Test bench measurement of FUNcube Dongle receiver

The FUNcube Dongle is a very attractive wideband SDR receiver (www.funcubedongle.com). Looking for RF data and characteristics on the Web shows hardly any results except some measurement from users, like FM sensitivity with SINAD. The reputation for a versatile receiver is done, and everyone knows the necessity of RF filters at the funcube's front end.
This report quantifies the performances of FUNcube Dongle in terms of strong signals handling capability. The measurements are confirmed by blocking level and third intercept point levels.
The second part of this report shows noise figure measurements to complete sensitivity characterization of the FUNcube Dongle.

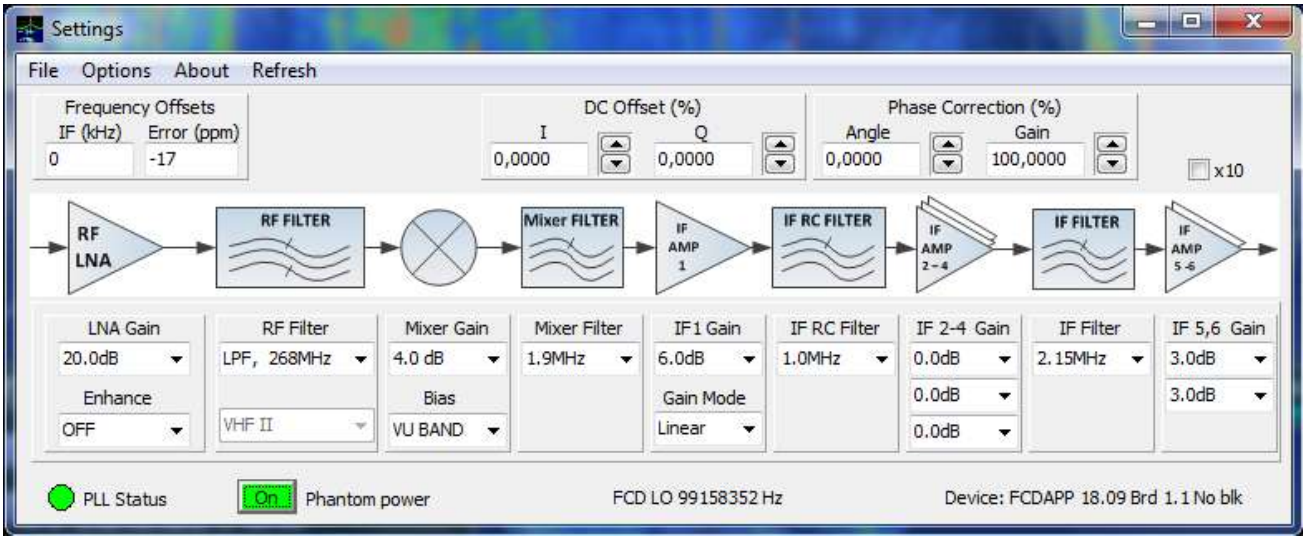
(picture from www.funcubedongle.com)

Linearity measurements :

Linearity measurements define strong signal level behavior of receivers. They include blocking level and third intercept point characterization.

Test setup for linearity measurements :

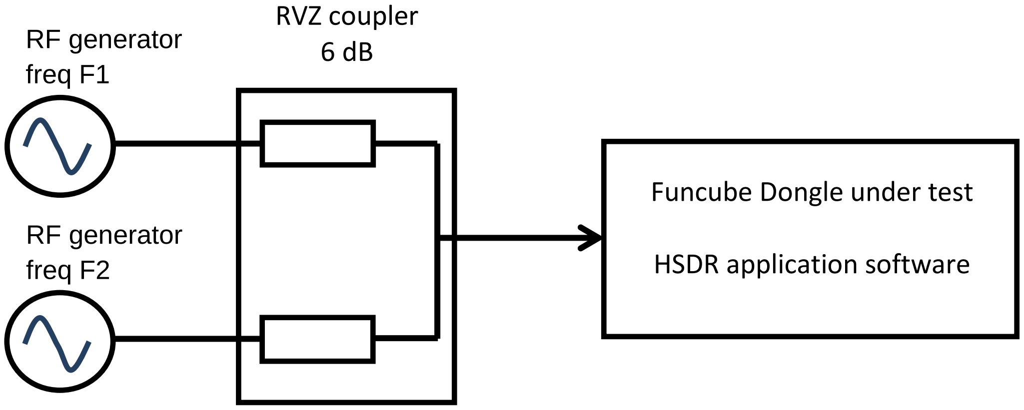
- Funcube Dongle tested S/N 2789
- Software HDSDR version 2.11
- Default gain settings: LNA= 20 dB, Mixer = 4 dB ; IF = 6 dB ; IF amplifiers 0/0/0 dB
- Phase and gain balance performed at 101 MHz with -75 dBm at input.
- Tuning +10 kHz from null center.



