DIRECT CONVERSION TO X-BAND USING A 4.5 GSPS SIGE DIGITAL TO ANALOG CONVERTER

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Abstract - *The ability of the new generation of Digital to Analog Converter (DAC)s to convert from a digital signal directly into high frequency bands can be seen as a large leap in capability allowing greater system flexibility, reduction in component footprint and power consumption.*

This paper presents a new high speed, high bandwidth Digital to Analog Converter (DAC) with high sample rate and high output bandwidth which enables the direct conversion of signals to frequencies up to X-band. The component features a number of innovative design features which enable the optimization of performance in the different Nyquist zones. These include various output shaping schemes and interface methods. Preliminary results will be presented which show the performance of the circuit at output frequencies greater than 8GHz.

The component's performance can result in highly flexible and waveform agile Radar signal generation systems and also the potential for improving flexibility of future wireless test systems.

INTRODUCTION

Technology advances in high speed digital to analog data converters are allowing significant changes in the way that microwave systems are designed. The ability of the new generation of Digital to Analog Converter (DAC)s to convert from a digital signal directly into L, S, C or even X band can be seen as a large leap in capability allowing greater system flexibility and reduction in power consumption. Since multiple up-mixers that would normally have been required can now be deleted along with the VCO/PLL jitter which adds at every up-conversion.

Currently modems employ a mixed analog/digital architecture requiring mixers for up conversion. The use of high performance DACs allows the replacement of a large number of these converters by a single DAC.

DIRECT UP-CONVERSION

For up-conversion using microwave DACs the effect of aliasing becomes an aid rather than a hindrance. The diagram in Figure 1 shows the aliases of a 400MHz signal when output from a microwave DAC using a sampling frequency of 3GSps.

The solid blue curve shows the Sinc X response typical of a DAC using a Non-Return to Zero (NRZ) coding with a zero at the sampling frequency. The signal at 400MHz is readily apparent in the first Nyquist zone but also the alias appears in the second Nyquist zone and images will also appear in the third and fourth zones.

If the DAC has sufficient analogue output bandwidth then all these replicas will be seen in the spectrum. (this is not the case with most of the DACs available today). Appropriate filtering around the frequencies of interest is all that is needed to isolate the required frequency.

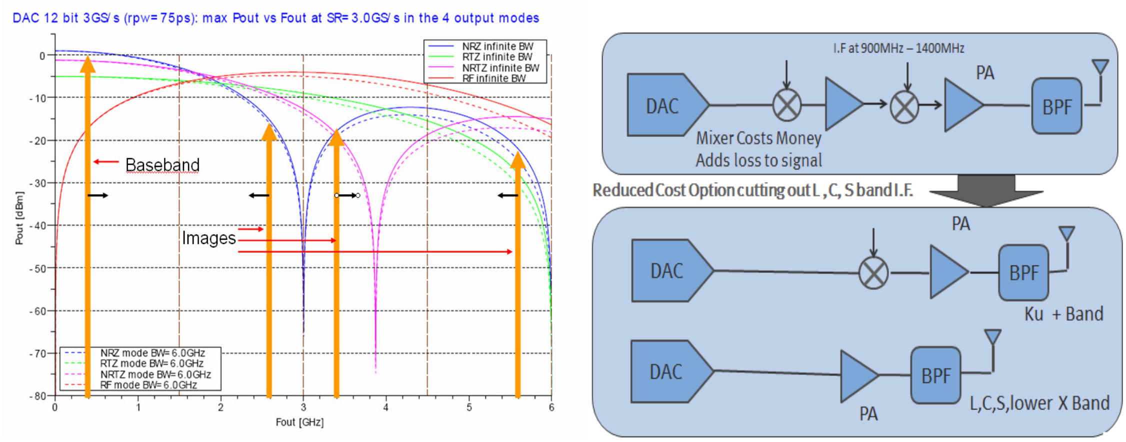

Fig. 1. Up conversion by aliasing and reduction in frequency converters stages

HIGH BANDWIDTH DAC

For many applications, the EV12DS400 Digital to Analog Converter (DAC 12Bits/4.5GHz) shows a very interesting opportunity for the L, S, C and other analog bandwidth signal generation. This product permits to generate a synthesized bandwidth with the same instantaneous dynamic (SFDR) level, without any parasitic limitation due to the aliasing frequency ±Fs/m±Fout (m=2,4,8). This allows applications to generate a very wide synthesized bandwidth.

Furthermore, it is possible to optimize the EV12DS400 by changing the working modes (NRZ, RTZ, NRTZ and RF modes) to obtain the best output analog power and the highest SFDR Level.

The enhanced noise-floor of that DAC is also an asset in such applications.

All these technical points proposed by the EV12DS400 DAC offer the possibility to simplify the emission design chain on electronic systems and to generate the largest instantaneous bandwidth with high SFDR level.

This component has been designed and fabricated on a 200GHz cut off frequency HBT SiGeC process.

It is setting new standards of high dynamic range performance over L, S and C bands through the combination of the following innovations:

- The introduction of innovative output modes bypassing the limits of sinc(Fout/Fclock) found in most DACs, and extending significantly DAC linearity.

- Architectural breakthrough, minimizing capacitive and inductive parasitics on critical nodes, thus allowing an extension of DAC usable output bandwidth above 8GHz.

The circuit is based on a 4 to 1 Multiplexer and a 12 bit current steering DAC, segmented for the most significant bits (MSB) and binary weighted for the least significant bits (LSB), the binary weighted structure being implemented by means of a R2R structure.

