EDGES MEMO #364

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

July 22, 2021

Telephone: 617-715-5533

To: EDGES Group

From: Alan E.E. Rogers

Subject: Study of EDGES-3 out of band noise

A close examination of the out of band noise in the EDGES-3 prototype and the new EDGES-3 system show an asymmetry in the data samples. In both cases the deviation from the mean is 30% larger for the negative values compared with the positive values. After further study it was discovered that Noisecom NC302L noise diode (see Figure 6 of memo 300 for the circuit) for the new EDGES-3 and the prototype were from the same batch which show an asymmetry. Noise diodes produce noise via the avalanche breakdown of a reverse-biased diode and have to be carefully selected to produce a symmetric Gaussian waveform. See memo 68 for more information on noise source diodes.

unit	Max ADC voltage	Min ADC voltage	Load sig percent	Cal sig percent
EDGES-3 prototype	0.24	-0.36	2.8	5.7
EDGES-3	0.36	-0.45	1.2	2.9
with new diode	0.27	-0.27	2.6	6.0

Table 1. Maximum and minimum ADC voltage and signal percent for 3-position switch positions for load and calibration

Previous determinations of the optimum strength for the out of band noise based on 2-tone tests were in the range of a few percent up to about 8 percent for the in-band signal to out of band noise ratio for the 8-bit ADC in the AC240 spectrometer discussed in memo 51 and even smaller percentages in the case of the DP310 ADC which uses interleaved sampling. Spurious Free Dynamic Range (SFDR) tests made on EDGE-3 in memo 307 show that keeping the normal sky noise signal at the level of a few percent while maintaining an ADC level at about half the full ADC range of +/- 0.5 is a good choice to maximize the SFDR while avoiding a significant data loss due to saturation of the ADC in the presence of strong RFI. Tests with the DP310 ADC in memo 42 discuss the effect of feedback within the ADC which can be reduced with a level of noise which dominates the signal. However, if the out of band is too dominant the non linearity in the ADC can cause spillover of the out of band noise into the in-band region.

The diode current was increased from about 4 to 6 ma. The revised circuit is shown in Figure 1. The peak to peak noise at the “video” output into the high impedance input of a scope is about 600 mv. The need for the out of band noise in EDGES is primarily to minimize the effects of RFI but also reduces the level of any spurs on the ADC due to the pick-up of DC to DC converter signals in the PC. A test of the effect of the out of band noise, made by turning it off, show that the effects on the 3-position switched spectra used for the calibration are very small but the out of band noise may be needed for maintaining highest SFDR needed to minimize the effects of RFI. The effect of small asymmetry in the noise in one batch of noise diodes is to produce early ADC saturation and this study was needed to locate the origin of the asymmetry. Orbcomm at 136-138 MHz and can be as strong as -80 dBm which is more than 4 times the calibration total power so that more than 75% out of band noise on calibration is needed to prevent approaching ADC saturation on Orbcomm.

As mentioned above tests using the 14-bit Signatec PX14400A show that the out of band noise has little effect but if out of band noise is not used it is it essential that the signal levels without RFI are low enough to prevent ADC saturation in the presence of RFI. Also, as shown in memo 41 a fairly constant power level at the ADC is needed to avoid non linearities from biasing the 3-position switch results.

A repeat of a test similar to that performed in memo 307 using a 100 MHz signal from the RF explorer. The results given in Table 2 show that fraction of out of band noise greater than about 50 percent is needed to achieve satisfactory performance in the presence of strong RFI. A SFDR of about 80 dB is needed to allow the removal of RFI signals stronger than about -80 dBm.

RF level dBm	Power level	ADC max	rms 7-terms
-79	51%	0.25	0.8 K
-73	68%	0.28	0.9 K
-69	85%	0.31	1.7 K
-66	91%	0.33	2.9 K

Table 2. Performance of the out of band noise vs RFI signal strength

The rms residuals in the results of Table 2 are limited by noise for RF level below -79 dBm due to the short 64 sec integration and 6 kHz resolution. These results show that EDGES-3 should handle Orbcomm signals. Some of the residual signal after removing 7-terms may be sidelobes of the RF Explorer.