Signal generators: SMG and SMS from Rhode & Schwarz

RVZ 6 dB coupler (two 50 Ohms resistances): from Rhode & Schwarz

Measurements were done at 101 MHz to avoid 10th of a local harmonic of the 10 MHz precision time base in F5RCT's lab.



Dynamic range test:

A single101 MHz signal is applied:

- **Minimum detectable signal in CW mode : -136 dBm**
  (it provides a reference for weak signals decodable in CW)

- **Maximum level : -68 dBm**

The maximum level is fixed when spikes appear 3 dB over the noise floor. The spacing of spikes is at the same frequency as the difference from center null to applied signal.

Receiver 3 dB blocking level :

- Wanted signal is generated at 101 MHz and -132dBm level
- Disturber signal is generated at 100 MHz. The level is increased for a 3 dB reduction of the wanted signal. (LNA gain is 20 dB)

Blocking level: -45 dBm

This level is typical for broadband integrated IQ low current receivers. An integrated mixer has a blocking level close to –20 to –25 dBm.
It explains the problem with HF converters sensitivity reduction due to local oscillator leak. A band filter or a filtered LNA is mandatory for using FCD on VHF or with converters.

F4EGX has used his FCD for satellite in the 437 MHz band, he got very good results by adding a filtered LNA at the front.

F6BZG tried to receive weather information from a local airport in the 128 MHz aircraft band directly with FCD at 20 dB LNA gain. Receiving quality strongly improved at 10 dB LNA gain due to proximity of the FM broadcast band!

Blocking level can be easily detected when noise decreases and quality improves as LNA gain is reduced.

Applying front end filters as bandpass will reduce strongly the effect of blocking signals. For example a 2 MHz band pass filter at 145 MHz preserves weak signals compression by FM and Aircraft transmitter.

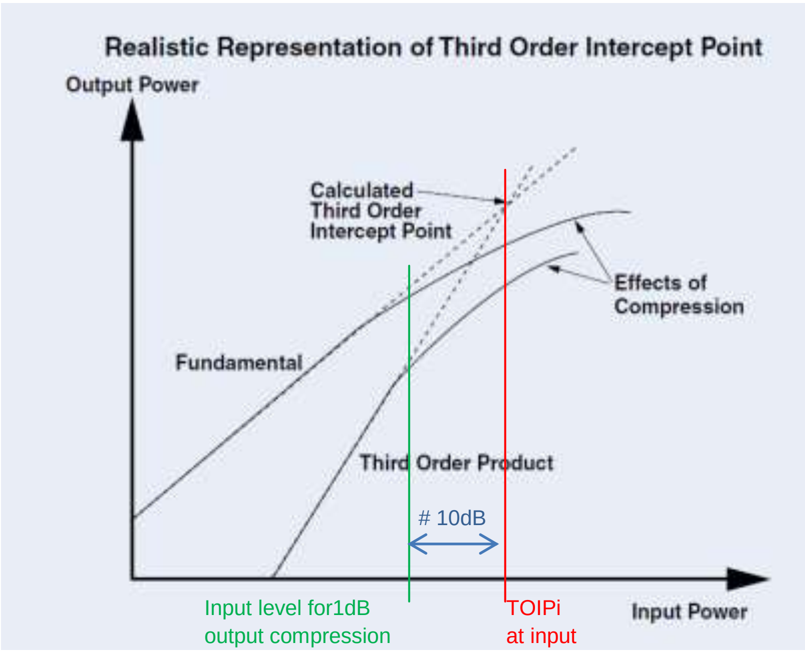
Input third order intercept point:

TOIP Intermodulation measurement is the most important parameter with noise figure. As the noise figure defines sensitivity, TOIP defines linearity and strong signal handling capability of a receiver.

The suffix 'i' in "TOIPi" means "at input". Interception point is measured at input of the receiver, and its level is related to input power in dBm.

