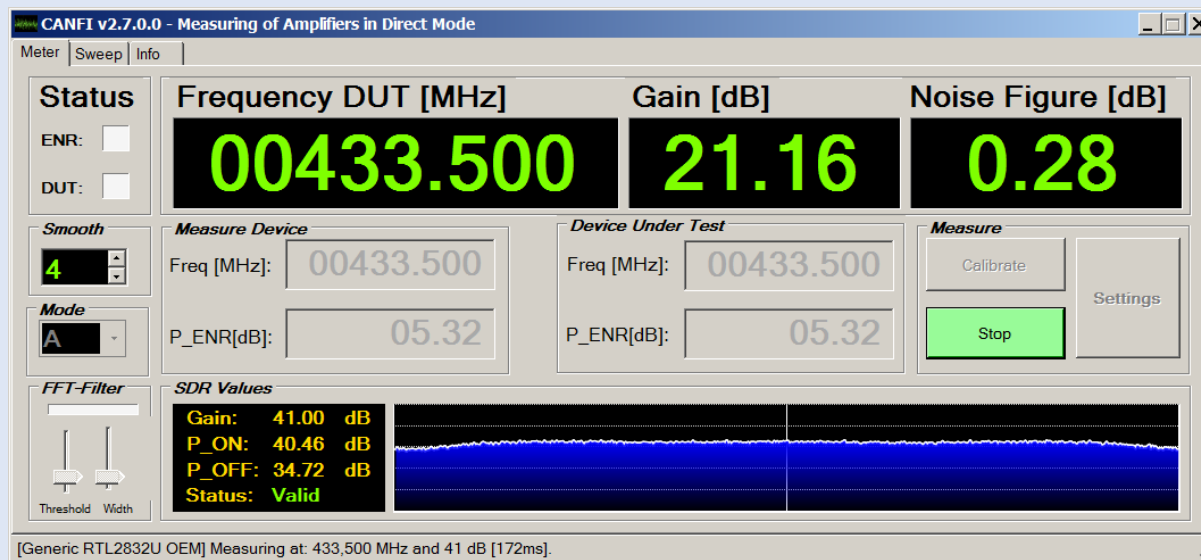


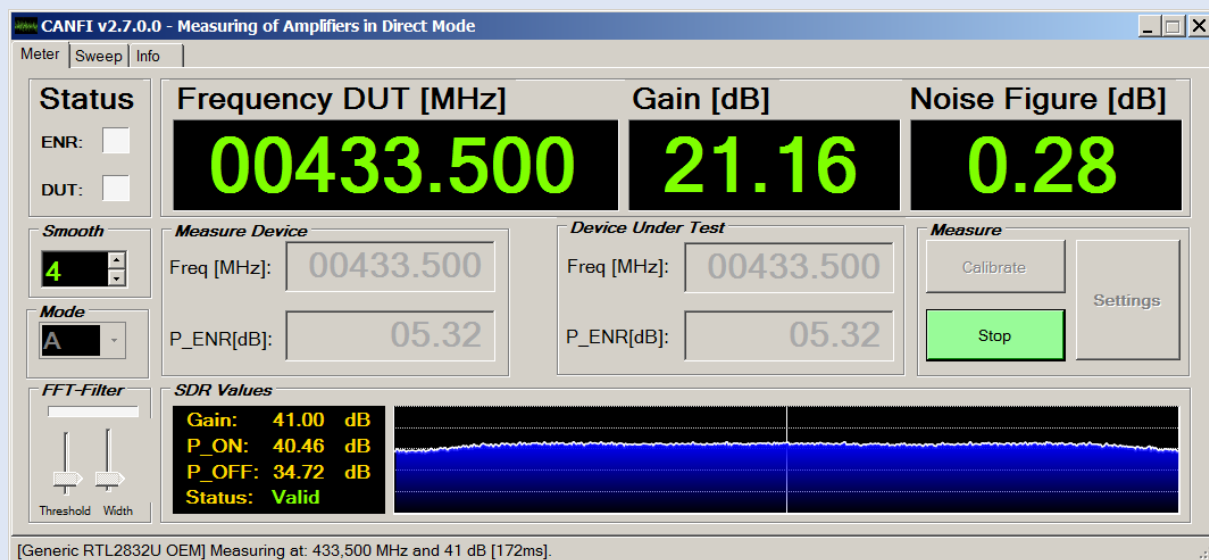
Small Noise Figures Measurement and CANFI



Mirek Kasal, OK2AQ



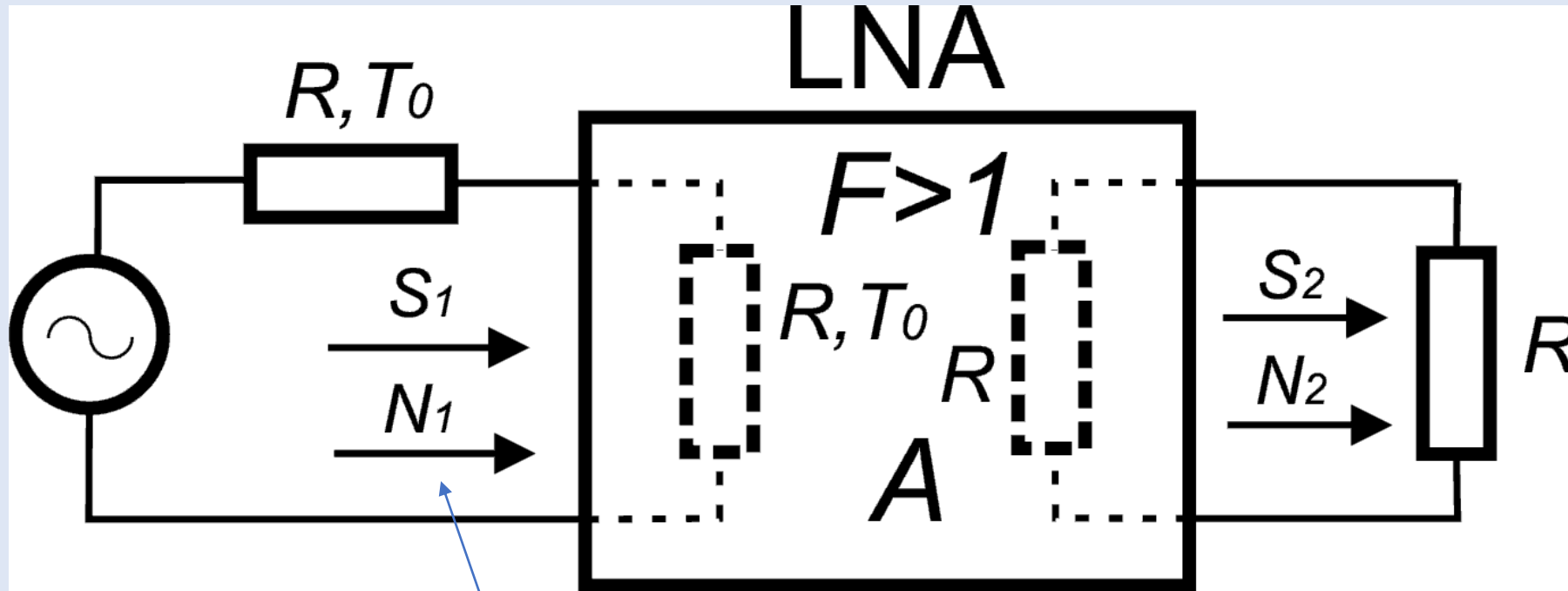
Měření malých šumových čísel a levný automatický indikátor šumového čísla