The DAC is based on a single core architecture, and does not rely on internal interleaved core DACs to achieve 4.5GS/s. This means that the DAC does not require any calibration before or during operation over temperature as is sometimes required with interleaved multi-cores architectures.

Fig. 2 shows the block diagram of this component.

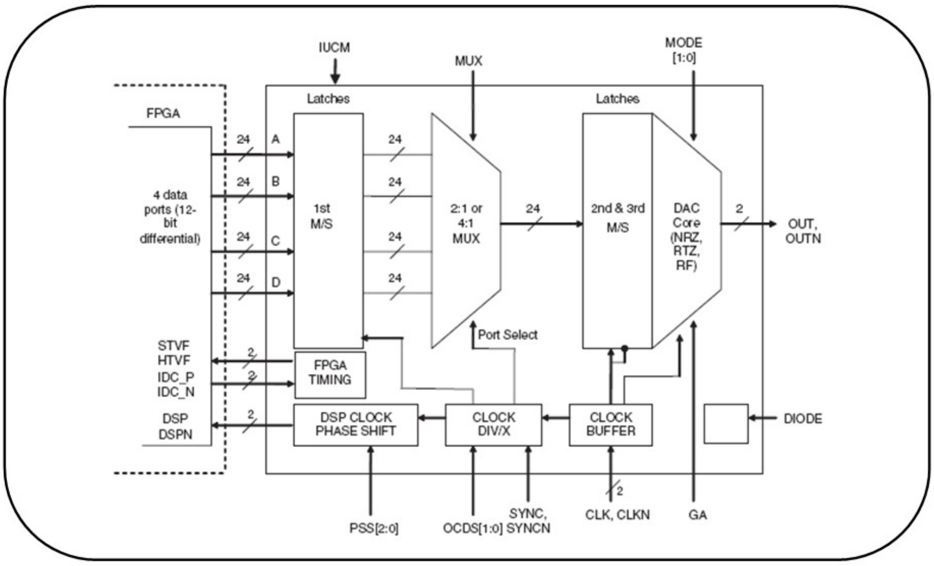

Fig. 2. Microwave DAC EV12DS400 block diagram

The DAC is based on innovative architecture concepts of Infineon's B7HF200 SiGeC HBT bipolar technology.

This technology features deep trench vertical isolated bipolar NPN transistors enabling peak cut-off frequency (f_T) of 200GHz for low current densities, with 4 levels of copper metal for very low interconnect parasitics, furthermore this technology displays sufficient matching of device to build a 12bit DAC without calibration or post process trimming.

OUTPUT WAVEFORM SHAPING

The EV12DS400 offers a number of different output waveform shaping modes, previously used by the EV12DS130A [1], which enables flexibility of the device to operate with optimum performance in different Nyquist zones.

NRZ Mode

The response of a classic NRZ DAC gives the well known sinc(x) attenuation where sinc(x)=sin(πx)/(πx), and x is the normalized output frequency (x=Fout/Fsample where Fsample is the sampling rate). The time and frequency domain responses are shown in Fig. 3.

