EQUIPMENT REVIEW

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Digital Down Conversion SDR receivers compared

Digital Down Conversion (DDC) software defined radio receivers are now a reality in the amateur market. Marco Bruno tested the SDR-IQ and Perseus on the bench and on the air.

OVERVIEW. The SDR-IQ [1] from RFSpace and Perseus [2] from Microtelecom are among the first DDC SDR receivers appearing on the amateur market. They have a similar hardware structure - a filter/attenuator block, an RF preamplifier driving an analogue to digital converter (ADC), a decimation/processing section and a USB interface. The sampled signal arrives at the PC where a program provides radio control, tuning, demodulation, spectrum monitoring and all needed functions.

The SDR-IQ uses a commercial downconverter chip (AD6620), while Perseus implements all functions in a Field Programmable Gate Array (FPGA). Audio output is via the PC sound card. Any digital mode decoder with audio input may be driven via utilities like Virtual Audio Cable.

The SDR-IQ is a follow up to RFSpace's SDR-14 and appeared about one year ago. Perseus is the first HF receiver produced by Microtelecom. Both radios cover the HF spectrum, approximately 500Hz – 30MHz for SDR-IQ and 10kHz-30MHz for Perseus which can tune from 0 to 40MHz but with reduced sensitivity and image rejection.

The SDR-IQ operates with the original software produced by Moetronix called *SpectraVue*. Perseus is delivered with two applications, *Perseus.exe* for receiver operations and *HFSpan.exe*, a spectrum analyzer covering 0 to 40MHz. Additionally, Winrad by Alberto, I2PHD, has control DLLs for SDR-14, SDR-IQ and Perseus.

This review concentrates on the receiver performance since a comparison between the available software would need a long article!

The SDR-IQ demodulates AM, FM, SSB and CW. *Perseus.exe* also has synchronous AM and DRM (with Dream or similar decoding software) and *SpectraView* provides DSB. I also used both receivers on digital modes like RTTY, FAX, ALE, Hellschreiber, Olivia and PSK31.

The SDR-IQ is powered via the USB interface (USB1) whilst Perseus uses USB2 with an external power supply (5V 1A nominal).

TEST CONDITIONS. Both receivers have selectable attenuators and gain settings. Additionally, Perseus has an optional dithering function and preselector by-pass. The various combinations of attenuator, gain and dithering settings result in a wide range of sensitivity, blocking and IMD values. Unless otherwise noted, Perseus was tested with dither ON, preselector ON, attenuator OFF and preamplifier OFF.

The SDR-IQ was tested with RF gain at maximum (0dB or +10dB depending on the application running) and IF gain at middle scale (12dB). For Perseus I used the native software by Nico, IN3NWV, (a beta version) and for the SDR-IQ alternatively *SpectraView* V2.31 by Moetronix or *Winrad* by Alberto, I2PHD.

Signal generators used for all tests were a pair of carefully adjusted HP 8640Bs followed by two Watkins-Johnson separation amplifiers (to increase the IMD dynamic range), a Minicircuits power combiner and a 1dB step attenuator (HP 355C). The IMD dynamic range of the test bench reached at least 106dB. All instruments were recently calibrated.

In the sensitivity and blocking dynamic range tests I considered ADC saturation as the RF level limiting the blocking dynamic range. DDC SDR receivers don't exhibit a conventional blocking performance, ie sensitivity does not necessarily reduce in the presence of large signals. Rather the ADC output distorts as it reaches full scale value.

Sensitivity was measured using the traditional audio 3dB (S+N)/N method as well as the measurement features of *SpectraView* and *Perseus.exe*. The two measurement techniques yielded comparable results. The noise figure (NF) has been deducted from the noise floor measurements. The results are shown in **Table 1**.

An interesting feature of Perseus is that the indicated signal level does not vary with the attenuator / gain / preselector setting. To achieve this the control program keeps track of the gains and losses in the signal chain and always displays the exact signal level in dBm to an accuracy of better than ±1dB.

Perseus' designer Nico, IN3NWV, measured the typical preselector attenuation at various frequencies and the PC software compensates accordingly. I found it very useful for measurements; it is in line with the behaviour of professional spectrum analysers and measurement receivers.

The S meter is graduated in dBm and S points and responds to average or peak power value of signals in the pass band. Both the SDR-IQ and Perseus S-meter response may be changed from RMS to peak reading.

