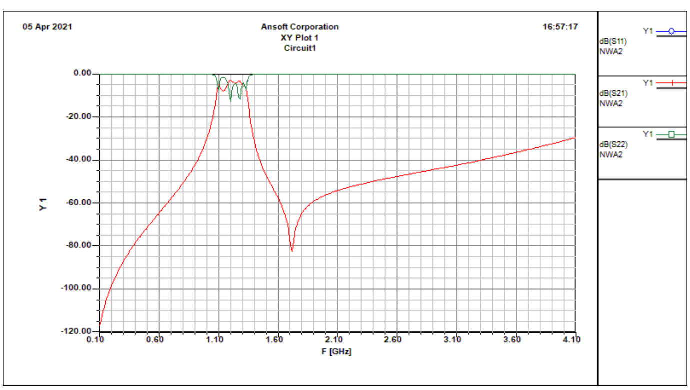

Fig. 5: Bandpass filter simulation – S_{11}, S_{22} and S_{21}.

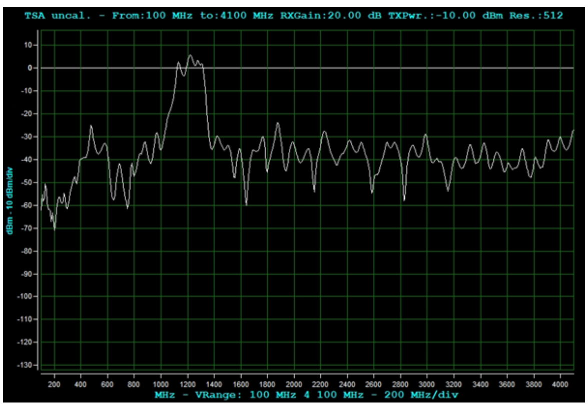

Fig. 6: Tuning of the bandpass filter can be provide directly with help of program SATSAGEN [2] without other instruments.

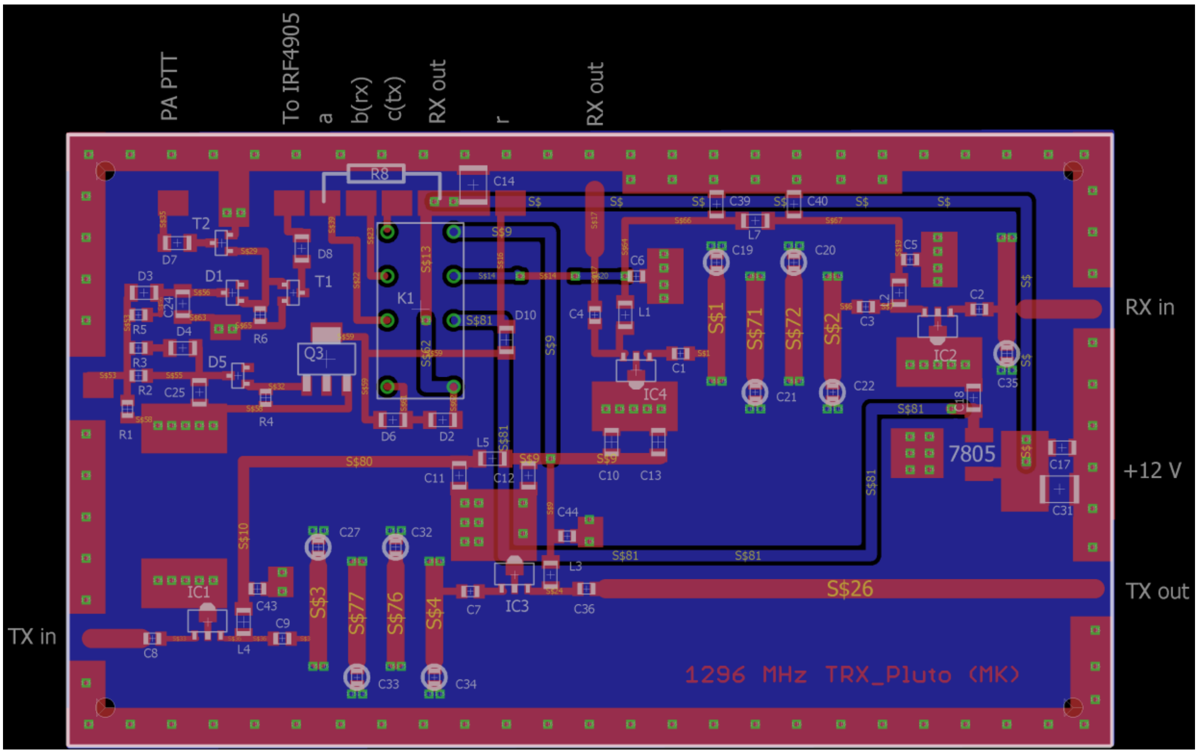

Fig. 7. Front-Ends PCB – the substrate is FR4 60 mil [5].

Fig. 8: Adalm PLUTO transceiver setup for 1296 MHz with laptop.