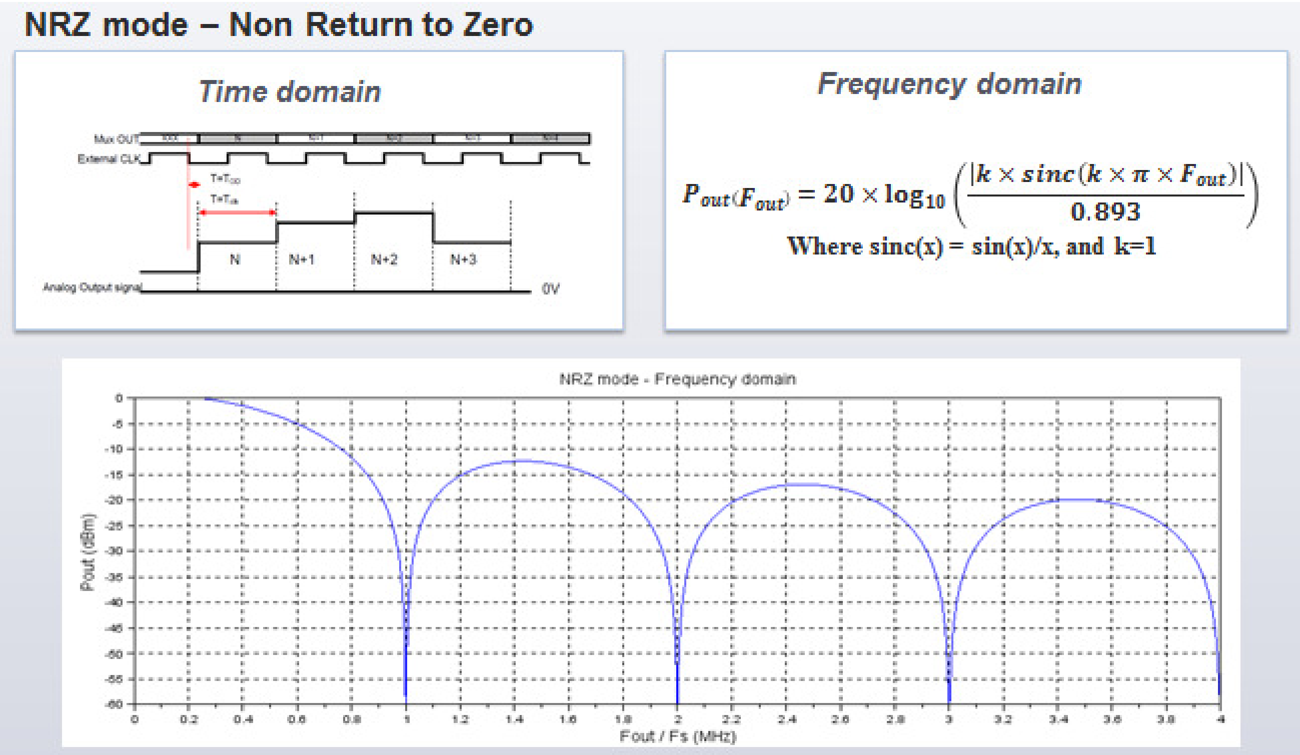

Fig 3. NRZ Mode

RTZ Mode

With a 50% resampling clock pulse width in RTZ mode, the zero order hold time window is half the clock period and allows the expansion of the DAC sinc function by a factor 2, the ideal formula of attenuation becomes sinc(x/2)/2. This enables operation in the 2nd and 3rd Nyquist regions. However, the RTZ mode induces a 6 dB loss in carrier power, which directly impacts the SFDR level in dBc.

The advantage of the RTZ mode is to enable the operation in the 2nd zone but the drawback is clearly that the signal is attenuated more in the first Nyquist zone.

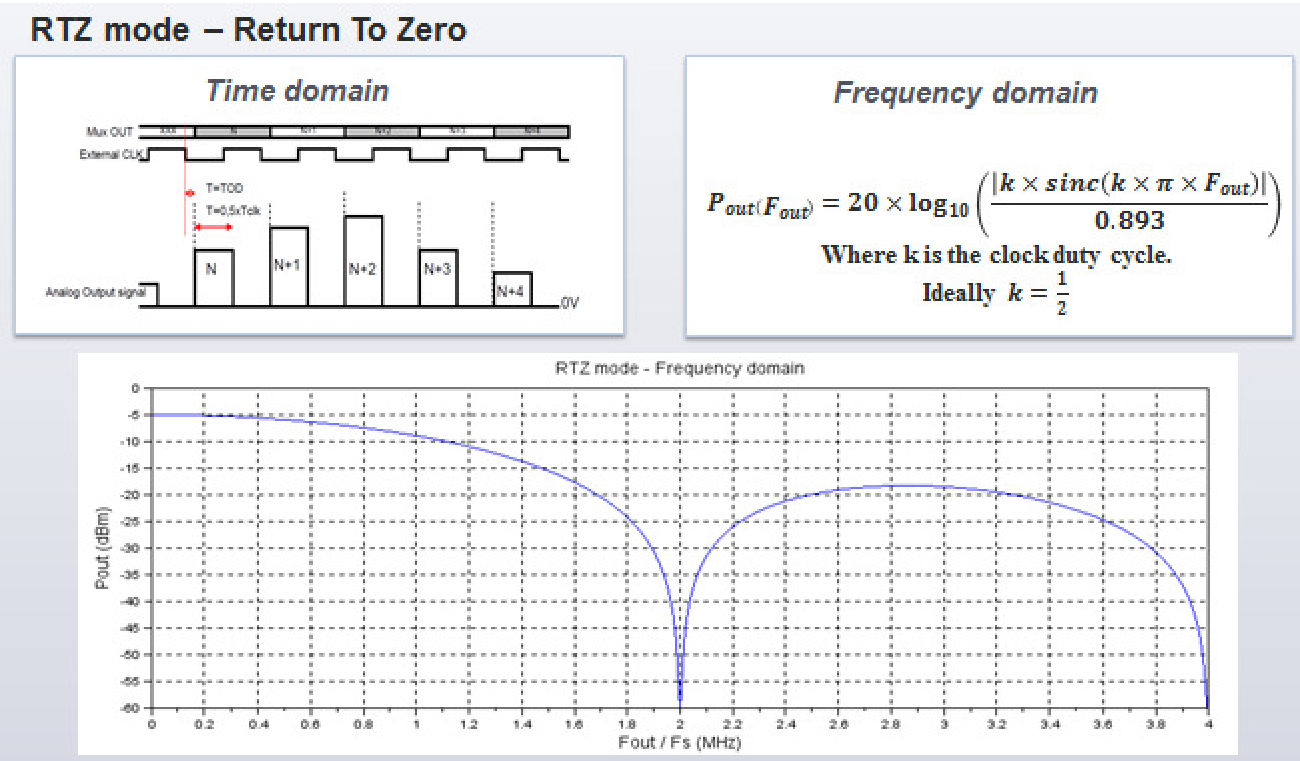

Fig 4. RTZ Mode

NRTZ Mode

We have also implemented the Narrow RTZ mode which combines the advantages of RTZ mode (increased spectral purity) with the advantages of NRZ mode (high power available in 1st Nyquist zone) thanks to an asymmetrical resampling.