INTERMODULATION. Third order intermodulation distortion (IMD) in digital receivers behaves quite differently from conventional analogue radios. The IMD may be evident even at low signal levels, where it is dominated by the ADCs quantization noise. 'Real' IMD products (ie, those caused by analogue stages non linearity and increasing with the third power of the input signal) are only evident at high signal levels. For more info see the web site of Leif, SM5BSZ **[3]** or the *RadCom* 'SDR' column **[4]**.

The ADC used in Perseus has a dithering function. This effectively reduces the amplitude of spurious responses due to the periodicity of the non linearities of pipelined ADCs, like those used in direct sampling receivers, at the expense of slightly raising the noise floor of the ADC.

The SDR-IQ has no such feature and relies on band noise to do some degree of dithering. I did some tests by applying to the input the real band noise coming from the antenna, but amplified to overcome the loss of power combiners, plus the two IMD test tones.

The result was that, using my vertical antenna, the band noise above 10MHz was not sufficient to provide sufficient dither noise. In which case on these frequencies IMD products are plainly visible. To provide an effective dither signal I needed to apply an out-of-band tone of at least -30dBm to the input using a third signal generator.

I also measured IMD performance at high signal levels, close to the ADC full-scale, since in this region the analogue components IMD products are dominant. The test data is in **Table 2**.

MEASUREMENT COMMENTS. Both receivers require a 10dB attenuator to be switched in during evenings on 7MHz to avoid ADC overload. See the side bar on required performance for an HF receiver. Broadcast signals at my QTH often reach 0dBm and sometimes higher (+3dBm measured).

The different circuit configurations become evident on 14MHz. On this band the SDR-IQ only has a few filters, acting as a 5-15 MHz bandpass, whilst the Perseus has nine switchable BPFs and one LPF.

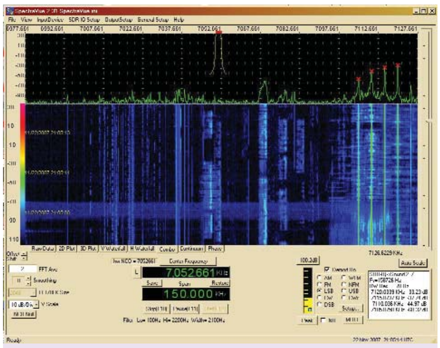
At 14MHz the Perseus uses a 12-17MHz band pass filter that effectively attenuates interferences from the 6, 7 and 9MHz broadcast bands. With these filters in circuit no input attenuation is needed and hence the full sensitivity of the receiver is available.

This effect was noticeable on 14MHz where weak PSK31 signals were difficult to copy on the SDR-IQ but, since the attenuator was not required, were 100% copy with the Perseus.

The Perseus dynamic range and IP3 were tested in several configurations, with high and low gain, wideband and with the preselector inserted. There were no significant differences, the IMD3IP staying between +29 and +33dBm.

More importantly, unlike a conventional analogue receiver, a DDC receiver's IMD figures do not change with tone spacing. Having only one frequency conversion and no roofing filters has many advantages. I measured the IMD dynamic range at 20kHz for measuring convenience, but there were no changes at 10kHz or 500Hz spacing.

The Perseus program running



The SDR-IQ program running

SPURIOUS RESPONSES. Both receivers have some spurious responses. Some are always present, others are 'birdies' related to strong input signals. There are no rules to find spurious responses; one has to search the bands and look at possible critical frequencies (oscillators, USB clock, sampling frequency subharmonics, images etc).

Perseus has a few spurious signals at 1, 5, 10, 15, 20 and 24MHz. All are subharmonics of the 80MHz sampling frequency, except 24MHz which comes from the USB interface clock. This is the strongest, at approx 1μV (-107dBm). All the others are around -115dBm. There are also a few very weak spurious signals at n*F sampling between zero and 1.7MHz and are possibly due to a magnetic coupling between the preselector coils and digital signals from the FPGA.

I was not able to find and measure numerical controlled oscillator (NCO) spurs. Nico, IV3NWV, considers that on Perseus these should be under -105dBc. Image products, due to the DDC conversion decimation process, exist at $F_o \pm F_{sampling}$; the worst case is -103dBc at 1MHz from the carrier for 500kHz sampling rate and are immeasurable at other sampling rates.