Figure 2 shows the spectrum when the calibration load signal is selected by the 3-position switch. In this case the in-band spectrum from 50 – 200 MHz is 6 percent of the total power from 0 – 200 MHz. Figure 3 shows the spectrum when the antenna, which is connected to a -83 dBm signal at 100 MHz from a RF explorer signal generator. Figure 4 shows the spectrum of the 3-position switched data with RFI excision which shows that at least for this short integration the out of band noise is adequate although it does not make a lot of difference.

So far the new EDGES-3 and the unit used in Oregon have been using FASTSPEC pfb case (ID) = 2 with 5 taps provided by the polyphase filter to enhance the SNR. Changing to case (ID) = 3 with 5-taps adds a sync function (see ASU memo 121), which makes a small improvement to the filtering and is what is currently being used by EDGES-2, so all EDGES-3 tests will use case (ID) = 3 with 5-taps.

Simulations show that spurs along with some non linearity in the ADC may not be canceled by the 3-position switch in the presence of RFI which changes the ADC level without the use of out of band noise. Figure 5 shows simulated data using a 14 bit ADC with the parameters given below:

Number of bits 14

Fractional levels	signal	load	cal
With noise	0.81	0.65	0.79
Without noise	0.37	0.20	0.34

Table 3. Signal levels as a fraction of full scale which is +/- 1.0

The RFI consists of a sine wave at 137 MHz and 10 sine waves from 88 to 108 MHz with 2 MHz spacing to simulate FM. The ADC spurs consist of 6 sine waves from 50 to 80 MHz. Each spur is 10 dB below the noise in a single frequency channel. The out of band noise was simulated using sine waves with random frequencies and phases centered at 5 MHz. 4e7 2048 sample data blocks with random Gaussian noise added were processed. The main plot is the 3-position switched spectrum on a scale of 5 dB per division. The plot at the top is the simulation without the out of band noise and the plot in the middle is an expanded version of the main plot. Both the top and the middle plot have a dB scale which is expanded by a factor of ten. The important point to notice is that the addition of out of band noise largely eliminates the negative dips in the spectrum due to the spurs in the ADC which are which are introduced by imbalance due to the non linearity and consequently are not canceled in the 3-position switched spectrum. The simulation also shows that ADC non linearities produce sidelobes on strong RFI signals which are significant at 10% non linearity but this effect scales with the non linearity squared and is not significant for non linearities below about 1%. ADC quantization is used but the effects of quantization is negligible for the 14 bit ADC at the high signal levels used in the simulation.

In summary we need out of band noise to remove the effects of ADC spurs and memo 41 shows that non linearities can also bias the 3-position switching results so that it is important for calibration accuracy to have the ADC power at a fairly constant level. Some earlier tests made with other changes to the circuit of Figure 1 that were later removed showed that it is important to have the level and frequency range to avoid having the peak power as low as 5 MHz and the need to spread out the power to avoid saturating the ZX60-6013E amplifier before saturating the ZKL-1R5 owing to the high attenuation of the 15pf filter which helps the high sky noise from dominating the inband power at the low end of the band. Circuit analysis shows that for the out of band noise the power from the ZKL-1R5 is 6.5 times higher than the output of the ZX60-6013E. The 1 dB compression points for the ZKL-1R5 and ZX6-6013E are +18 and +13.4 dBm respectively and at the ADC saturation level of +/- 0.5 volts this corresponds to +4 dBm at 50 ohms which is well below the amplifier compression points. The simulations show that non linearity at the 10% level have a large effect and need to be below 1% for acceptable performance. Also see memo 41 for the results of other simulations and details of the effects of non linearities.