This mode has the following advantages:

- Optimized power in 1st Nyquist zone
- Extended dynamic through elimination of noise on transition edges
- Improved spectral purity

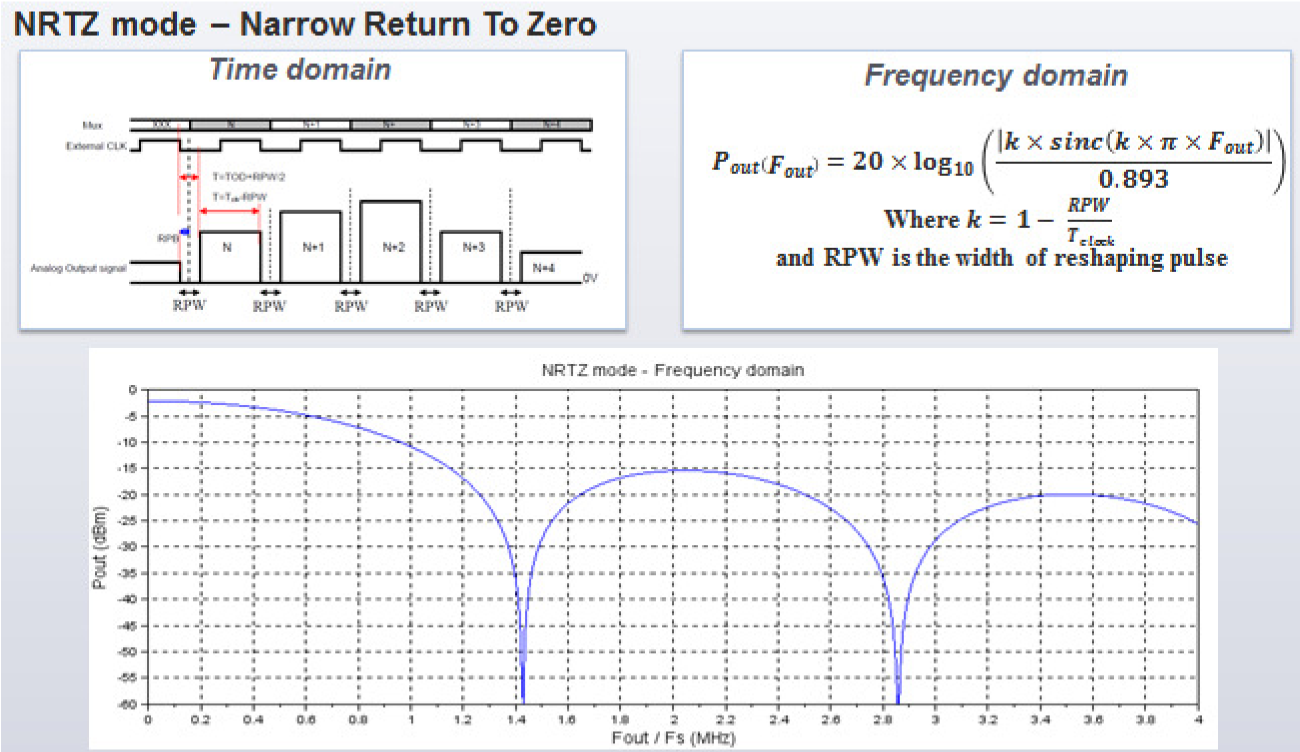

Fig 5. NRTZ Mode

RF Mode

For operation in the 3rd Nyquist zone with maximized available power, an alternate mode called "RF" has been introduced.

RF mode is optimal for operation at high input frequency, since the decay with frequency occurs at higher frequency than for RTZ. Unlike NRZ or RTZ modes, RF modes present notches at DC and 2N*Fs, and minimum attenuation for Fout = Fs.