The SDR-IQ has the same kind of spurious responses, but at different levels. It has n*F sampling signals at approximately 90dBfs (-80dBm) up to 5MHz. However, they disappear when the 5MHz HPF is switched in. There is a 12MHz signal at -90dBm, surrounded by noise sidebands visible from 11960 to 12040kHz (probably due to the USB clock). A clear one is at 13333kHz at -90dBm, and a weaker one at 26666kHz. But the real problem is the image rejection that averages at approximately -60dBc with a worst case of -43 dBc for a 190kHz sampling rate. This is probably due to limitations of the down-converter chip used after the ADC. Except for these items both receivers have exceptionally low spurious response; much less than a typical multiple-conversion superhet.

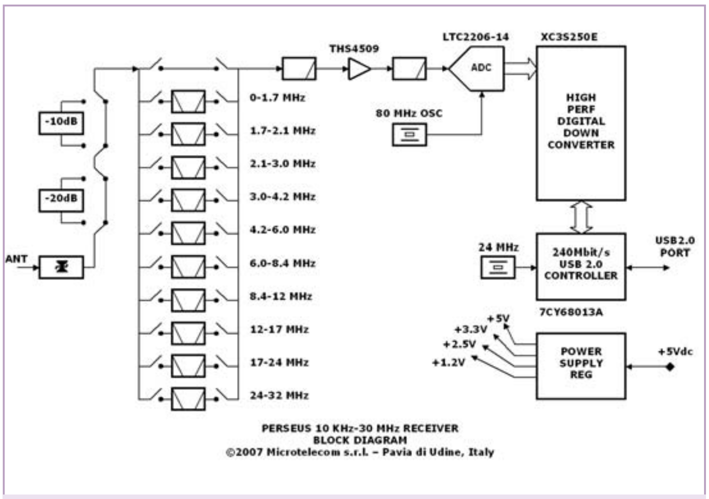
One further advantage of this type of receiver is that the performance may be improved by loading a new software release. Initially Perseus exhibited a clearly visible image response. This was due to a subtle programming error in the VHDL code and was corrected in the current software release.

SIGNAL LATENCY, SYSTEM INTERFACING. A possible inconvenience of SDR receivers is signal latency, that is the processing delay of the complete receiver chain. An event at the antenna input appears at the audio output after a time delay. If the delay is long enough it may interfere with fast operations (contest, data modes, etc).

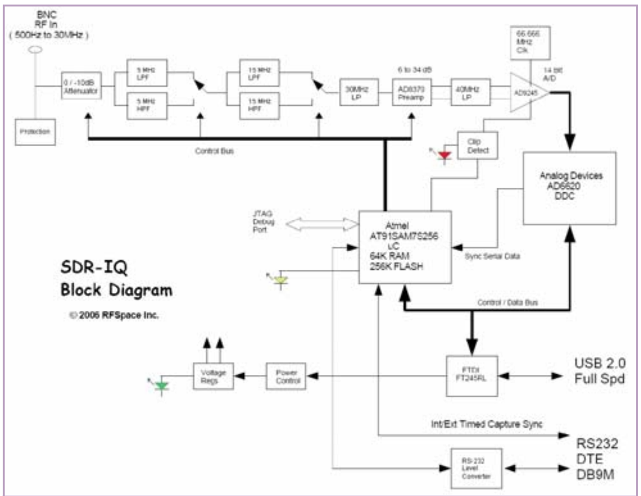
At the current state of the art, using PC software for signal processing, full QSK operation is not possible because of this latency. Even tuning a manual preselector for maximum signal may require slow, careful adjustment. The signal latency may be reduced by careful engineering of buffer stages and may depend on the PC audio section too. I measured typical delays of 300-400ms in different configurations and on different PCs.

Alberto, I2PHD, suggests that the latency could be reduced by decreasing the amount of audio buffering in the PC software. Windows is not a real time operating system and such buffers are needed to avoid crackling audio (caused by no data being ready for the output digital to analogue converter (DAC) of the PC audio board).