We will not enter into theoretical details about TOIP, but let's recall the basics regarding TOIP :

- A rule of thumb to estimate TOIP is 10dB higher than compression level: here we got -45 dBm as compression level, then it gives approximately -35 dBm as TOIPi ! ☹



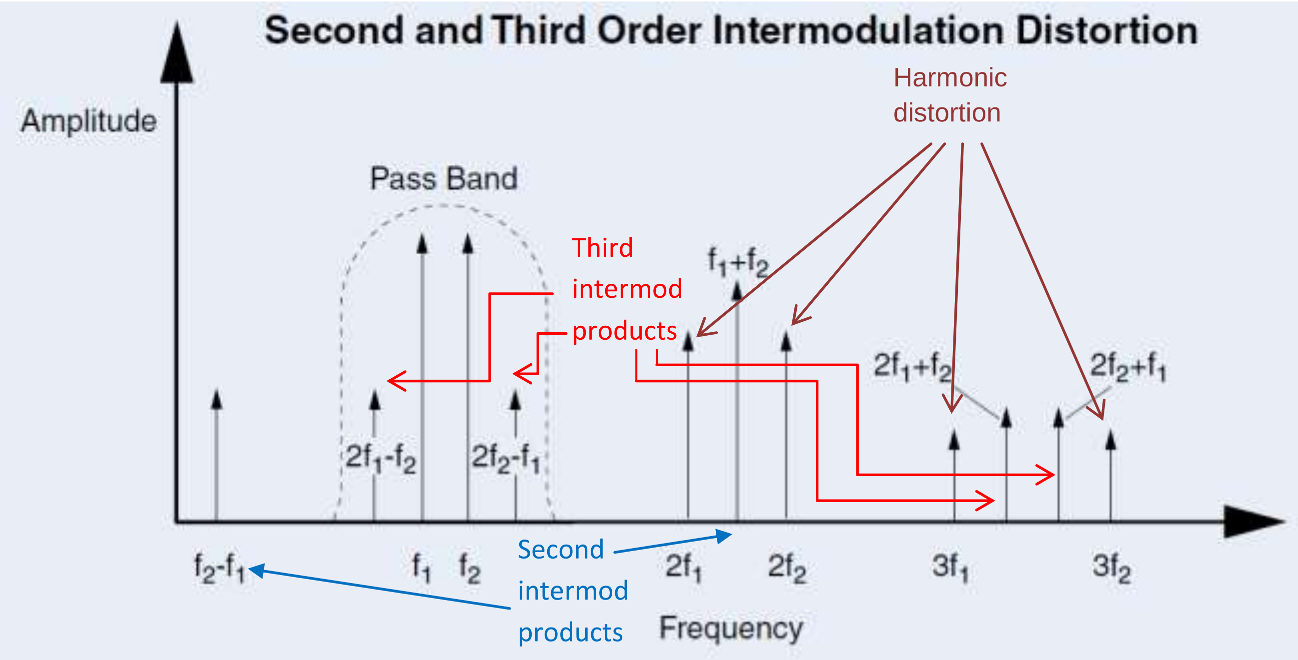
- For VHF band a good requirement for TOIPi is better than -10 dBm
- For HF band, it is recommended to have at least +10 dBm of TOIPi
- TOIP intermodulation is very aggressive. If the two disturbing signals are 1 dB higher, intermodulation signal products are 3 dB higher!
- Based on previous statement, a resistive attenuator of 10 dB front of receiver will reduce intermodulation products by 30 dB! …but sensitivity is 10 dB worse!

- Calculating TOIPi of a chain has opposite behavior than noise figure chain: TOIPi of latest stage is very important and global TOIPi depends on TOIPi and gain of each block. Having 10 dB gain front LNA with high TOIPi will degrade total TOIPi of 10 dB anyway!

- Intermodulation caused by out of receiving band signals (broadcast transmitter on HF) can be easily improved by band pass filter at antenna input. It is more difficult to remove LNA and mixer intermodulation: having a tunable 3 kHz tight filter at antenna input is impossible to build!

- Second order intermodulation is easily removed with a large band pass filter.

The diagram below shows intermodulation and harmonic distortion caused by two signals F1and F2:



Measurement accuracy:

- Absolut level tolerance of the 2 RF generators is +/- 0.5 dB
- Reading on IMD3 level is +/-0.5 dB
- Tolerance on IP3i value is +/- 1.5 dB

Measurement procedure is very simple:

- F1 and F2 generators are increased simultaneously to create an intermodulation signal on the receiver tuned here at 101 MHz.