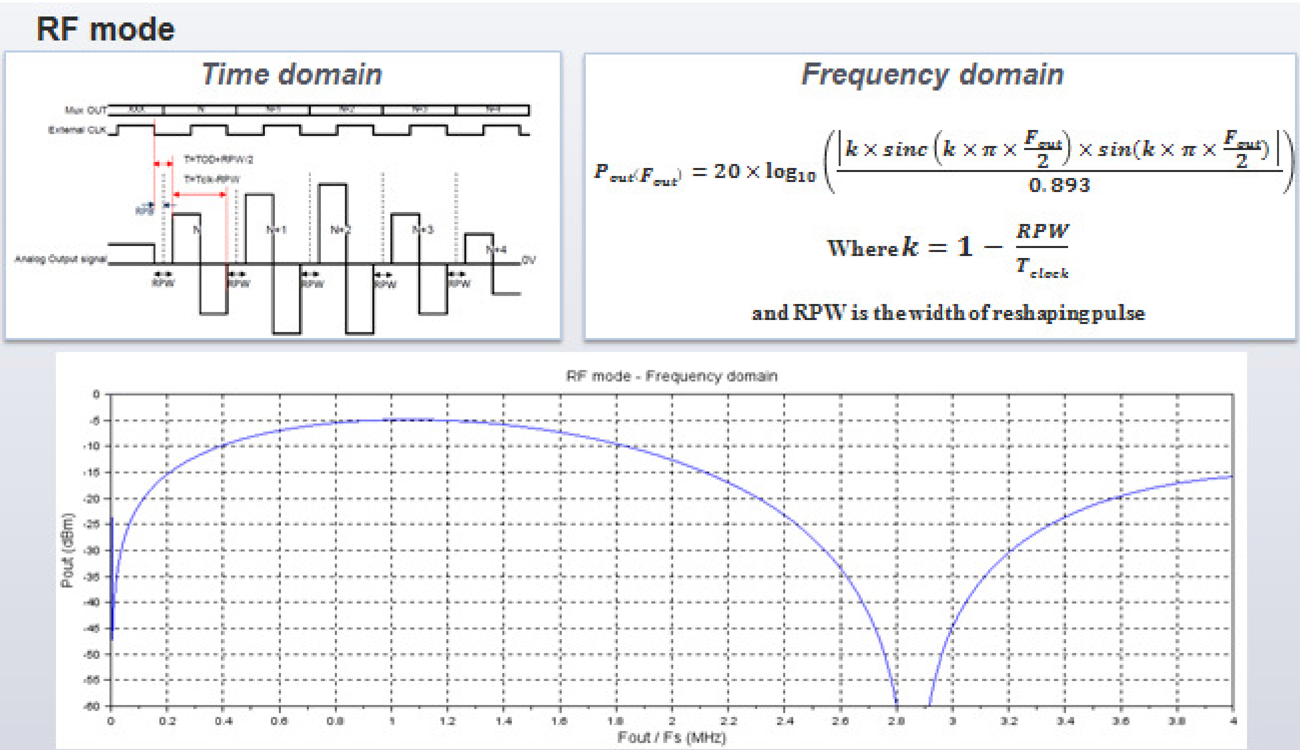

Fig 6. RF Mode

PROGRAMMABLE FEATURES

NRZ is the best mode regarding noise performances of the DAC, while RTZ has the higher SFDR values. NRTZ mode is a trade-off between noise and SFDR constraints. The RPW parameter corresponds to Tτ of previous figures and varies in [35ps-90ps] range.

Choosing the lower RPW value @4.5Gsps puts the device in a pseudo-NRZ mode, enhancing consequently the noise but inducing an SFDR decrease in the same time.

With higher RPW values, circuits works near the RTZ mode @4.5Gsps, which means a high SFDR value (68dB) and poor noise performances.

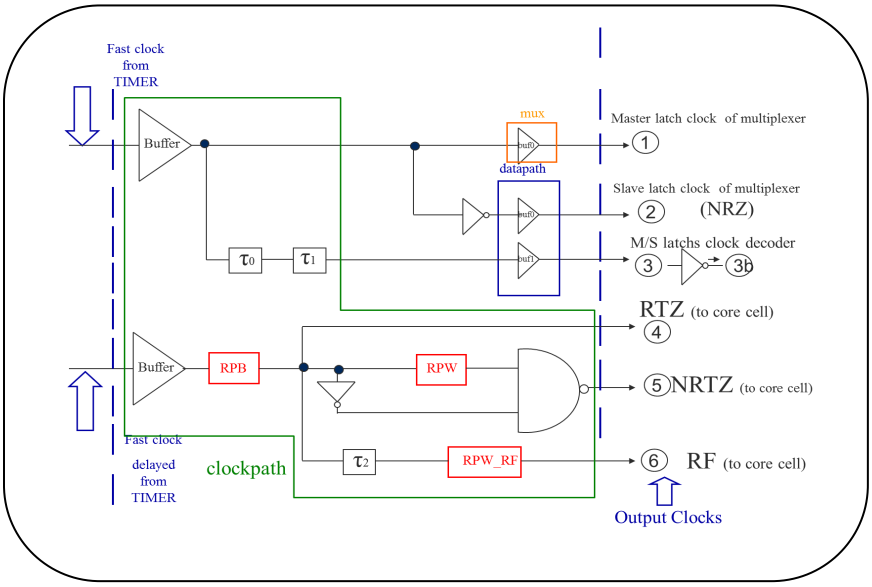

Fig. 7. RPW functions diagram

RESULTS

Noise Power Ratio

Noise power ratio (NPR) was initially used in early frequency division multiplexing communication systems. It measured the effect of signals in the other bands on the band in question. It is a useful parameter for assessing the performance of ADCs and DACs for communications systems.

For an ADC, the measurement uses a Gaussian noise source and a notch filter to remove the noise signal in the band of interest. A DAC test system will generate the test pattern in the digital domain.

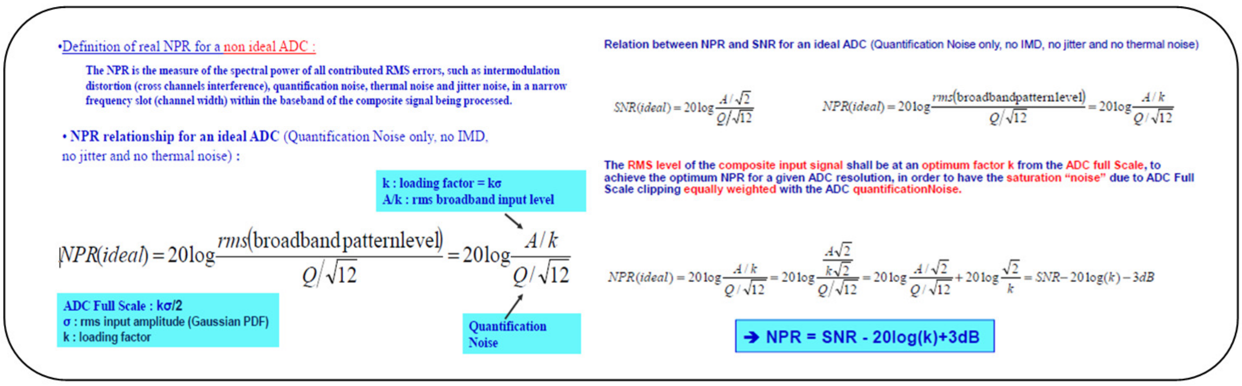

Fig. 8. NPR Formulae

It can be seen in Figure 9 that NPR values of 46dB can be achieved in the first Nyquist zone. For higher Nyquist zones the RF mode would be used.