Mirek Kasal, OK2AQ



Šumový činitel F a šumové číslo $F[\text{dB}]$



$$R = 50 \Omega$$

$$T_0 = 290 \text{ K}$$

$$F = \frac{S_1 / N_1}{S_2 / N_2}$$

$$S_1$$

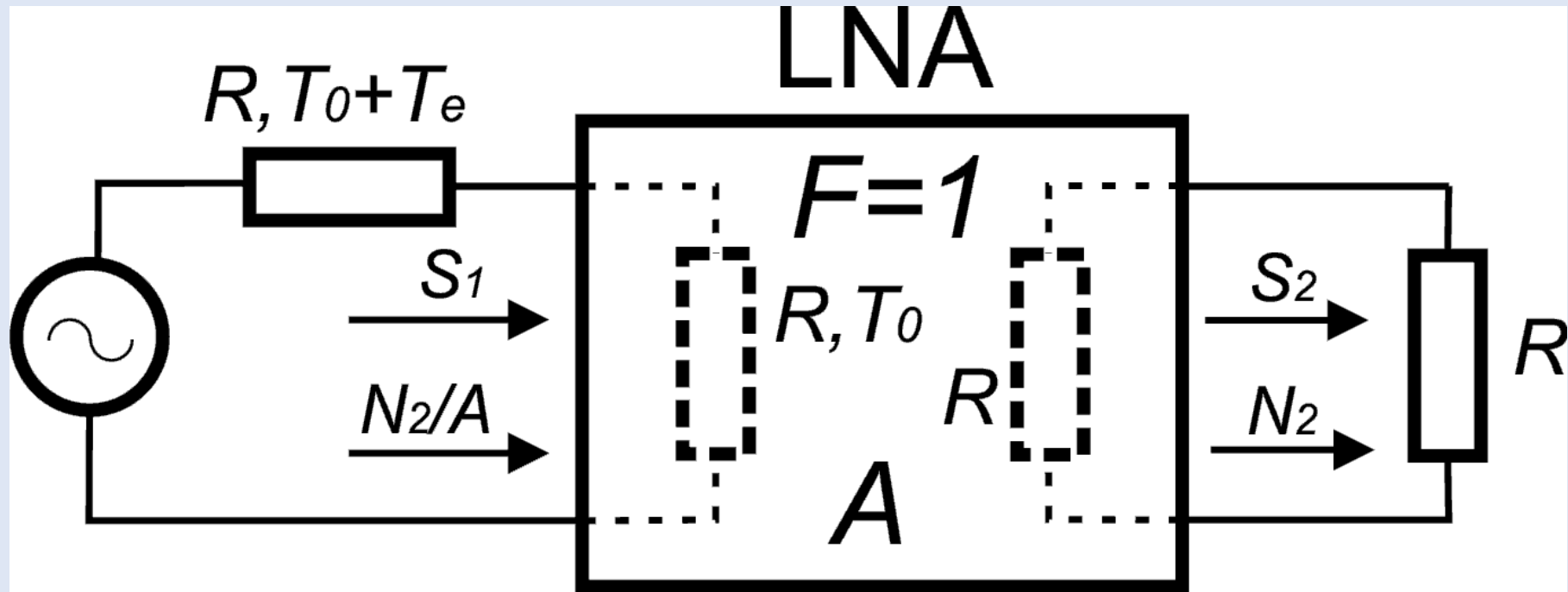
$$S_2 = S_1 \cdot A$$

$$N_1 = k \cdot T_0 \cdot B_n$$

$$N_2 = k \cdot T_0 \cdot B_n \cdot A \cdot F$$

$$F[\text{dB}] = 10 \cdot \log F$$

Ekvivalentní šumová teplota T_e



$$N_2 = k \cdot T_0 \cdot B_n \cdot A \cdot F = (k \cdot T_0 \cdot B_n + k \cdot T_e \cdot B_n) A$$

$$F = \frac{T_0 + T_e}{T_0}$$

$$T_e = T_0(F - 1)$$

$$T_0 = 290 \text{ K}$$

$$(17^\circ \text{ C})$$

Kaskádní řazení výkonově přizpůsobených dvojbranů

$$F = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2} + \dots + \frac{F_n - 1}{A_1 A_2 \dots A_{n-1}}$$

$$T_e = T_{e1} + \frac{T_{e2}}{A_1} + \frac{T_{e3}}{A_1 A_2} + \dots + \frac{T_{en}}{A_1 A_2 \dots A_{n-1}} \quad \text{[K]}$$

