CANFI: _Cheap_ Automatic Noise Figure Indicator

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What is a noise figure meter?

- Noise figure is defined by source ENR and a measured power ratio:

\[
F = \frac{ENR}{(Y-1)} \quad \text{while} \quad Y = \frac{P_{ON}}{P_{OFF}}
\]

- Noise figure meter = relative power meter + calibrated noise source + calculator

- Requirements for the power meter:
  - precise ratio measurement (< 0.1 dB)
  - frequency selective with adjustable center frequency and wide bandwidth (> 1 MHz)
Why a DVB-T USB stick?

**PROs:**

- Cheap
- ADC has inherently better linearity than analogue detectors
- Higher sampling rate than audio ADC based SDRs
- Wide range tuner covers most VHF / UHF frequencies

**CONs:**

- 8 bit resolution limits dynamic range
- Some birdies
- Thermal drift
Inside the DVB-T USB stick

- Tuner: E4000, FC001x, R820T, ...
- Baseband: RTL2832U
  - 8 Bit ADCs for I and Q, 2 MS/s
  - USB 2 Interface
Inside the DVB-T USB stick

- Tuner IC determines:
  - Frequency range
  - Gain control stages
  - Noise figure
  - Dynamic range

- We use Elonics E4000:
  - Includes 1296 MHz
  - Data sheet with detailed information available
E4000 signal path and gain control

- 8 stages with switchable gain
- No AGC allowed for CANFI
- MGC scheme is part of rtlsdr.dll and must be modified
- CANFI needs less headroom than typical SDR application
ADC linearity measurement

- Test of tuner / ADC linearity
- Signal source:
  - amplified Gaussian noise (Zener diode and 3 stage amp)
  - followed by a step attenuator (10 dB + 0...39 dB + 10 dB)
- Attenuator assembly calibrated and tested with three different VNAs
- Test program reads I and Q samples, corrects DC offset, calculates power and averages over a selectable sample size
- Tuner / ADC noise with no input measured separately and subtracted from total noise power
ADC linearity measurement: result

- <0.1 dB error over any 15 dB ratio between 25 and 55 dB relative input signal power
- Remaining error partly due to thermal drift during measurement
- Clipping at levels >55 dB
Clipped level error correction

- Clipping events are counted separately and could be used in future for a correction to extend the dynamic range (not yet implemented)
Additional Hardware

- Preamp for lower noise figure (DVB-T stick has about 10 dB) and better input match
- Switchable 28 V supply for noise source
- USB hub for single connection and power supply
- Built-in USB memory stick with software and calibration data
MGA30889 preamp

- MMIC in SOT89 case
- 15dB flat gain between 0.04 - 2 GHZ
- Internally matched
- NF ca. 2dB
- 5 V power supply (must be stabilized)

But: stability problems
Terratec Cinergy RC + MGA30889

- Upper side:
  - DVB-T board
  - Case and input connector removed

- Lower side:
  - 5 V boost voltage converter
  - Preamp with MGA 30889
SER2USB and 28 V boost converter

- **Upper side:**
  - SER2USB board
  - Case and Sub-D9 connector removed
  - USB power + RTS

- **Lower side:**
  - LM2733 boost converter
  - Output filter
  - MOSFET switch BTS462 32 V, 100 mOhm, SMT
CANFI Hardware

- Complete HW in a box
- USB powered (additional external supply recommended)
- Includes SW on a USB memory stick
Software

- Measurement engine and GUI by Frank DL2ALF
- Developed in C# for WinXP - Win8 OS
- Status: alpha release
- Can be ported to Linux for a possible embedded noise figure meter on RasPi / BeagleBone / ...

- Early test software, modified DLL and Linux ports by Alex DL8AAU

- Theoretical background by Henning DF9IC
Software functionality

- Calibration: measures $P_{ON}$ and $P_{OFF}$ with noise source connected to the test set for each of 11 gain steps in a 50 dB gain range; single frequency calibration only
- Measurement: measures $P_{ON}$ and $P_{OFF}$ with noise source connected to the DUT and calculates noise figure and gain
- Selectable averaging and sample rate (bandwidth)
- Administration and interpolation of ENR tables
- Real time spectrum shows interference problems
Measurement & calibration types

• Preamp for 60-1700 MHz:
  • Preamp noise figure and gain
  • Direct measurement and calibration

• Frequency converter from any frequency to 60-1700 MHz:
  • Converter noise figure and conversion gain
  • Direct measurement and calibration

• Preamp for frequencies >1700 MHz:
  • Preamp noise figure and gain
  • Measurement and calibration through external frequency converter

• DUT input frequency and DUT or converter output frequency must be specified
CANFI demonstration
Next steps

- More tests and comparison to professional test sets
- Revision of preamp and 28 V converter boards
- GUI fine tuning
- Release of beta version of the software: 1st half of 2014
Cheap noise source for CANFI?

- BZV55-12 @ 6 mA into 22 Ohm load
- spectrum equalization by high pass 2 x 47 pF / 22 Ohm
- attenuator pad and DC blocking capacitor
- temperature compensated current source
Gain error

- Measurement error if gain changes between ON and OFF state; measured noise figure:

$$F = \frac{ENR}{Y \cdot \frac{G_{OFF}}{G_{ON}} - 1}$$

- To minimize gain error the reflection coefficient of the noise source should not change between ON and OFF

- $$\Delta \Gamma = \Gamma_{ON} - \Gamma_{OFF}$$ must be minimized
|ΔΓ|

144 MHz  0,0045
432 MHz  0,0045
1296 MHz 0,0044
Zener diode  15 dB ENR 2,5 GHz

$|\Delta \Gamma|$

- 144 MHz  0,0033
- 432 MHz  0,0033
- 1296 MHz 0,0019

- 10 dB higher ENR
- less gain error

than HP346A
Conclusion

- Noise figure meter functionality demonstrated based on a RTL2832U/E4000 DVB-T USB stick plus external hardware (total cost < £ 100)

- Compatible to professional noise figure test sets

- Low cost noise source useable up to 2.5 GHz