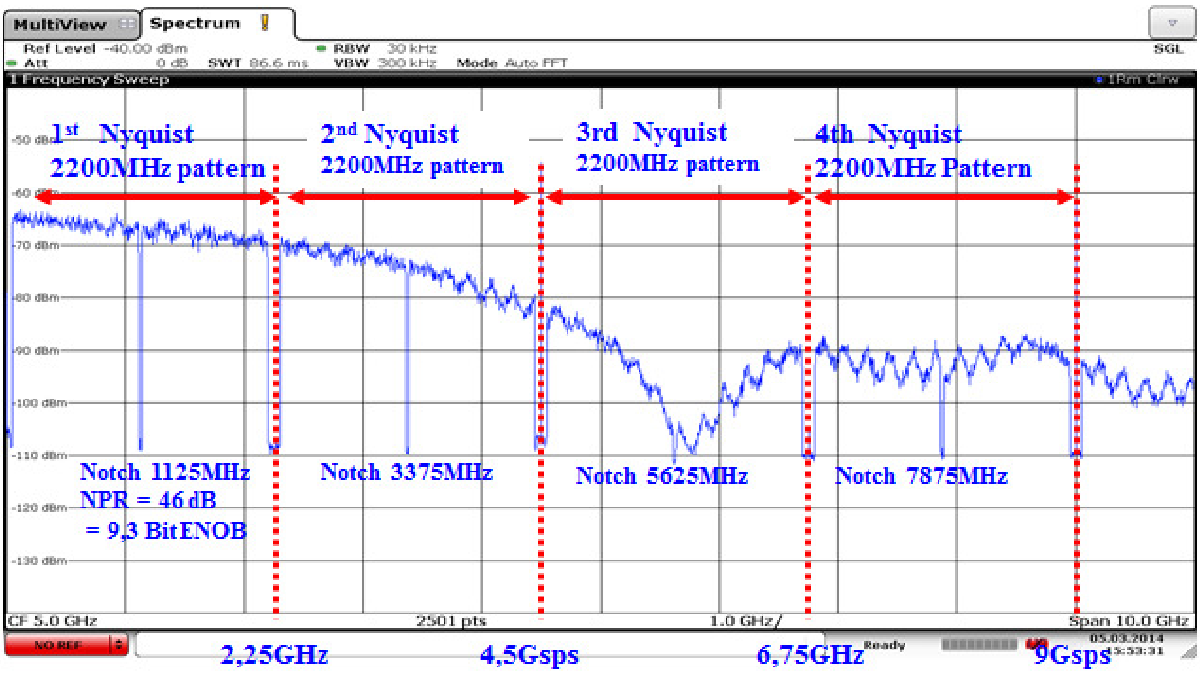

Fig 9. NPR results of EV12DS400 up to 9GHz using NRTZ mode

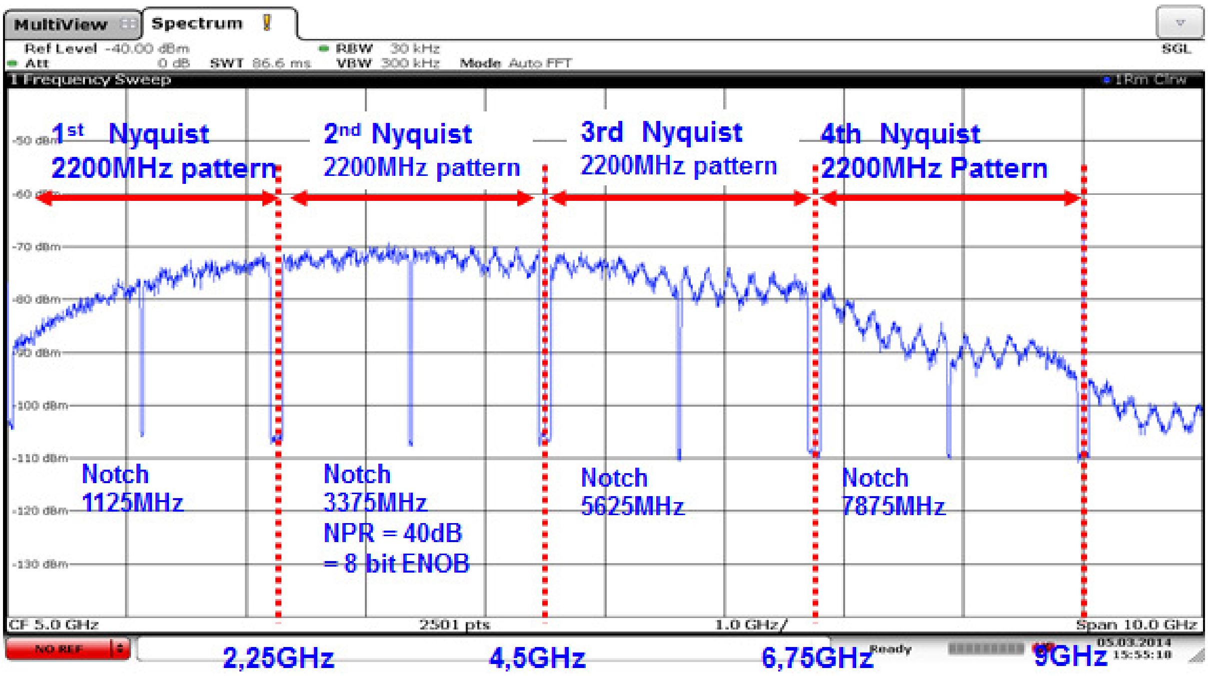

Fig 10. NPR results of EV12DS400 up to 9GHz using RF mode

Single Tone

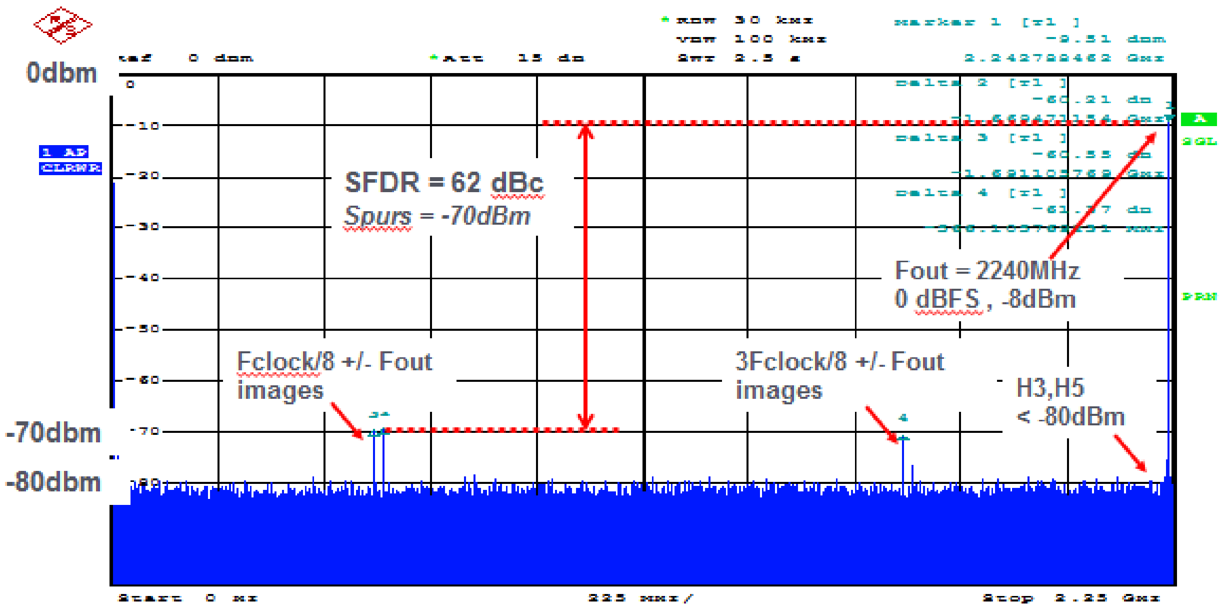

Fig. 11. Single Tone Fout = 2.24GHz Fclk = 4.5GHz

Multitone Patterns

Fig. 12 and 13 show some multi-tone patterns. Fig.12 shows a 5 multitone pattern and shows that the device is capable of outputting signals up to 12GHz. Fig. 13 shows a zoom around a 10 tone pattern showing the maximum spur power of better than -70dBm.