ATENUÁTOR

$$F = \frac{S_1 / N_1}{S_2 / N_2} = \frac{1}{A}$$

$$S_1$$

$$S_2 = S_1 \cdot A$$

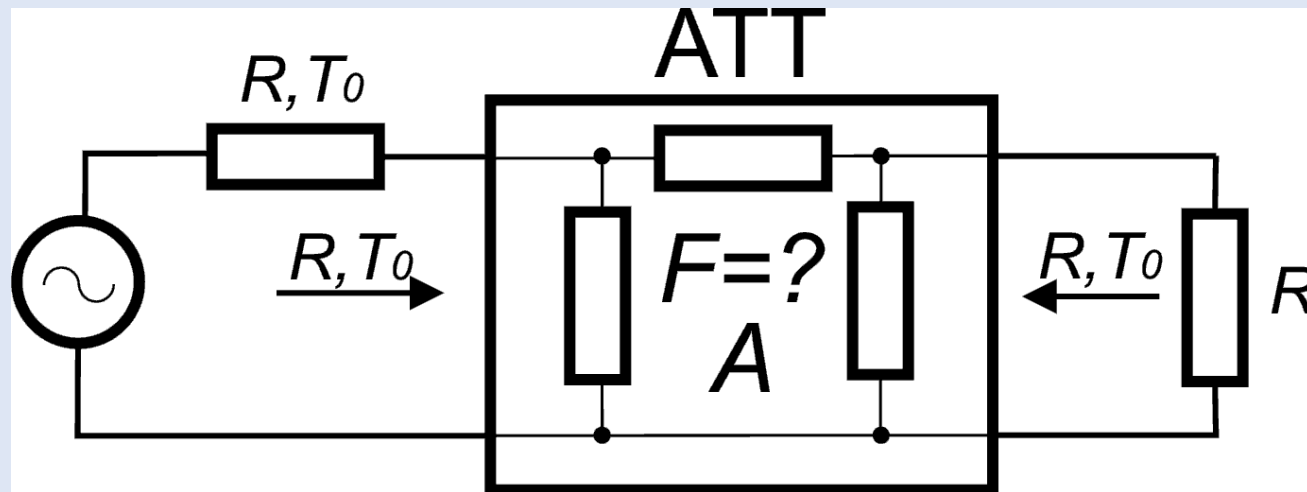
$$N_1 = k \cdot T_0 \cdot B_n$$

$$N_2 = k \cdot T_0 \cdot B_n$$

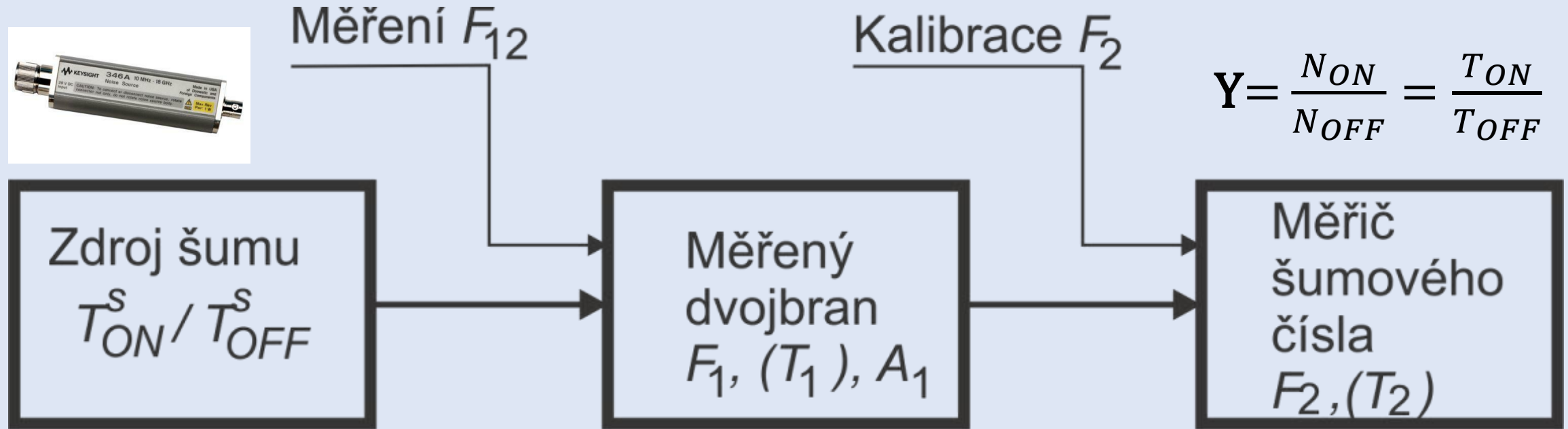
$$T_e = T_0 \left(\frac{1}{A} - 1 \right)$$

ÚTLUM

$$L = 10 \log \left(\frac{1}{A} \right)$$



Kalibrace a měření šumového čísla



$$ENR = \frac{T_{ON}^S - T_{OFF}^S}{T_0}$$

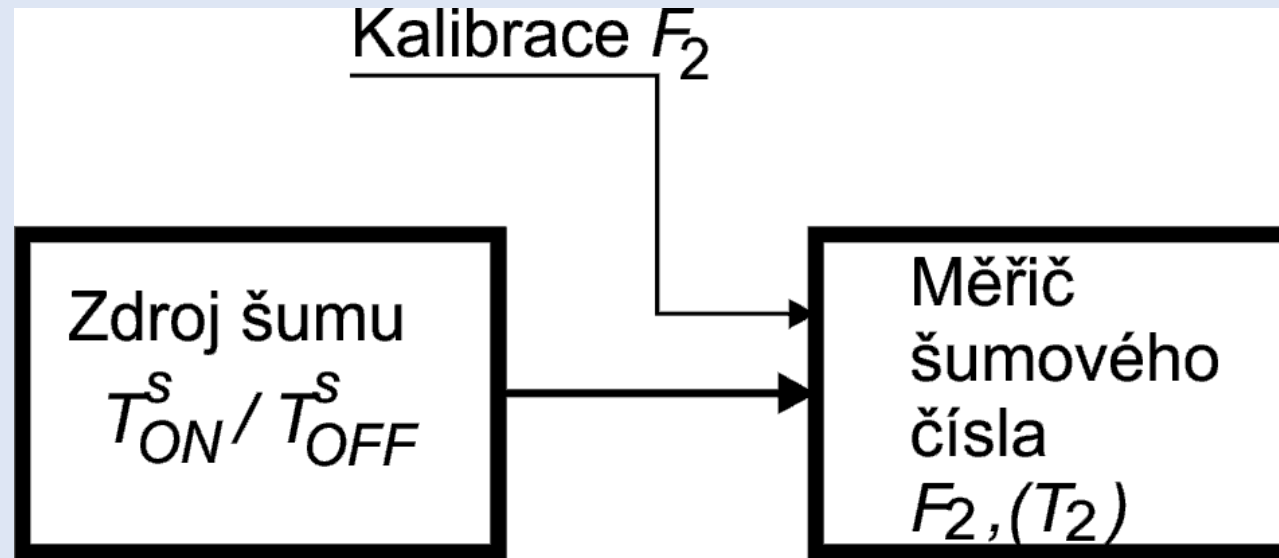
[K]

$$T_0 = 290 \text{ K}$$

ENR - Excess Noise Ratio

$$ENR[\text{dB}] = 10 \cdot \log \left[\frac{T_{ON}^S - T_{OFF}^S}{T_0} \right]$$