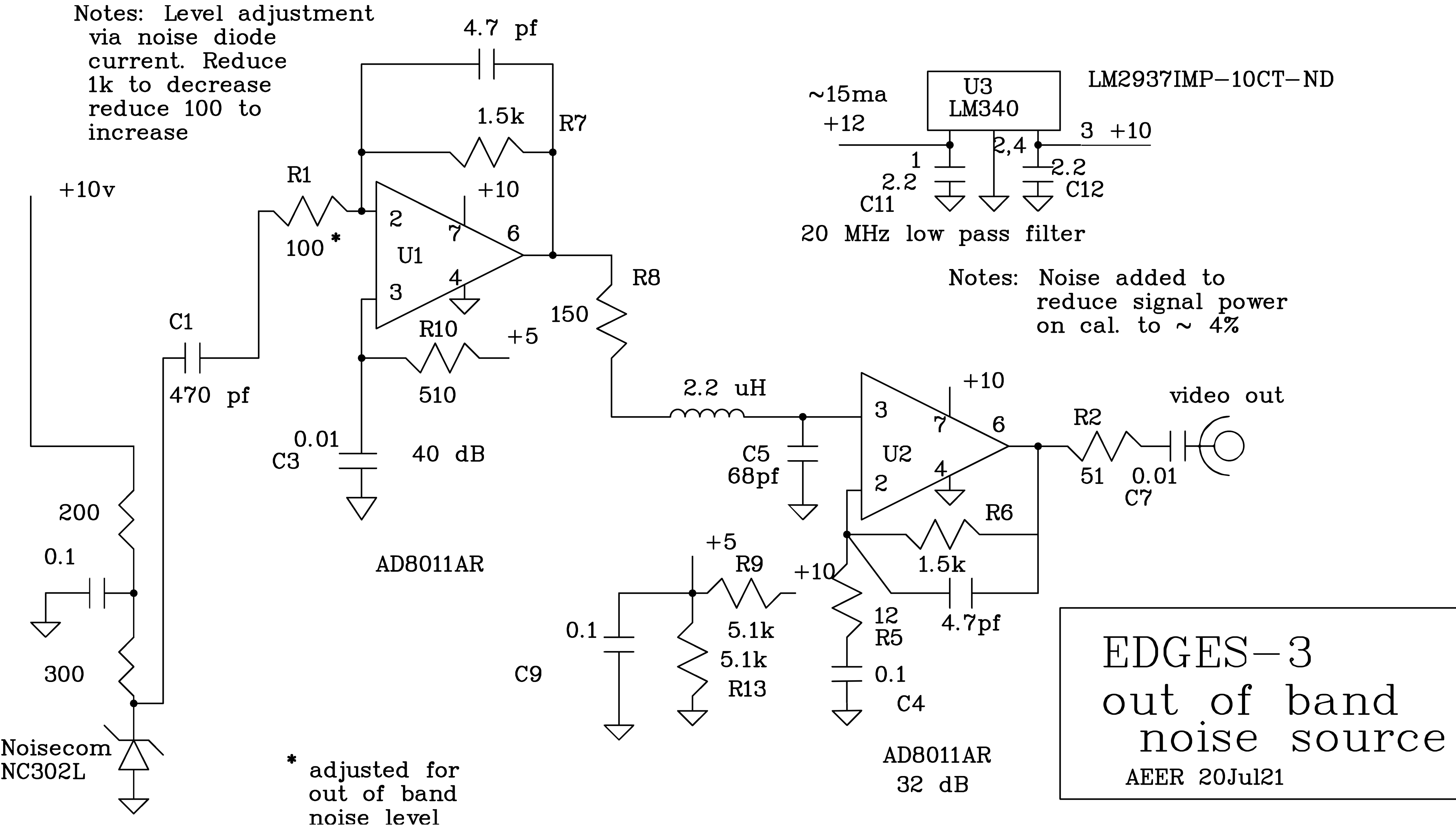

Figure 1. Revised circuit diagram of the EDGES-3 out of band noise source.