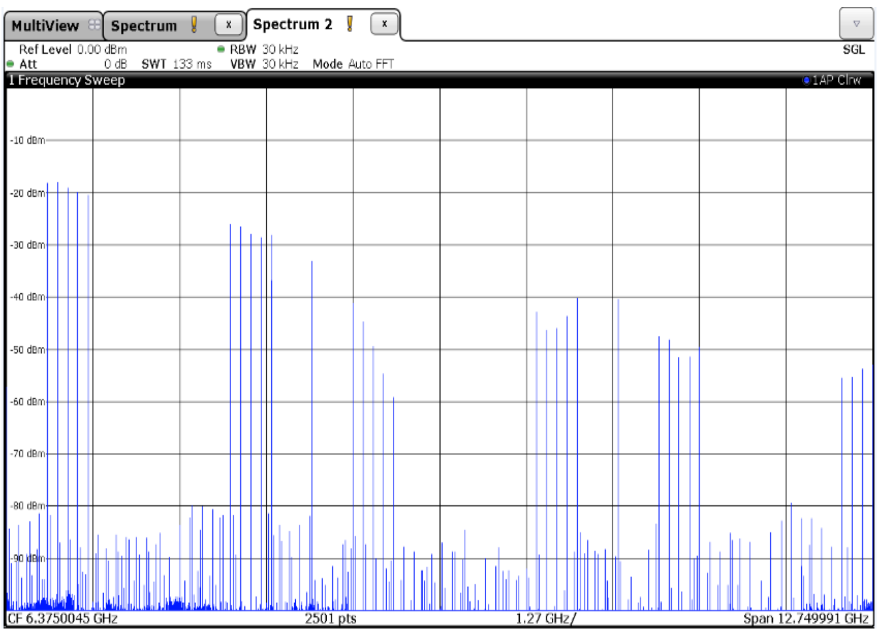

Fig. 12. Multitone Pattern using NRTZ mode to 12GHz

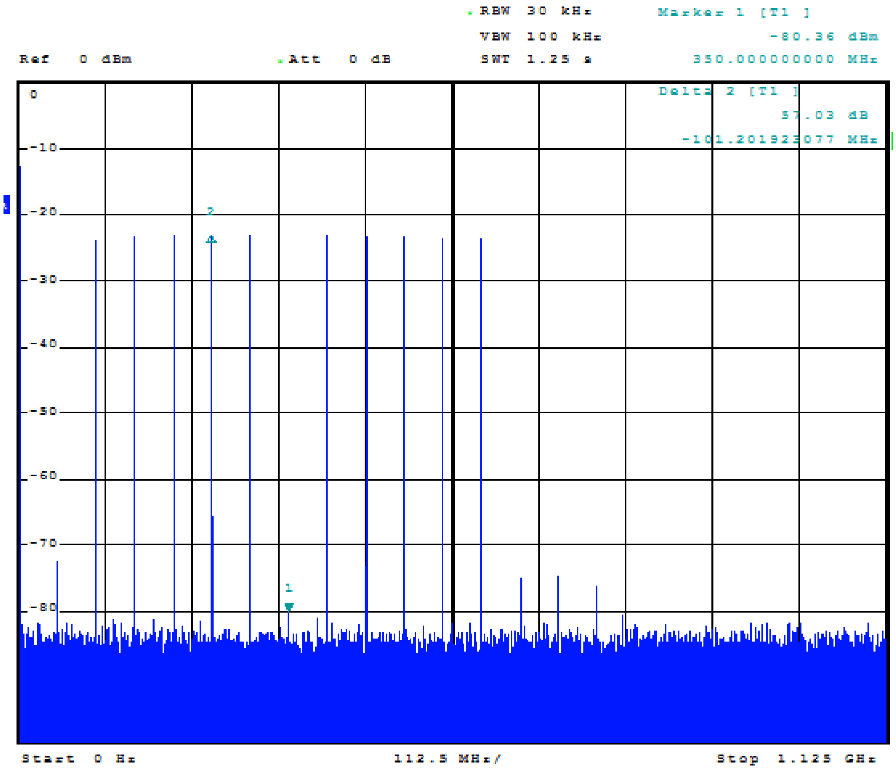

Fig. 13. Multitone Pattern using NRTZ mode

APPLICATIONS

Wireless Test Systems

Within wireless test equipment, the ability to generate or digitize as wide bandwidth as possible becomes very attractive for flexibility. These requirements for flexibility and multi frequency norms mean that direct conversion multi-band systems are being considered as the basis of flexible test equipment. For example a data converter with a wide instantaneous bandwidth can accommodate many different frequencies at the input or output.

If a multi-standard receiver/transmitter is implemented by stacking different receivers for different standards into a single receiver, the area and power consumptions can be high[2] . It can be seen that using a high sample rate data converter – here is illustrated using a converter with sample rate of 4.5GSps, that multiple bands can be accommodated within one Nyquist zone.

This means that replicating hardware (RF front ends, down conversion and demodulation) for each communication standard becomes unnecessary since all this can be performed in the digital domain.

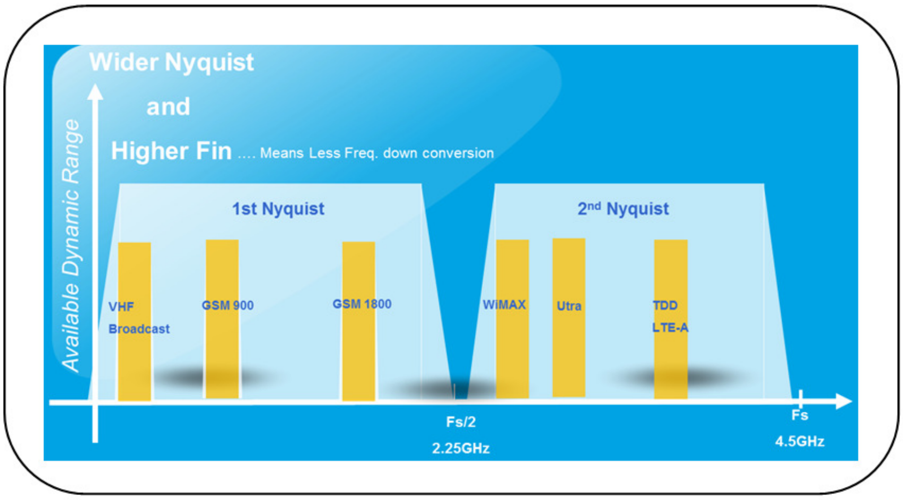

Fig. 14. Accessing Multiple Communications Standards using one Data Converter

Military Systems

Designers of electronic warfare (EW) systems are constantly looking for DACs which provide not only Nyquist zones larger than 2 GHz but which also offer flat frequency response in these large instantaneous , and in addition which also generate these signals with a centre frequency positioned in the microwave frequency range. Waveform agility in active radar systems can provide performance improvements such as reduced target-tracking error, improved target detection, higher target identification accuracy [3].