KALIBRACE

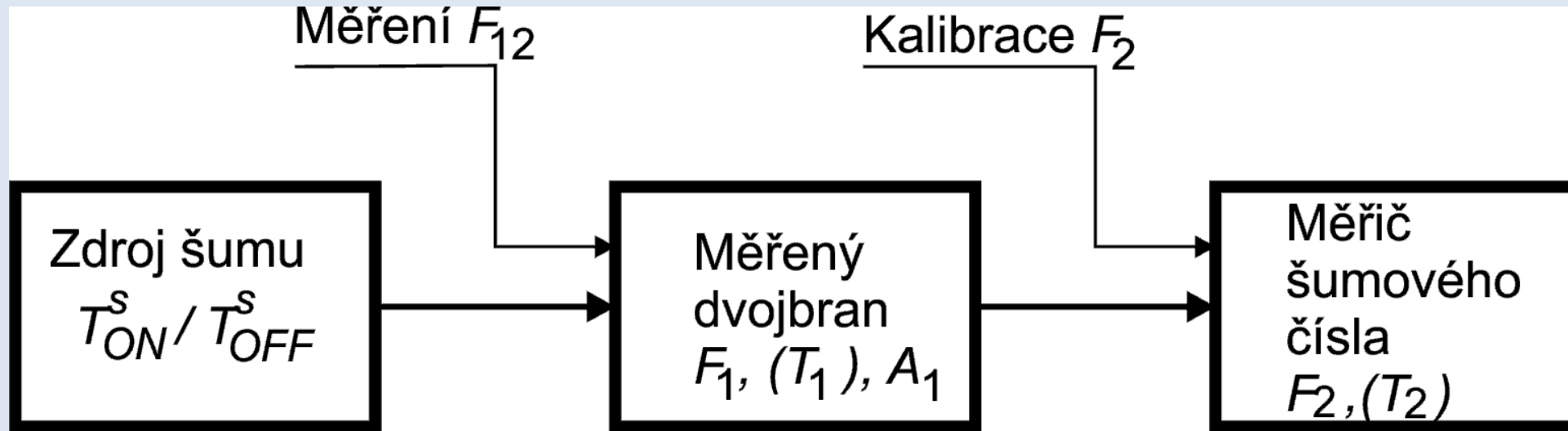


$$Y = \frac{T_{2ON}}{T_{2OFF}} = \frac{T_{ON}^S + T_2}{T_{OFF}^S + T_2}$$

$$T_2 = \frac{T_{ON}^S - Y_2 T_{OFF}^S}{Y_2 - 1}$$

$$F_2 \stackrel{T_{OFF}^S = T_0}{=} \frac{ENR}{Y_2 - 1}$$

Měření F



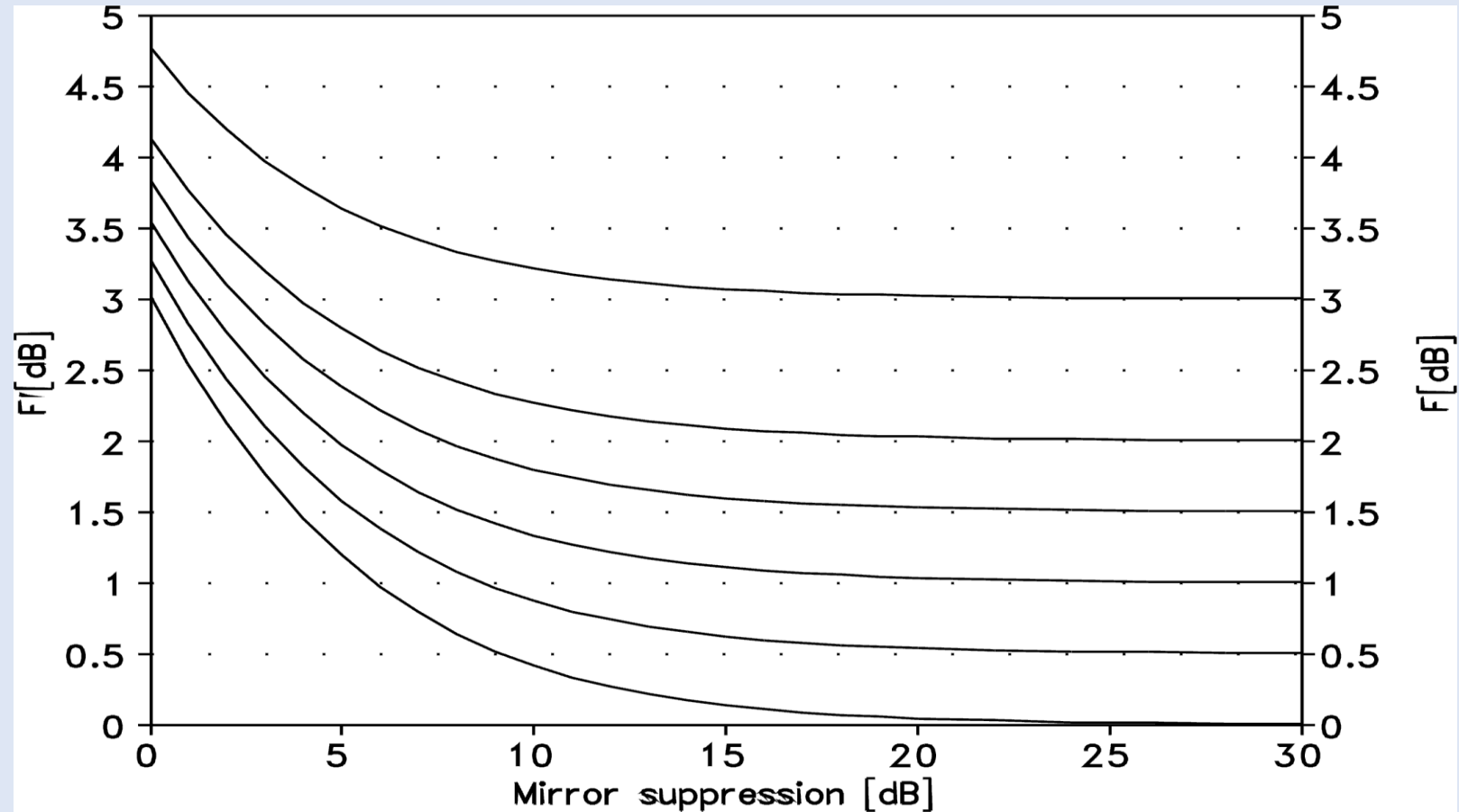
$$Y_{12} = \frac{T_{12ON}}{T_{12OFF}} \quad T_{12} = \frac{T_{ON}^S - Y_{12} T_{OFF}^S}{Y_{12} - 1} \quad F_{12} \stackrel{T_{OFF}^S = T_0}{=} \frac{ENR}{Y_{12} - 1}$$

$$A_1 = \frac{N_{12ON} - N_{12OFF}}{N_{2ON} - N_{2OFF}} \quad T_1 = T_{12} - \frac{T_2}{A_1} \quad F_1 = 1 - \frac{T_1}{290}$$

$$A_1 [\text{dB}] = 10 \cdot \log A_1 \quad F_1 [\text{dB}] = 10 \cdot \log F_1$$

Chyby měření

- Impedanční nepřizpůsobení
- ENR co nejmenší, přijímač musí být lineární
- Kvalitní přechodky na vstupu DUT, pokud jsou potřeba
- Co největší šířka pásma (obvykle 3 – 4 MHz), kratší doba nutná pro averaging
- Pro DUT se směšovačem měření SSB/DSB:
 - $T_A \neq T_0$



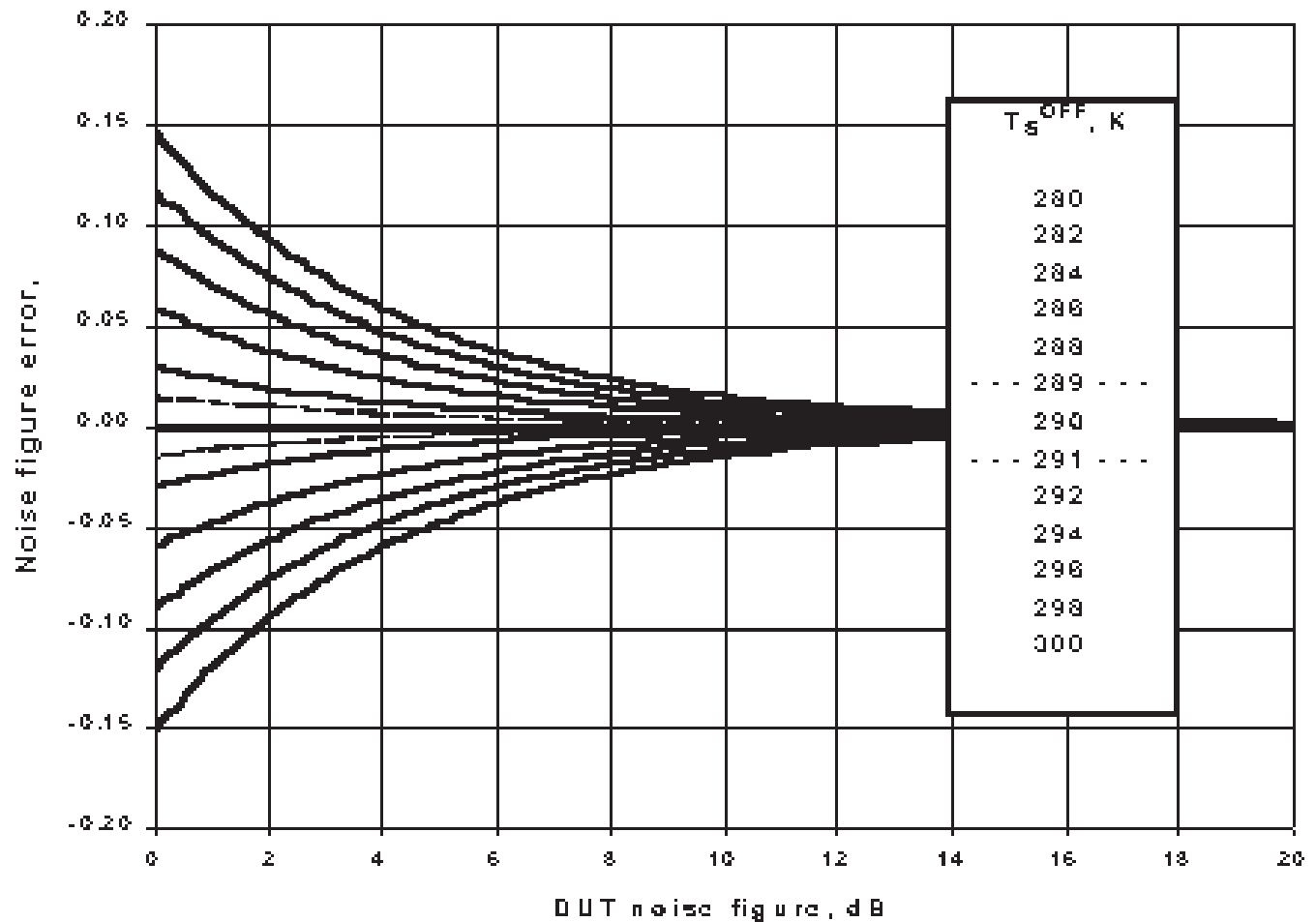
– $T_0 \neq 290$ K

Je-li teplota okolí T_A : $ENR' = \frac{T_0}{T_A} ENR$; $ENR'[\text{dB}] = 10 \log \frac{T_0}{T_A} + ENR[\text{dB}]$