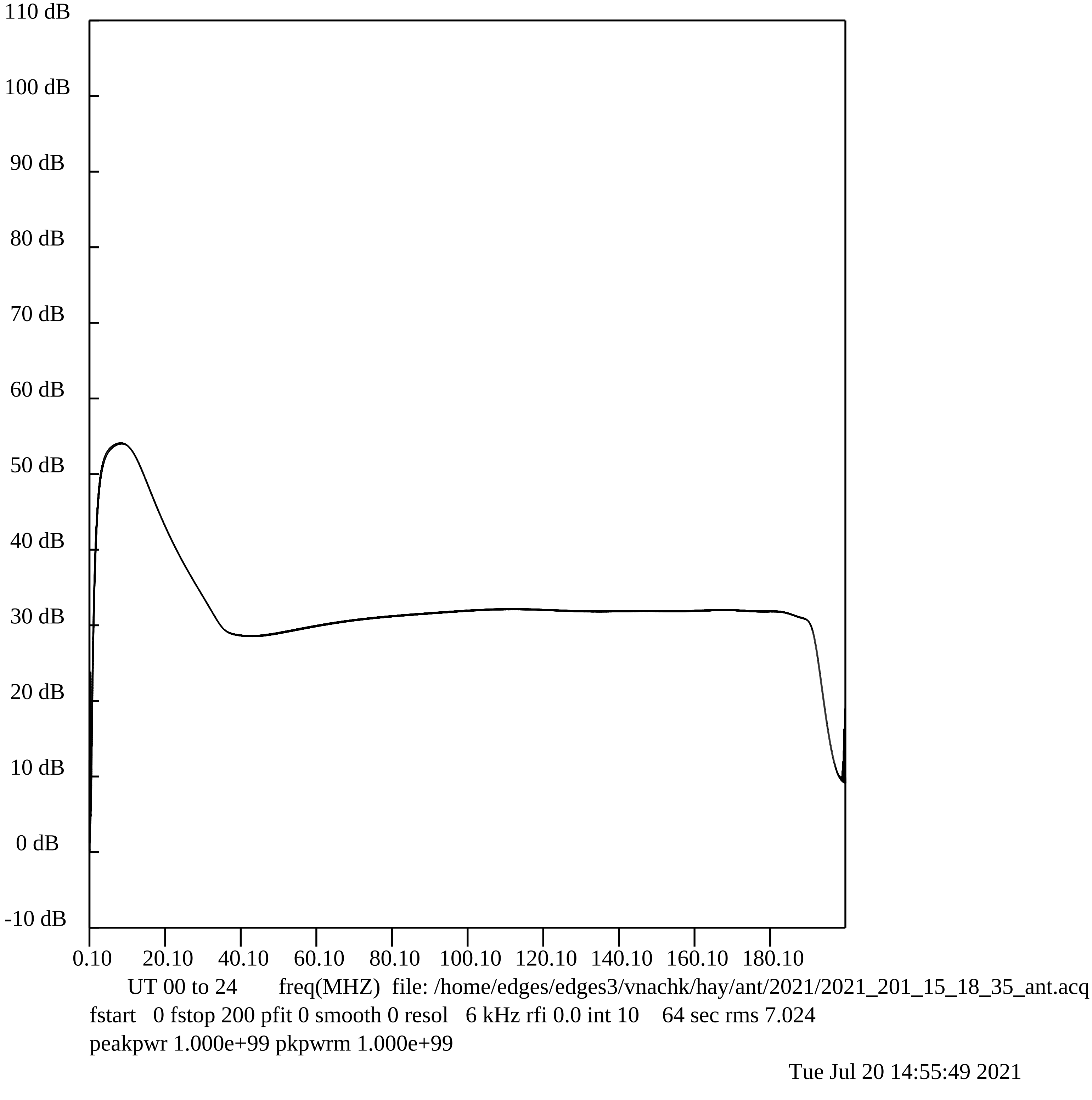

Figure 2. The spectrum when the calibration load signal is selected by the 3-position switch.