Software

Adalm PLUTO works well as a transceiver with SDR Console v3.2. In my case, however, there is one "effect" with the frequency setting. When PLUTO is run with this program it is tuned 5 kHz higher. I solve the problem by first initializing PLUTO with SATSAGEN (in "generator" mode I check the frequency, e.g. 1296.065 MHz). Subsequent launching with SDR Consol is then without problems with the exact frequency. I use virtual audio cables for the connection to the WSJT-X program. With the VB audio cable I did not like it, if two VB audio cables were running at the same time, there were collisions between them. With VAC [6], even three virtual audio cables work together without collisions. To control the transceiver with the WSJT-X program, two virtual serial ports also need to be created - e.g. with the VSPE program [7]. In WSJT-X we then set the control to Kenwood 2000. CW operation is handled by standard keyed tone to the SSB modulator, using the 3rd VAC. For keying I used the program "Morse Keyer" [8] with a paddle connected via another serial port. However, there is a problem with the keying, caused by the high latency. The monitor keying is therefore done with the help of "Audio Repeater" [9]. The overall scheme of the program interfacing is shown in Fig. 9. In CW, the Tx is switched on with the "Tune" button in the WSJT-X main window, but a keyed VAC is connected to the modulator - line 3. In this configuration, the Doppler shift compensation also works very accurately in all modes with a step of 1 Hz.

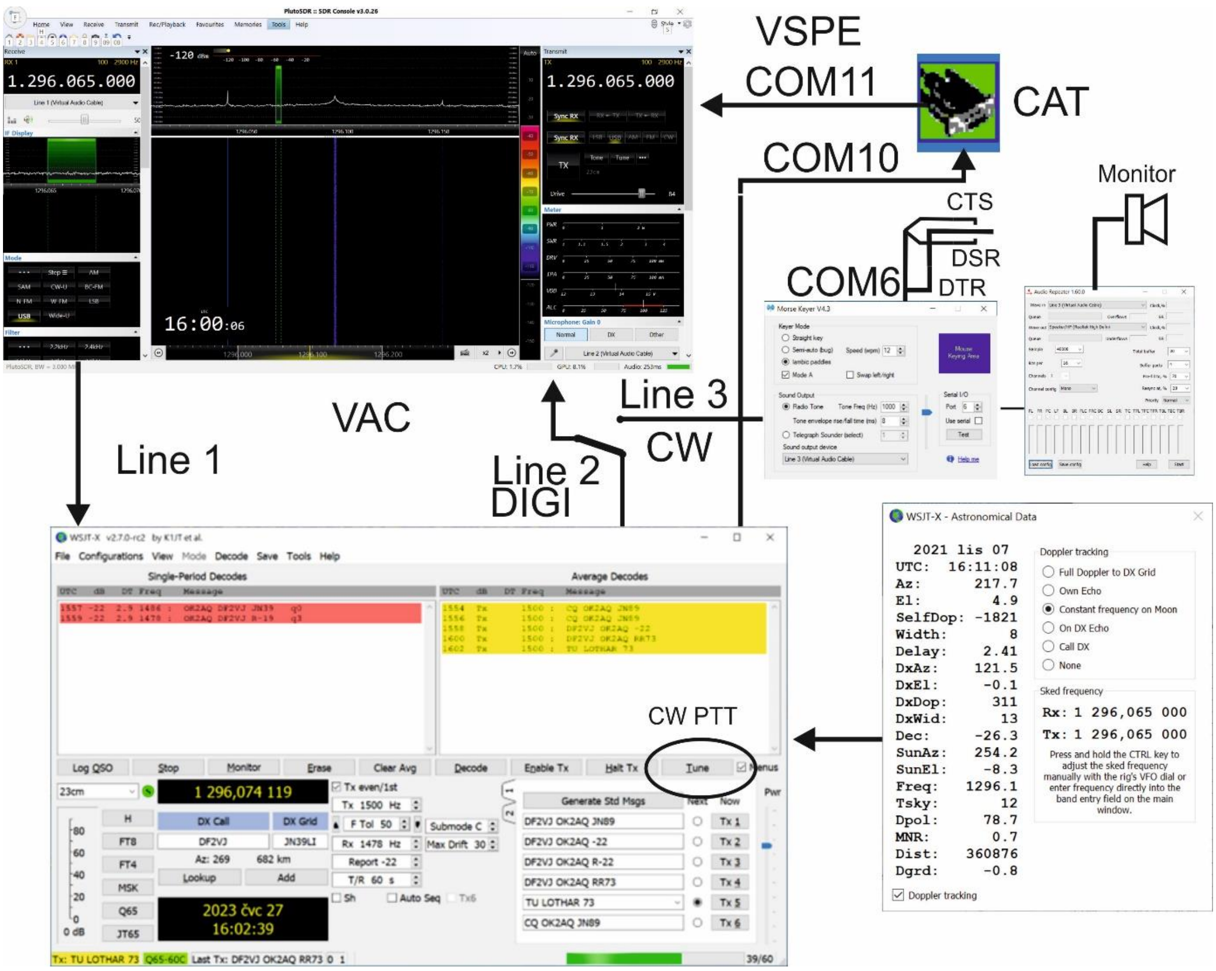

Fig. 9: Software interconnection.