$$F'_{12} = \frac{ENR}{Y_{12}-1} + 1 - \frac{T_A}{T_0}$$

a s kalibrací

$$F'_1 = F'_{12} - \frac{F_2 - \frac{T_A}{T_0}}{A_1}$$



| | HLAVA | | | DUT | | | | RX | |
|-------------|--------|---------------------|-----------|---------|----------|--|-------|-------|------|
| ENR | 4 | 6 dB | F_1 | 1,26 | 1 dB | | F_2 | 2 | 3 dB |
| T_0 | 290 K | | T_1 | 75,4 K | | | Y_2 | 3 | |
| T_{ON}^s | 1450 K | | A_1 | 40 | 16 dB | | T_2 | 290 K | |
| T_{OFF}^s | 290 K | | | | | | | | |
| | | | Y_{12} | 4,11 | | | | | |
| | | $T_A = T_0 = 290 K$ | T_{12} | 82,65 K | | | | | |
| | | | F_{12} | 1,285 | 1,09 dB | | | | |
| | | | | | | | | | |
| | | | F_{12}' | 1,25 | | | | | |
| | | $T_A = 300 K$ | F_1' | 1,226 | 0,885 dB | | | | |
| | | | | | | | | | |

CANFI

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter | Sweep | Info

| Status | Frequency DUT [MHz] | Gain [dB] | Noise Figure [dB] |
|--|---------------------|-----------|-------------------|
| ENR: <input type="checkbox"/> DUT: <input type="checkbox"/> | 00433.500 | 21.16 | 0.28 |

Smooth: 4

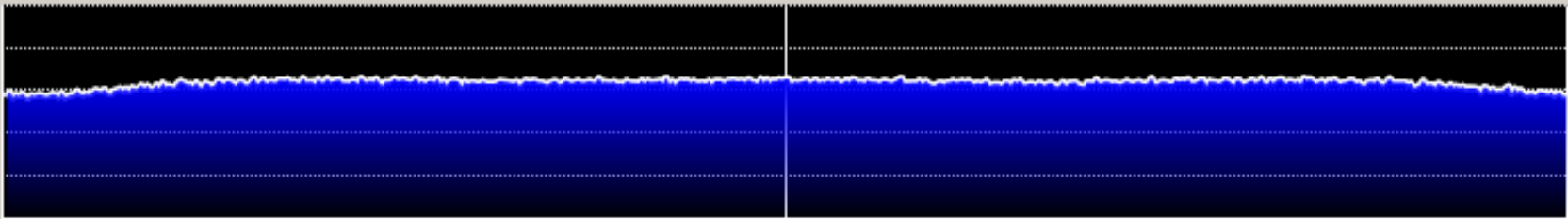
Mode: A

FFT-Filter: Threshold Width

| Measure Device | Device Under Test | Measure |
|---|---|-------------------------------|
| Freq [MHz]: 00433.500 P_ENR[dB]: 05.32 | Freq [MHz]: 00433.500 P_ENR[dB]: 05.32 | Calibrate Settings Stop |

SDR Values

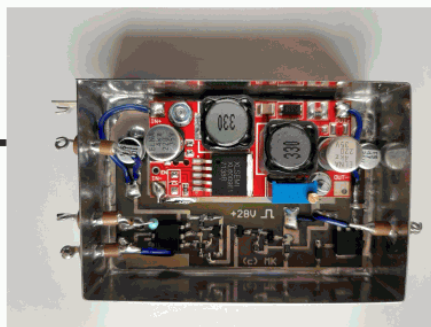
| | | |
|---------|-------|----|
| Gain: | 41.00 | dB |
| P_ON: | 40.46 | dB |
| P_OFF: | 34.72 | dB |
| Status: | Valid | |



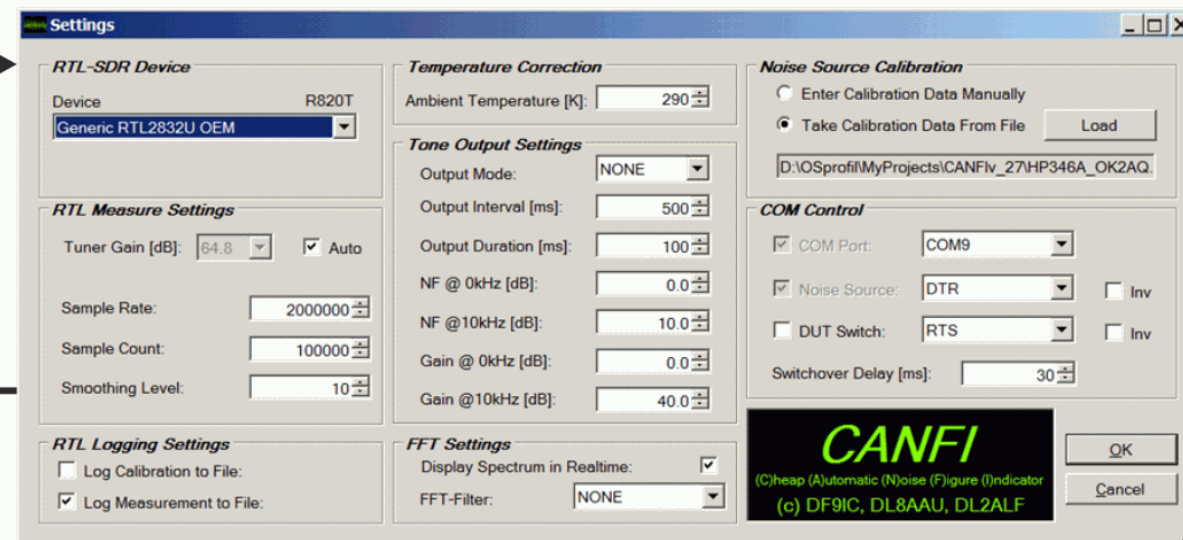
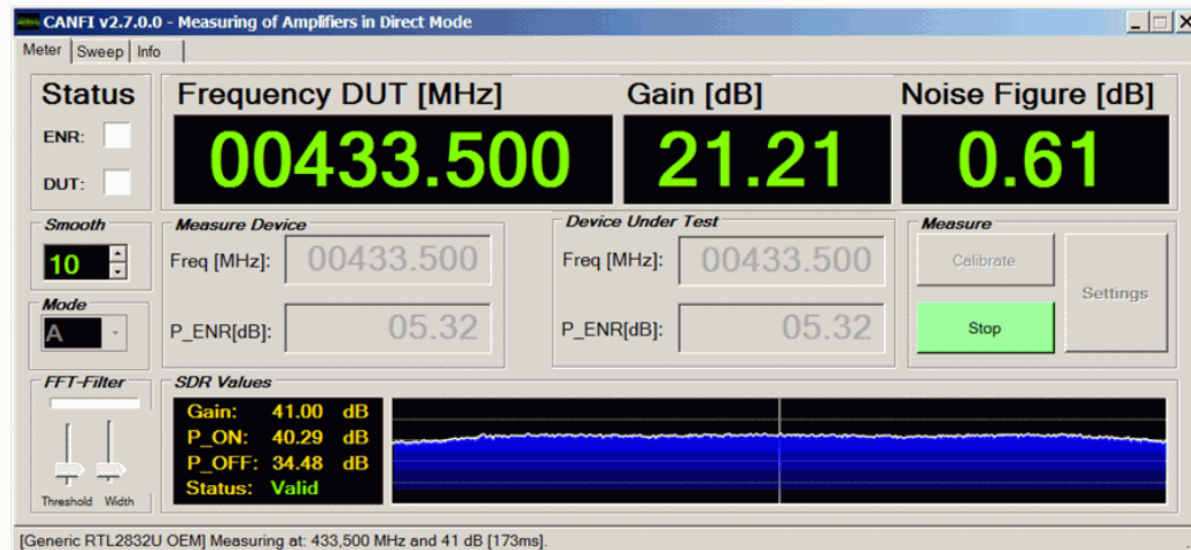
[Generic RTL2832U OEM] Measuring at: 433,500 MHz and 41 dB [172ms].