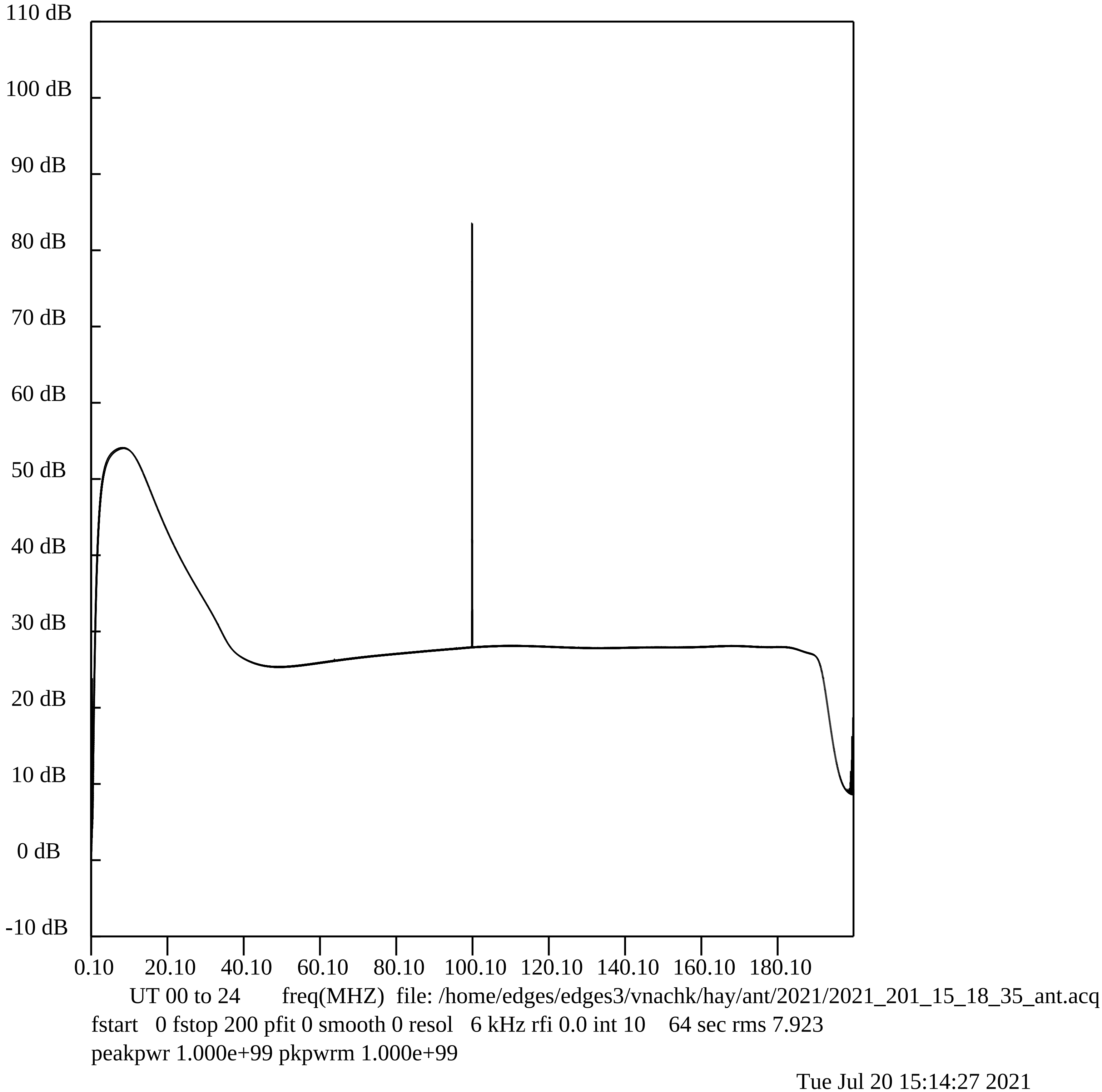

Figure 3. The spectrum when the antenna signal is selected by the 3-position switch.