Experience of operation

The overall arrangement of the workstation for EME operation is shown in Fig. 10. An offset dish with an aperture of 1.8 m is irradiated by a septum feed and an extended horn adapted to f/D = 0.8, Fig. 11 [10] [12]. The location of the LNA and isolation relay can be seen in Fig. 12 and the measured LNA parameters in Fig. 13.

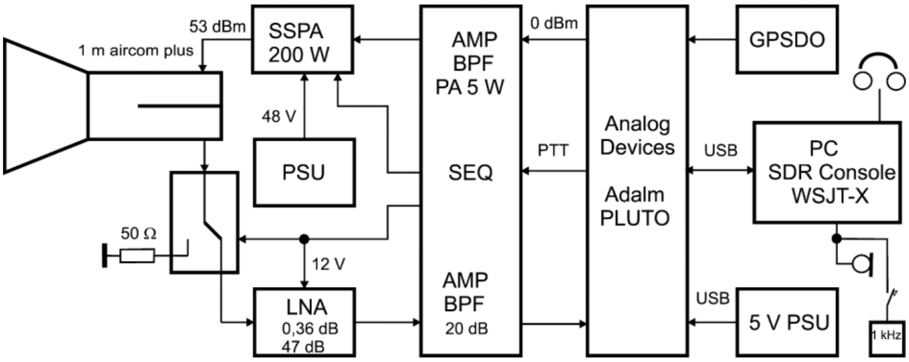

Fig. 10: EME Workstation with Adalm PLUTO arrangement.

Fig. 11: 1,8 m offset dish with horn-septum feed.

Fig. 12: LNA + isolation relay.

EME digital mode connections are very convenient and stations praise the signal quality. Doppler shift compensation is precise with 1 Hz steps in both receive and transmit. Within a short time, 144 initials were successfully established [11]. The transition to the new EME frequencies 1298-1300 MHz will also be without problems. CW operation is a bit more complicated because there are two other programs in coordination and also, with low power, the actual echo is not always visible, so the transmitter frequency has to be accurately calculated. The CW could certainly be handled differently with a simpler setup (with other hardware – keyed ton generator). But I tried to use ready-made programs that are generally available.

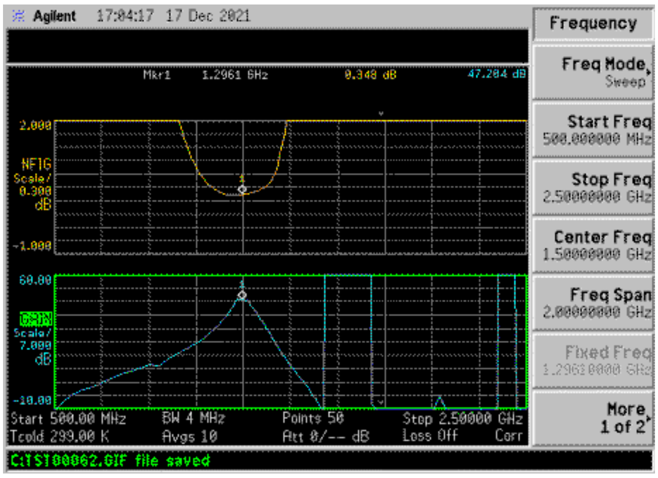

Fig. 13: Measured LNA parameters.

Reference

[1] https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/ADALM-PLUTO.html#eb-overview

[2] Program SATSAGEN: https://www.albfer.com/en/2020/02/21/satsagen-2/

[3] F5OEO Adalm Pluto firmware: https://www.f5uii.net/wp-content/uploads/2020/10/pluto.zip

[4] Kuneth W., OE8FNK: “HYDRA”: A CW/SSB/FM Range Extender for ADALM PLUTO for the 3 cm Band. DUBUS No. 3, 2020, Vol. 49, pp. 9-15

[5] PCB: https://www.radio.feec.vutbr.cz/esl/files/EME/Doc/23cm/PLUTO_TRX_Eagle.zip

[6] Vitual Audio Cable VAC: https://vac.muzychenko.net/en/

[7] Virtual serial ports emulator: https://eterlogic.com/Products.VSPE.html

[9] Morse Keyer: https://sourceforge.net/projects/morse-rss-news/

[9] Audio repeater: https://vac.muzychenko.net/en/repeater.htm

[10] https://www.radio.feec.vutbr.cz/esl/files/EME/Doc/OK2AQ_23cm.pdf

[11] https://www.radio.feec.vutbr.cz/esl/files/EME/EME1296.htm

[12] Kasal, M., OK2AQ: Slabé signály (Weak Signals). VUTIUM Brno 2023, ISBN 978-80-214-6149-9, p. 276