CANFI

LNA +
Přijímač SDR
 $F_2, (T_2)$



2 x USB



CANFI - Hardware

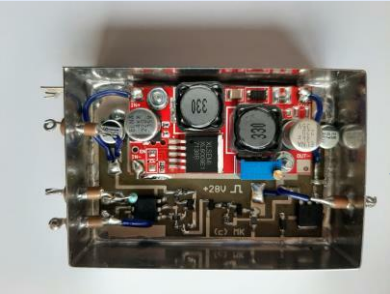
USB hub +5 V ext.

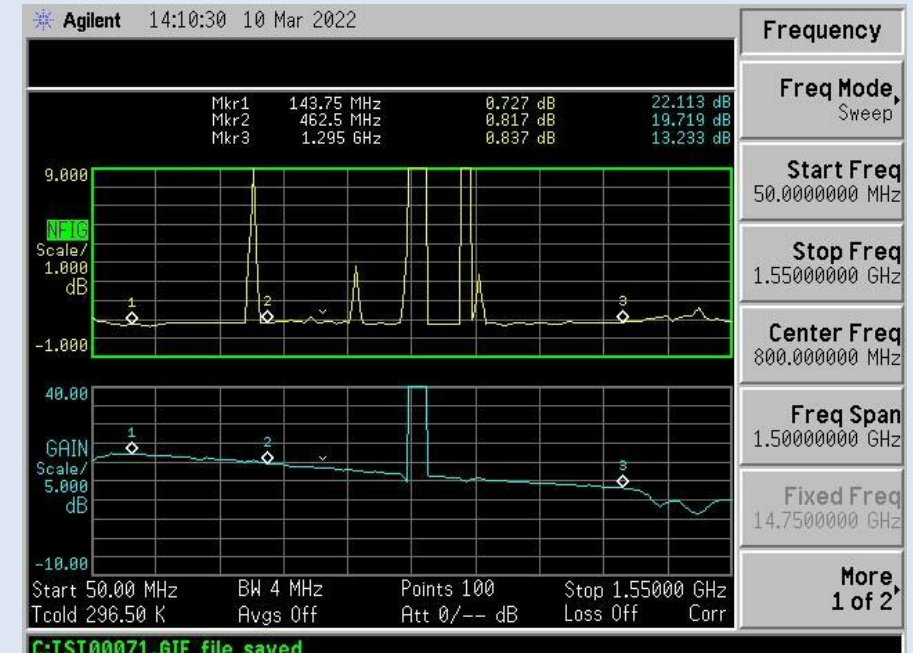
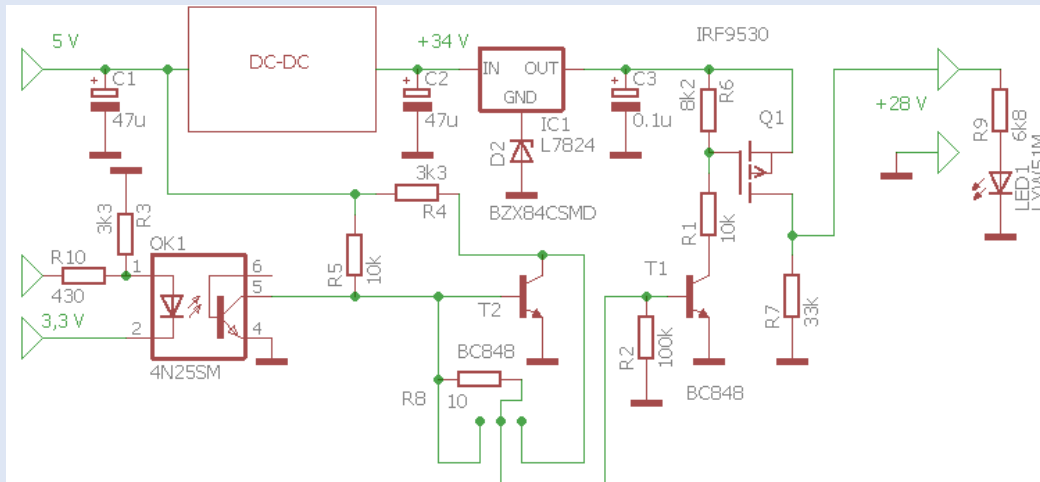
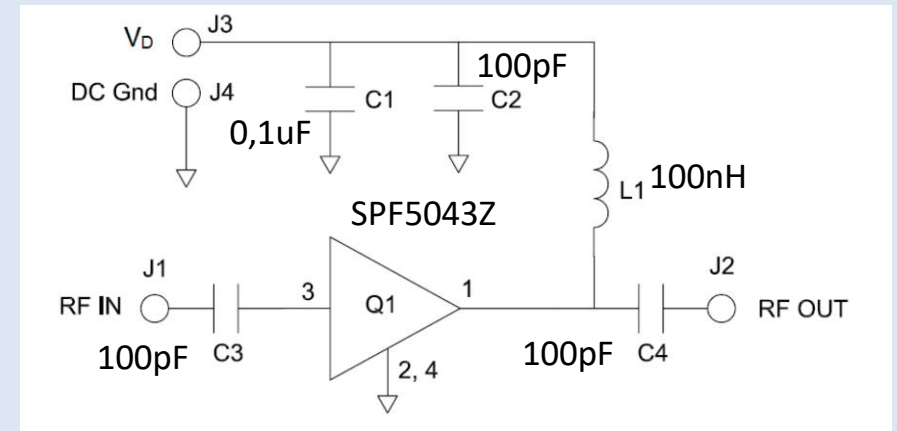
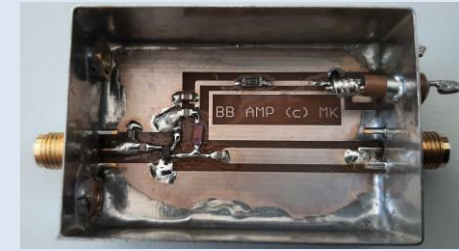
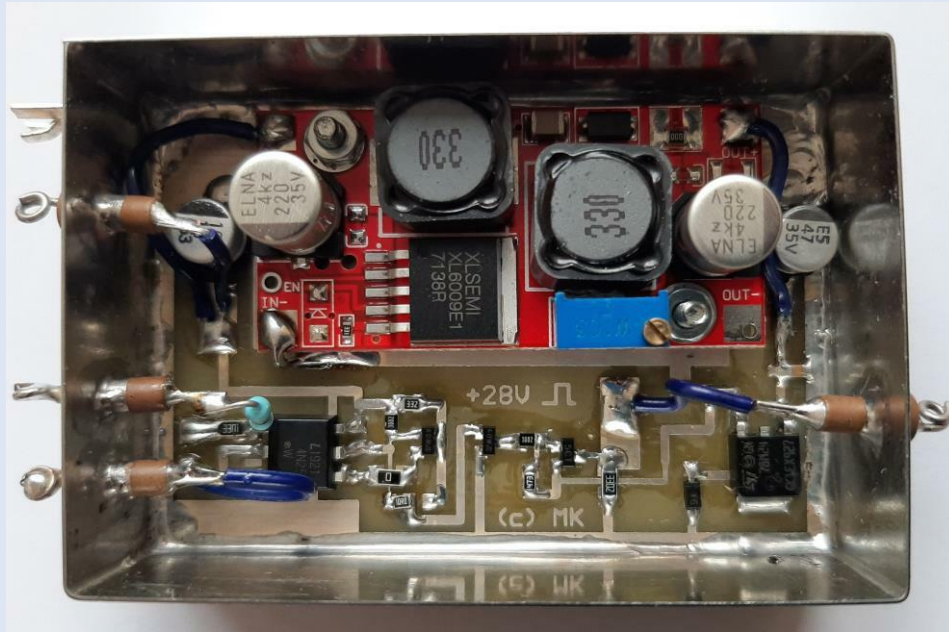
USB -UART