- We note the power level of F1 and F2 : Pi(F1) = Pi(F2)

- We note the intermodulation level on the spectrum screen of HDSDR by placing the mouse on it as a marker.

- One of the generators is set at maximum attenuation (not set to RF OFF, or shut down) to keep the coupler matched at 50 Ohms.

- The other generator is set at 101 MHz and level is adjusted to get the same value as held by the marker on HDSDR screen. The reading of generator power is the received IMD product level.

- TOIPi is calculated by the formula: TOIPi = (3xPi-Pimd3i)/2   with values in dBm.

FCD TOIPi results:

We did measurements at 1 MHz spacing of disturbing signals for different gain values of FCD's LNA to get an idea about out of band disturbances.

F1 = 102 MHz
F2 = 103 MHz
F(IMD) = 101 MHz

LNA gain	F1 and F2 power level Pi(F1) = Pi(F2) [dBm]	Received IMD3 product level Pimd3i [dBm]	TOIPi = (3xPi-Pimd3i)/2 [dBm]
20 dB	-70	-140	**-35,0**
10 dB	-61	-128	**-27,5**
0 dB	-53	-119	**-20,0**
-5 dB	-50	-115	**-17,5**

The value of -35 dBm is confirmed by previous blocking level measurement.

Compared to VHF transceivers, TOIPi of -35 dBm is the best compromise of a broadband integrated front end with 20 dB gain LNA.

With HF converter, signals levels at -63 dBm (S9+10dB), out of frequencies of interest, are easily achieved. They generate intermodulation level of -119 dBm stronger than minimum detectable signal in CW mode (as measured first at -136 dBm).

Then we did one measurement at 10 kHz spacing to get global TOIPi of receiving chain and processing.

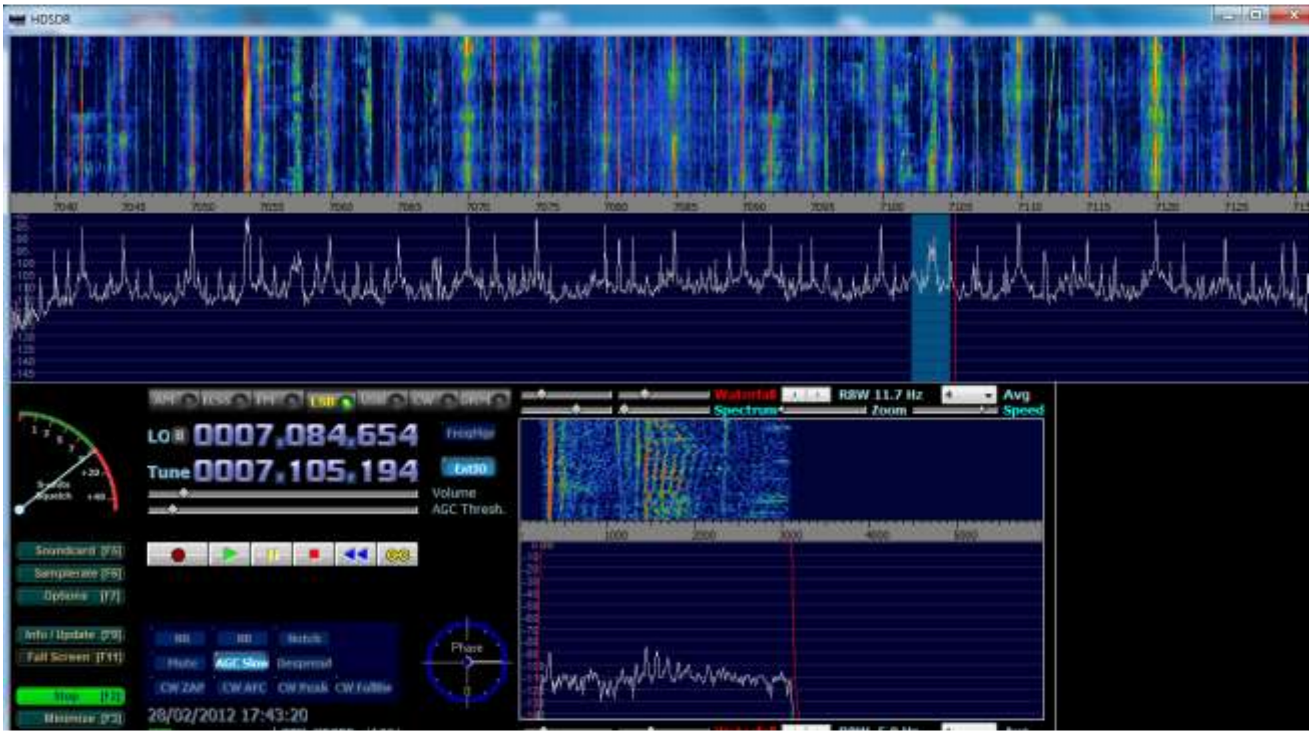
F1 = 101.01 MHz
F2 = 101.02 MHz
F(IMD) = 101.00 MHz