Again up-conversion can also be used to eliminate components and provide flexibility.

CONCLUSION

Advances in technology are changing communications systems architectures and the high speed, high bandwidth DACs are part of these changes. Their main advantages are:

- Flexibility – different modulation schemes and frequencies can be easily added
- Fast switching between frequencies is possible giving high rate frequency hopping
- The ability to use a single DAC to encode multi-channel system gives savings in PCB real estate.
- Performing the IQ modulation in the FPGA removes the sensitivity to phase and gain shifts in the IQ modulator.

A microwave DAC, EV12DS400, has been developed which can transform signals generated in baseband to L, S, C and lower X bands. The device has been measured to give SFDR values of between 65dBc and 50dBc depending on mode used, at output frequencies above 8GHz and NPR values of 46dB in the first Nyquist zone.

The output analog bandwidth of the device is estimated at 8GHz.

REFERENCES

1. Bore F. et al, “3Gsps 7GHz BW 12 bit MuxDAC for Direct Microwave Signal Generation over L, S or C Bands”, *IEEE COMCAS Tel Aviv 2011*

2. José R. García Oya, Andrew Kwan, Fernando Muñoz Chavero,Fadhel M. Ghannouchi, Mohamed Helaoui, Fernando Márquez Lasso,Enrique López-Morillo and Antonio Torralba Silgado, “Subsampling Receivers with Applications to Software Defined Radio Systems”, *Intech publication*

3. Sandeep P. Sira, Ying Li, Antonia Papandreou-Suppappola Darryl Morrell, Douglas Cochran, and Muralidhar Rangaswamy, “Waveform-Agile Sensing for Tracking”, *IEEE Signal Processing Magazine* [53]