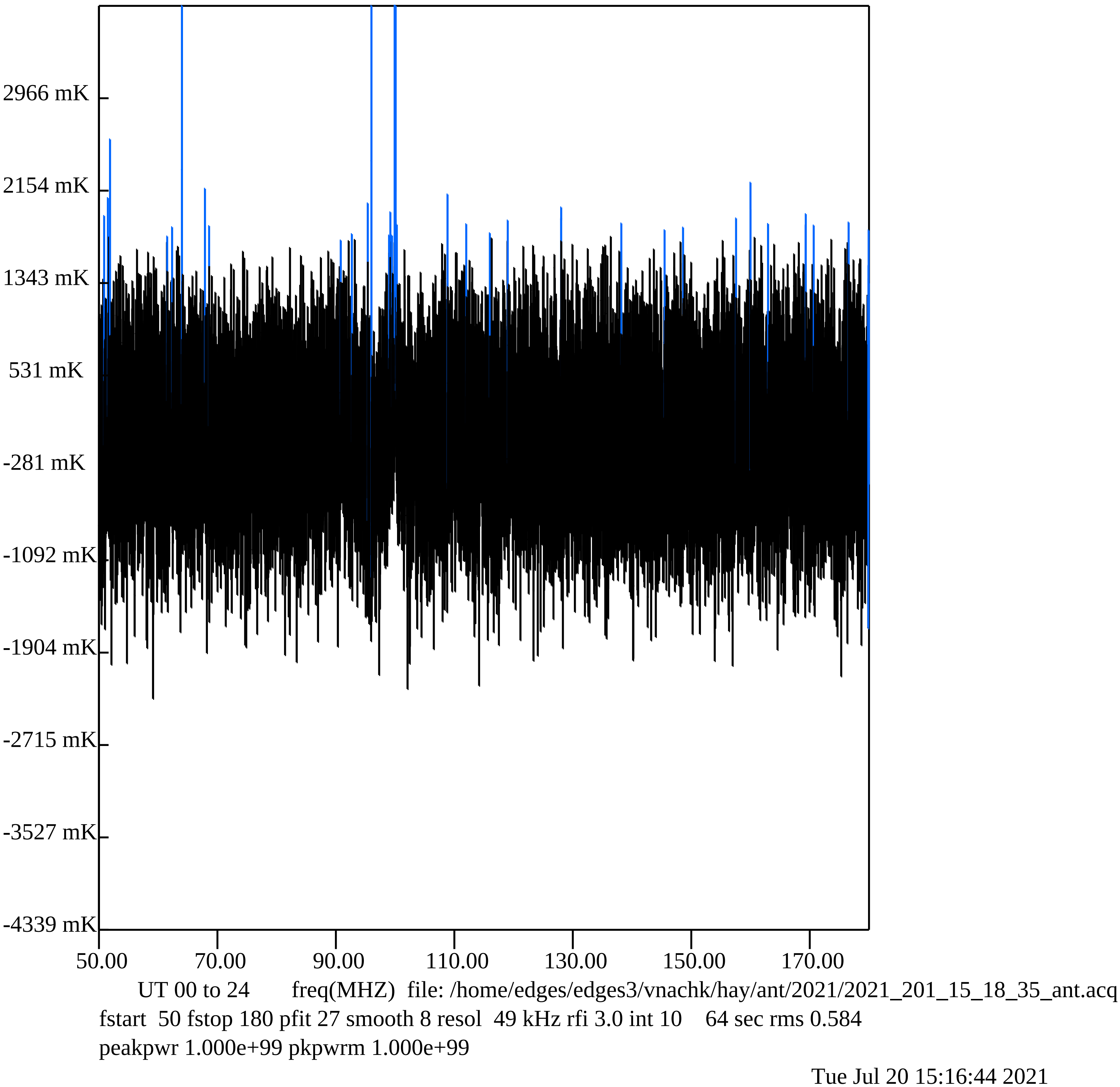

Figure 4. The 3-position switched result with RFI excision applied on the 100 MHz test signal of -82 dBm.