LNA gain	F1 and F2 power level Pi(F1) = Pi(F2) [dBm]	Received IMD3 product level Pimd3i [dBm]	Interception point TOIPi = (3xPi-Pimd3i)/2 [dBm]
0 dB	-54	-119	**-21,5**

In band intermodulation of processing chain on receiver has quite no influence on TOIPi value. We are close to uncertainty tolerances.

TOIP measurement confirms the necessity of band filters or selective LNA to get the best from FCD receiver. When receiving weak satellite signals in cities be aware of mobile base station proximity (900 and 1800 MHz)!

We note absence of electromagnetic shielding of this receiver. Even with input terminated to 50 Ohms (coaxial load), FM signals are visible 6dB over displayed spectrum noise. It could be solved by adhesive cooper foil coating and connections to ground shield of SMA and USB socket.



Example of saturation and intermodulation with HF converter at FCD input

Noise figure measurements:

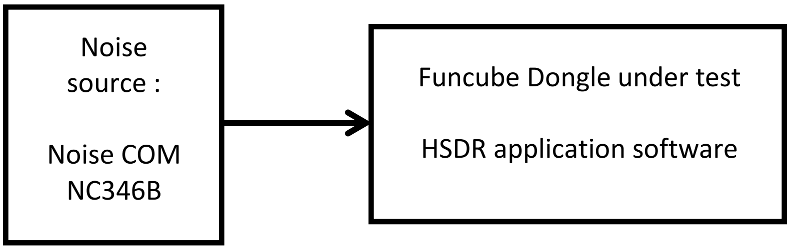
Noise figure measurements define sensitivity of the receiver by amount of noise at output. Output signal to noise is input signal to noise degraded by noise figure. A good noise figure for VHF and UHF receivers is less than 4 dB without external LNA. As reference, the IC-910H commercial transceiver has a 3.7 dB noise figure on the VHF band.

Test setup for noise figure measurements:

- Funcube Dongle tested S/N 2789
- HDSDR Software version 2.11
- Default gain settings: LNA= 20 dB, Mixer = 12 dB ; IF = 6 dB ; IF amplifiers 0/0/0 dB
- Phase and gain balance performed at 101 MHz with -75 dBm at input.
- Tuning +10 kHz from null center.

A calibrated noise source is connected to FCD. This source is turned on and off to get output noise level as “hot” (on) and “cold” (off).

HDSDR is configured in USB, RBW = 93 Hz, AVG = 128, SPAN 300 to 3000 Hz in the demodulation window. Scaling offset and zoom are adjusted to maximum resolution for 0.25 dB appreciation.
A calculation sheet will extract Y from output noise level in dB to calculate noise figure in dB.



Y method noise figure measurement:

The measured noise ratio at the output of the DUT is commonly called ”Y-factor”. The Y-factor is the ratio of the noise power of the DUT when the noise generator is turned on (hot :Nh) to that when it is turned off (cold : Nc reference noise). Without going into great details regarding derivation, noise figure can be related to input stimulus.

The Y-Factor is the ratio of Hot and Cold noise powers (in watts) and is defined as: Y=Nh/Nc

If the Noise source is at room temperature, then Nc = N0 and the equation becomes: Y= Nf/N0

Note that the Y factor method is a relative method and does not depend on the rest of the equipment. All you need is to measure the power levels accurately while the noise source is OFF and ON.

The noise figure is related to the Y factor as below:
F = ENR/[Y-1]

Note that the above parameters are in linear units. Normally, the ENR provided on the noise source is in decibels. This needs to be converted to linear units for computing the noise figure or convert Y-1 to dB.

NFdB = ENRdB - 10log(Y - 1)

which can be simplified as, if Y >> Y-1

NFdB = ENRdB – YdB With YdB = PdB(Nh) – PdB (Nc)

NFdB = ENRdB - PdB(Nh) + PdB (Nc)

and the error associated in NF with this approximation is:
ER = ENR / (Y^2 - Y) (linear units)

Advantages of this method:

- There is less equipment required. You need a noise source and a power meter to measure the power levels with the noise source ON and OFF.
- The method can be used to measure the noise figure over a wide frequency range.