+5 V

+28 V pulse

LNA SPF5043





Mode: A – LNA; B – konvertor; C – LNA s konvertorem

The screenshot displays the CANFI v2.7.0.0 software interface for measuring amplifiers in direct mode. The main display area shows three large green digital readouts: Frequency DUT [MHz] at 00433.500, Gain [dB] at 21.16, and Noise Figure [dB] at 0.28. Below these, the 'Measure Device' and 'Device Under Test' sections show input fields for Freq [MHz] (00433.500) and P_ENR [dB] (05.32). The 'Measure' section contains 'Calibrate' and 'Stop' buttons, with 'Stop' highlighted in green. The 'Settings' button is also visible. On the left, the 'Status' section has 'ENR' and 'DUT' checkboxes. The 'Smooth' section shows a value of 4. The 'Mode' section shows 'A' selected. The 'FFT-Filter' section has 'Threshold' and 'Width' sliders. The 'SDR Values' section shows Gain: 41.00 dB, P_ON: 40.46 dB, P_OFF: 34.72 dB, and Status: Valid. A spectrum plot is visible at the bottom right. The status bar at the bottom indicates: [Generic RTL2832U OEM] Measuring at: 433,500 MHz and 41 dB [172ms].

| Metric | Value |
|------------------------------|-----------|
| Frequency DUT [MHz] | 00433.500 |
| Gain [dB] | 21.16 |
| Noise Figure [dB] | 0.28 |
| Mode | A |
| Smooth | 4 |
| Measure Device Freq [MHz] | 00433.500 |
| Measure Device P_ENR [dB] | 05.32 |
| Device Under Test Freq [MHz] | 00433.500 |
| Device Under Test P_ENR [dB] | 05.32 |
| Gain [dB] | 41.00 |
| P_ON [dB] | 40.46 |
| P_OFF [dB] | 34.72 |
| Status | Valid |

Settings

RTL-SDR Device
 Device: R820T
 Generic RTL2832U OEM

RTL Measure Settings
 Tuner Gain [dB]: 21.6 Auto
 Sample Rate: 2000000
 Sample Count: 100000
 Smoothing Level: 6

RTL Logging Settings
 Log Calibration to File:
 Log Measurement to File:

Temperature Correction
 Ambient Temperature [K]: 300

Tone Output Settings
 Output Mode: NONE
 Output Interval [ms]: 500
 Output Duration [ms]: 100
 NF @ 0kHz [dB]: 0.0
 NF @ 10kHz [dB]: 10.0
 Gain @ 0kHz [dB]: 0.0
 Gain @ 10kHz [dB]: 40.0

FFT Settings
 Display Spectrum in Realtime:
 FFT-Filter: NONE

Noise Source Calibration
 Enter Calibration Data Manually
 Take Calibration Data From File **Load**
 C:\Users\Mirek\MyPrograms\CANFlv_27\HP346A_!

COM Control
 COM Port: COM4
 Noise Source: DTR Inv
 DUT Switch: RTS Inv
 Switchover Delay [ms]: 20

CANFI
 (C)heap (A)utomatic (N)oise (F)igure (I)ndicator
 (c) DF9IC, DL8AAU, DL2ALF

OK
Cancel

```

Lister - [g:\CANFlv_27\HP346A_OK2AQ.cal]
Soubor Upravit Možnosti Kódování nápověda 100 %
// CanFi calibration file (c) 2020 by OK2AQ
// Syntax: Frequency[GHz]; ENR[dB]
// Example: 10.0; 15.53
0.01; 5.43
0.1; 5.35
1.0; 5.28
2.0; 5.48
3.0; 5.41
4.0; 5.42
5.0; 5.39
6.0; 5.40
7.0; 5.41
8.0; 5.49
9.0; 5.51
10.0; 5.53
11.0; 5.54
12.0; 5.49
13.0; 5.50
14.0; 5.52
15.0; 5.63
16.0; 5.75
17.0; 5.78
18.0; 5.58
  
```

Settings

RTL-SDR Device
 Device: R820T
 Generic RTL2832U OEM

RTL Measure Settings
 Tuner Gain [dB]: 3.2 Auto
 Sample Rate: 2000000
 Sample Count: 100000
 Smoothing Level: 6

RTL Logging Settings
 Log Calibration to File:
 Log Measurement to File:

Temperature Correction
 Ambient Temperature [K]: 296

Tone Output Settings
 Output Mode: NONE
 Output Interval [ms]: 500
 Output Duration [ms]: 100
 NF @ 0kHz [dB]: 0.0
 NF @ 10kHz [dB]: 10.0
 Gain @ 0kHz [dB]: 0.0
 Gain @ 10kHz [dB]: 40.0

Noise Source Calibration
 Enter Calibration Data Manually
 Take Calibration Data From File
 C:\Users\mirek\MyProjects\CANFlv_27\HP346A_0

COM Control
 COM Port: COM3
 Noise Source: DTR Inv
 DUT Switch: RTS Inv
 Switchover Delay [ms]: 30

FFT Settings
 Display Spectrum in Realtime:
 FFT-Filter: FFTW

CANFI
 (C)heap (A)utomatic (N)oise (F)igure (I)ndicator
 (c) DF9IC, DL8AAU, DL2ALF

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter Sweep Info

Status
 ENR:
 DUT:

Frequency DUT [MHz]
 00432.140

Gain [dB]
 --.--

Noise Figure [dB]
 1.15

Smooth
 4

Measure Device
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Device Under Test
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Measure

SDR Values
 Gain: 41.00 dB
 P_ON: 36.64 dB
 P_OFF: 31.35 dB
 Status: Valid

FFT-Filter
 Threshold Width

[Generic RTL2832U OEM] Measuring at: 432,140 MHz and 41 dB [163ms]

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter Sweep Info

Status
 ENR:
 DUT:

Frequency DUT [MHz]
 00432.140

Gain [dB]
 -0.20

Noise Figure [dB]
 -0.03

Smooth
 4

Measure Device
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Device Under Test
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Measure

SDR Values
 Gain: 41.00 dB
 P_ON: 36.43 dB
 P_OFF: 31.27 dB
 Status: Valid

FFT-Filter
 Threshold Width

[Generic RTL2832U OEM] Measuring at: 432,140 MHz and 41 dB [162ms]

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter Sweep Info

Status
 ENR:
 DUT:

Frequency DUT [MHz]
 00432.140

Gain [dB]
 -3.14

Noise Figure [dB]
 3.14

Smooth
 4

Measure Device
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Device Under Test
 Freq [MHz]: 00432.140
 P_ENR[dB]: 05.32

Measure

SDR Values
 Gain: 41.00 dB
 P_ON: 34.63 dB
 P_OFF: 31.46 dB
 Status: Valid

FFT-Filter
 Threshold Width

[Generic RTL2832U OEM] Measuring at: 432,140 MHz and 41 dB [166ms]

Settings

RTL-SDR Device
 Device: R820T
 Generic RTL2832U OEM

RTL Measure Settings
 Tuner Gain [dB]: 64.8 [Auto]
 Sample Rate: 2000000
 Sample Count: 100000
 Smoothing Level: 10