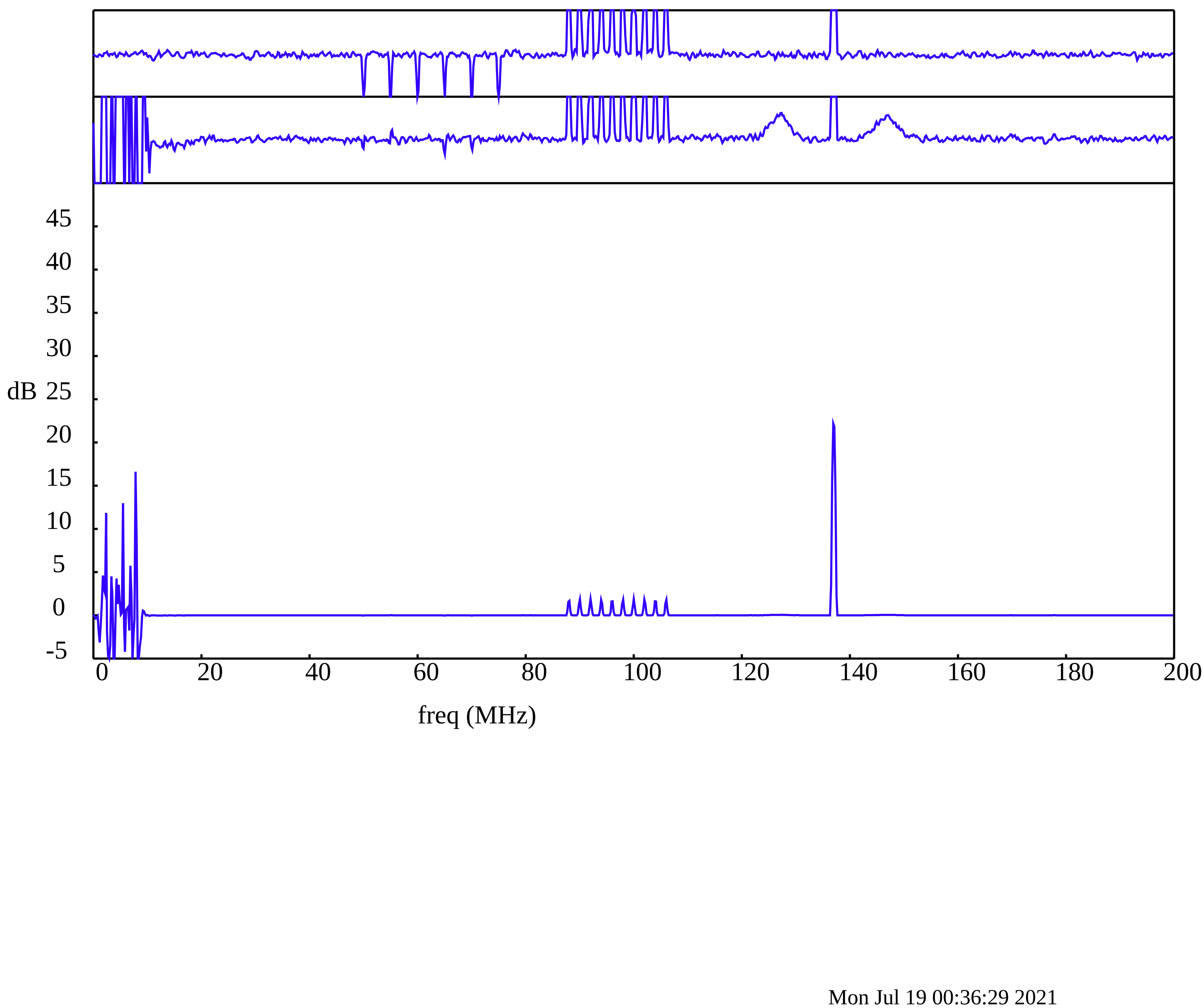

Figure 5. A simulation of the need for out of band noise to remove the effects of 10% non-linearity in the ADC which lead to poor cancellation of the spurious signals in the ADC in the 3-position switched spectrum see text for details.