Disadvantages of using this method:

- Due to the limitation of noise source, if the DUT noise figure is very high, the results may not be very accurate.
- The other equipment needs to be stable so that you can get repeatable measurements.

Measurement accuracy:

- Absolut level tolerance of noise source is +/- 0.02 dB
- Reading on noise level is +/-0.25 dB
- Tolerance on Y value is +/- 0.5 dB
- Tolerance on NF value is +/- 0.6 dB

In the table below, noise figures are returned for different frequencies and gain configuration of the FCD receiver.

Best sensitivity performance is obtained at 437 MHz at 3.2 dB noise figure with highest LNA gain at 30 dB.
On the VHF band (100 and 144 MHz), a 5 dB noise figure with 20dB LNA gain is acceptable compared to real receiving conditions. Changing LNA gain from 20 to 30 dB slightly improves sensitivity (0.5 to 1 dB) but the receiver input TOIP is -10 dB worse! In TOIP measurements, we didn't evaluate the TOIPi level with 30 dB LNA gain because the receiver is blocking and intermodulations reduce global performances.
As best compromise, we recommend using the FCD with an external LNA followed by a band-pass filter and 10 to 20 dB for LNA gain configuration.

At 1296 MHz FCD's input loss is higher than on the 437 MHz band. Anyway, using a good LNA is necessary to compensate feeder loss from antenna.

We checked noise figure at 51 MHz. Our receiver is able to demodulate but we are out of the 64 MHz minimum specified frequency.

FCD tuned Freq (MHz)	FCD LNA gain (dB)	Output Cold noise (- dBm)	Output Hot noise (- dBm)	Y factor (dB)	(Y-1) factor (dB)	Source ENR (dB)	Noise Figure (dB)
100	20	123,50	112,50	11,00	10,64	15,80	**5,16**
100	30	118,75	107,25	11,50	11,18	15,80	**4,62**
100	10	126,00	120,50	5,50	4,06	15,80	**11,74**
144,3	20	122,50	112,00	10,50	10,09	15,80	**5,71**
	30	119,00	107,25	11,75	11,45	15,80	**4,35**
437	20	122,00	111,00	11,00	10,64	15,70	**5,06**
	30	118,75	106,00	12,75	12,50	15,70	**3,20**
1296	20	122,50	113,00	9,50	8,98	15,50	**6,52**
	30	118,75	108,00	10,75	10,36	15,50	**5,14**
51	20	123,00	118,50	4,50	2,60	15,80	**13,20**
	30	118,75	113,00	5,75	4,40	15,80	**11,40**
100(*)	20	123,50	112,50	11,00	10,64	15,80	**5,16**
	30	119,25	107,25	12,00	11,72	15,80	**4,08**

Finally, we evaluated performances with a modified CT1FFU HF converter [1]. We used a different noise source with a 22 dB excess noise.
Due to low values of Y NF, results are approximated or worse!
Offset frequency: 106.250 MHz

7	10	129,75	127,50	2,25	-1,80	22,00	**24,0**
30	20	127,00	125,00	2,00	-1,56	22,00	**23,5**

Normally a good HF receiver should have 12 to 15 dB noise figure, but this converter works properly on 20, 40 and 80m bands even with 0 dB LNA gain!

Conclusion :

The FUNcube dongle has good sensitivity and fully takes advantage of its capabilities; these tests show the requirement of filters at receiver input.
Do not forget that this product has been developed for teaching purposes. It allows all access to a very wide frequency range (64 to 1700 MHz) with all narrowband modes for a very competitive price. This is already in itself a great feat!
A fraction of the purchase price will go to AMSAT UK for their space projects.
Thanks to Arnaud F6BZG and Claude F5HSH for their contribution to this report.

F5RCT Jean-Matthieu STRICKER

[1] : Test report and modifications of the CT1FFU HF converter available on
http://f5rct.free.fr/explorer/ in directory Documents\Banc.Essais\

Links :
IMD3 measurement :
http://zone.ni.com/devzone/cda/tut/p/id/4384

http://downloadfile.anritsu.com/RefFiles/en-US/Services-Support/Downloads/Application-Notes/Application-Note/11410-00257a.pdf

Noise figure :
http://www.qsl.net/ct1dmk/noisefm.pdf
http://www.qsl.net/ct1dmk/nfsa.html