I think that some work on this subject has to be performed for the SDR radio to gain acceptance in the wider market. Both receivers also lack a transmitter interface (muting signal input). Of course one may leave the receiver on while transmitting, possibly using a shorting, high isolation, RF



Perseus block diagram



SDR-IQ block diagram

TABLE 1: Receiver performance companson

	Perseus	SDR-IQ
Noise floor, 2.4kHz BW, dither off, max gain, at 14.2MHz	-123dBm (preamp ON, preselector OFF)	- (has no preamp)
Equivalent noise figure	17dB	-
Noise floor, 2.4kHz BW, dither off, normal gain, at 14.2MHz	-122dBm (preamp OFF, preselector OFF)	-117dBm (no attenuator)
Equivalent noise figure	18dB	23dB
A/D overload level, normal gain	-2dBm	-9dBm
Blocking dynamic range, 2.4kHz BW	120dB	108dB

Note: activating dither on Perseus increases the noise floor by about 1dB, as does inserting the preselector. The NF ranges from 17 to 19 dB depending on settings and operating band.

TABLE 2: IMD measurement comparison

	SDR-IQ (max gain)	Perseus (dither on, preamp off)
Calculated IMD 3IP	14dBm	33dBm
IMD3 dynamic range	90dB	102dB

switch to reduce receiver overload, but this is not an ideal solution.

ON AIR IMPRESSIONS. I mainly used both receivers for SSB and data mode reception, not being a CW fan. Except for the dynamic range limitations of the SDR-IQ, both perform very well.

Audio quality is simply excellent, listening fatigue is reduced, and to operate a receiver with a 'point-and-click' mouse action is very exciting. I also bought an external 'tuning knob' (Griffin PowerMate USB Multimedia Controller), but then found it more convenient to simply use the mouse.

Perseus used under *Winrad* requires quite a powerful PC to work properly, in particular at the maximum sampling rate (500kHz). *Winrad* does a lot of processing; the native program, *Perseus.exe*, requires fewer resources and works well on a 2GHz Pentium with Windows XP and 512MB RAM.

I understand that Alberto is going to release a new version of *Winrad*, which should be currently available, and requires almost the same CPU resources as Perseus' native software.

The sensitivity is adequate on high bands in my listening position (suburban area). I would like to have a preamplifier for operation in remote areas on high bands.

Band pass tuning and selectivity are extremely effective in SDR receivers. With all three programs, tuning on interfered channels is a pleasure since one may visually place the filter skirts to pass exactly the wanted signal. Both performed very well for fax, PSK31 and RTTY reception.

On digital modes, one learns quickly to recognise the type of emission by looking at the waterfall: most emissions have a very distinctive pattern.

Another very interesting feature is the possibility of recording the whole spectrum slice sampled by the receiver (400kHz in Perseus, 192kHz in SDR-IQ) for further analysis or playback. This is very much appreciated by SWLs.

Required dynamic range performance for a communication receiver

Recently I saw a NATO study [5] on current noise levels in HF bands. The report assesses the potential impact of xDSL and power-line communications on the HF spectrum, perceived as a worsening of noise levels.

For me, the interesting figure is that the noise level from 14MHz up may be as low as 10dB (equivalent noise figure). So, an HF receiver should have 10dB NF, or better, to be limited by band noise and not by internal noise. This equates to approximately -130dBm in a bandwidth of 2.4kHz; many receivers on the market reach this sensitivity level.

This requirement was well known even in the 1960s – Racal HF receivers had an NF in the order of 7dB. Conversely, in my QTH (northern Italy) during the evenings I often measure +3dBm RF power from my antenna on the broadcast bands. I have measured a single signal peaking at +2dBm!

Using an upper limit of 10dBm for the maximum signal that should be handled by a communication receiver in those conditions the span between +10 and -130dBm is 140dB. This is the required blocking dynamic range for a receiver that 'sees' all the HF spectrum and is limited by atmospheric noise. Such a dynamic range is out of reach of any current receiver technology so preselectors and attenuators will stay with us for a while.

REFERENCES
[1] SDR-IQ. www.rfspace.com/SDR-IQ.html
[2] Perseus. www.microtelecom.it/perseus/index.htm
[3] SM5BSZ. www.nitehawk.com/sm5bsz/
[4] 'SDR', RadCom Jan and Feb 2008
[5] NATO study on HF noise. www.ftp.rta.nato.int/public/PubFullText/RTO/TR/RTO-TR-IST-050/$$TR-IST-050-ALL.pdf

WEBSEARCH
Yahoo groups:
Perseus http://groups.yahoo.com/group/perseus_SDR/
SDR-IQ http://groups.yahoo.com/group/sdr-iq/