RTL Logging Settings
 Log Calibration to File:
 Log Measurement to File:

Temperature Correction
 Ambient Temperature [K]: 290

Tone Output Settings
 Output Mode: NONE
 Output Interval [ms]: 500
 Output Duration [ms]: 100
 NF @ 0kHz [dB]: 0.0
 NF @ 10kHz [dB]: 10.0
 Gain @ 0kHz [dB]: 0.0
 Gain @ 10kHz [dB]: 40.0

Noise Source Calibration
 Enter Calibration Data Manually
 Take Calibration Data From File [Load]
 D:\OSprofil\MyProjects\CANFlv_27\HP346A_OK2AQ

COM Control
 COM Port: COM9
 Noise Source: DTR [Inv]
 DUT Switch: RTS [Inv]
 Switchover Delay [ms]: 30

FFT Settings
 Display Spectrum in Realtime:
 FFT-Filter: NONE

CANFI
 (C)heap (A)utomatic (N)oise (F)igure (I)ndicator
 (c) DF9IC, DL8AAU, DL2ALF

OK Cancel

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter Sweep Info

Status
 ENR:
 DUT:

Frequency DUT [MHz]
00433.500

Gain [dB]
21.21

Noise Figure [dB]
0.61

Smooth
 10

Measure Device
 Freq [MHz]: 00433.500
 P_ENR[dB]: 05.32

Device Under Test
 Freq [MHz]: 00433.500
 P_ENR[dB]: 05.32

Measure
 Calibrate
 Stop
 Settings

SDR Values
 Gain: 41.00 dB
 P_ON: 40.29 dB
 P_OFF: 34.48 dB
 Status: Valid

Threshold Width

[Generic RTL2832U OEM] Measuring at: 433,500 MHz and 41 dB [173ms].

CANFI v2.7.0.0 - Measuring of Amplifiers in Direct Mode

Meter Sweep Info

Diagram

Measure Device
 Start [MHz]: 00400.000
 Stop [MHz]: 00500.000
 Step [MHz]: 00010.100

Device Under Test
 Start [MHz]: 00400.000
 Stop [MHz]: 00500.000
 Step [MHz]: 00010.100

Sweep
 Mode: SINGLE
 NF[dB]: --
 Gain[dB]: --

Measure
 Calibrated
 Measure
 Settings

[Generic RTL2832U OEM] Idling at: 400,000 MHz and 21 dB [41ms].

Agilent 14:55:06 7 Mar 2022

Marker Frequency 433.500000 MHz

Mkr1 433.5 MHz 0.637 dB 21.262 dB

Marker
 1 2 3 4

State
 Normal

Band Pair
 Ref Normal

Trace
 Data Memory

Search

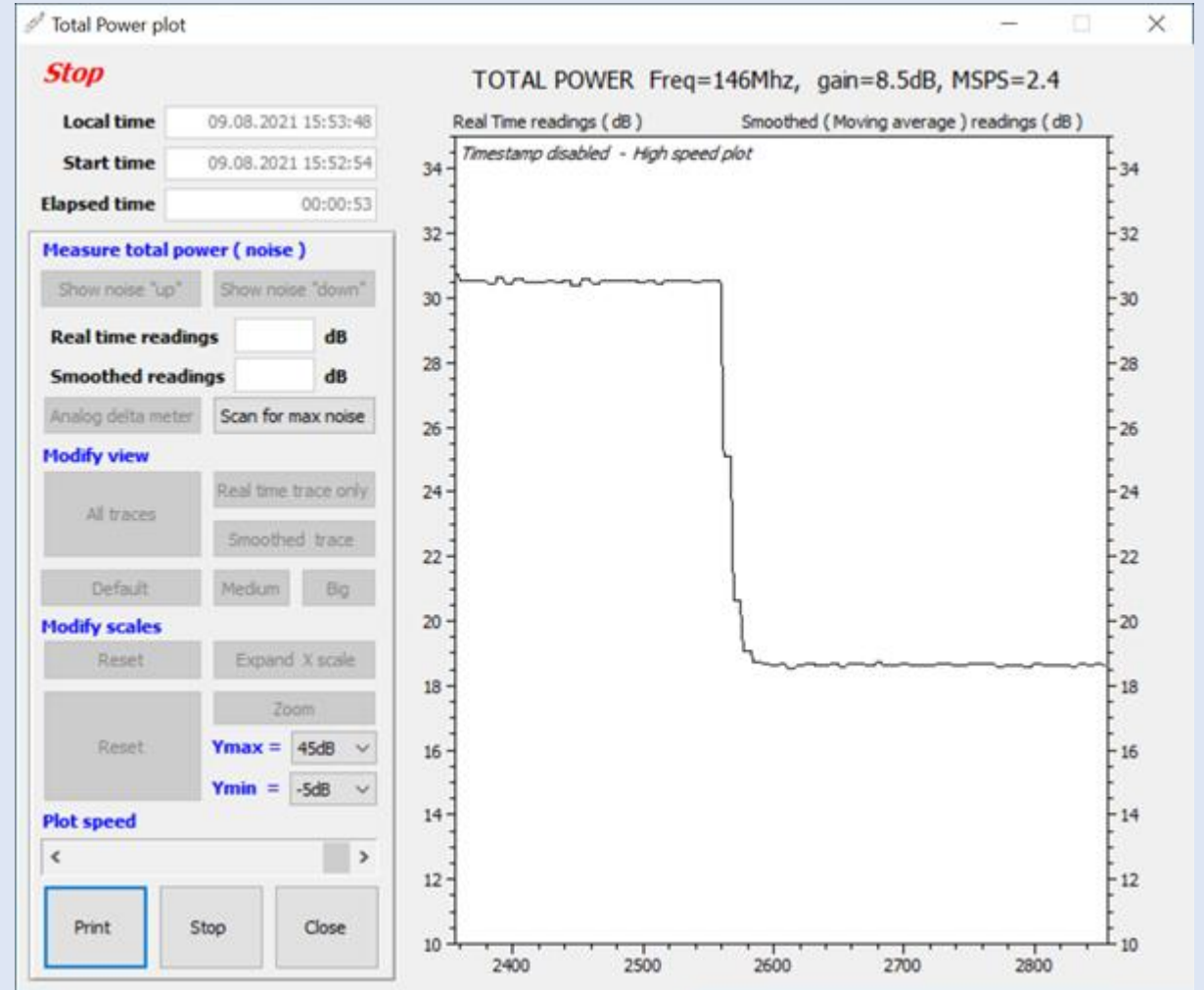
Markers
 All Off

Start 400.00 MHz BW 4 MHz Points 100 Stop 500.00 MHz
 Tcold 296.50 K Avgs Off Att 0/-- dB Loss Off Corr

RTL-SDR s LNA na vstupu lze využít ke všem dalším aplikacím bez omezení.

Zajímavé je použití s programem **Total Power** od IONAA pro měření šumu Slunce, Měsíce a

<http://i0naa.altervista.org/index.php/downloads>



Reference

- [1] Agilent Technologies: Noise Figure Measurement Accuracy – The Y-Factor Method. Application Note: AN 57-2, <https://www.testworld.com/wp-content/uploads/noise-figure-measurement-accuracy-the-y-factor-method.pdf>
- [2] Keysight Technologies: Fundamentals of RF and Microwave Noise Figure Measurements. AN 5952-8255, <https://www.keysight.com/zz/en/assets/7018-06808/application-notes/5952-8255.pdf>
- [3] Keysight Technologies: Noise Figure Uncertainty.
- [4] <https://rfmw.em.keysight.com/NFUcalc>
- [5] <http://www.canfi.eu/index.html>

DĚKUJI VÁM ZA POZORNOST
THANK YOU FOR YOUR ATTENTION