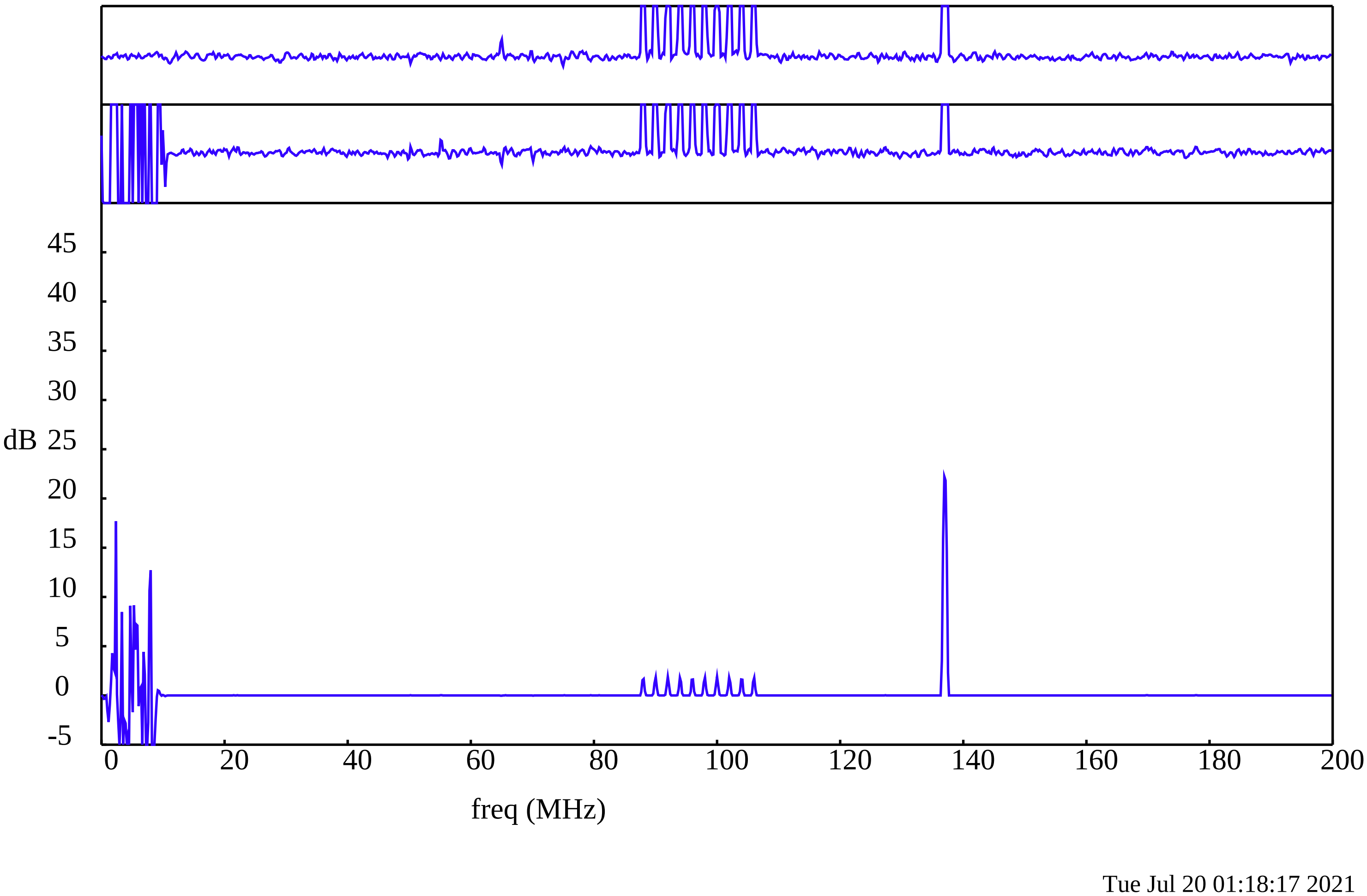

Figure 6. The simulation of Figure 5 without non-linearity.