L-Band Direct RF Sampling Receivers

G Durga Srinivas, Mohit Kumar, K Sreenivasulu, Vishal Maheshwari

Electronics and Radar Development Establishment (LRDE)
CV Raman Nagar, Bangalore-560093, INDIA
g.d.srinu414@gmail.com

Abstract
At lower frequency ranges the analog receivers are replaced by digital receiver because of significant advantages like programmability, insensitive to temperature etc., as the technology advancement in ADC and VLSI allows sampling of RF signals directly up to 3GHz with current available COTS devices without any pre-analog down-conversion. In this paper design of direct sample receivers for L-band radar using high speed and high analog input bandwidth ADCs and high speed FPGAs, issues, advantages are discussed in detail. The schemes for high speed digital down conversion and pulse compression also described.

Key words*: Direct Sampling, ADC, VLSI*

I Introduction:

A direct RF sampling receiver front end uses an Analog-to-Digital Converter (ADC) to sample the RF signal without first mixing the signal down to a lower intermediate frequency. Figure 1 and Figure 2 compares a traditional super-heterodyne RF front end with a direct RF sampling front end. The main difference between the two receivers is that the traditional RF front end uses local oscillators and mixers to down-convert the signal to an intermediate frequency (IF), typically in the MHz range, before it samples the signal using an ADC. The direct RF sampling front end eliminates the mixing stages.

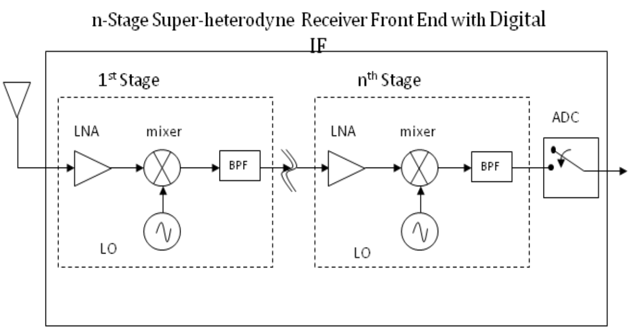

Fig: 1. Super-heterodyne receiver front end.

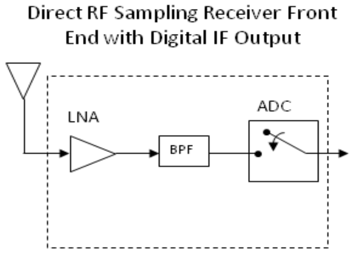

Fig: 2. Direct RF sampling receiver front end.

A single direct RF-sampling ADC can replace an entire IF-sampling or Zero IF-sampling subsystem of mixers, LO synthesizers, amplifiers, filters, and ADCs, while achieving greater flexibility, digitally programmable systems and also drastically reducing bill of materials (BOM) cost, design time, board size, weight, and power.

Direct RF sampling offers several advantages for Radar RF front end design. First, it reduces the parts count, as it is obvious from Fig. 2, and it eliminates the need to design and fabricate a mixing chip with a specially tailored frequency plan. Second, it simplifies the design of new receivers for the new signals that will become available as Radar gets modernized. All that is needed to work with a new carrier frequency is to select an appropriate sampling frequency and to incorporate an appropriate BPF. Third, it is possible to make a single RF front-end for multiple frequency bands. This approach to multi-frequency Radar receiver front end design eliminates the need for multiple frontends, which reduces the parts count and eliminates some potential sources of inter-channel line bias.

The direct RF sampling front also can sample at a rate lower than the carrier wave frequency range. The bandpass sampling theorem enables this type of approach, but only if the bandpass filter (BPF) upstream of the ADC has been designed to filter out unwanted signals and noise that is not near the nominal carrier frequency.

This paper uses a bandpass sampling theorem approach and presents two schemes for direct RF sampling. In first scheme, a single sampling frequency with tunable Numerically Controlled Oscillator (NCO) and in second scheme, two sampling frequencies with two tunable NCO's (selected depending upon the RF frequency)to down convert L-band RF signal (1.2GHz to 1.4GHz) to baseband signal is discussed. Also pulse compression implemented on the first scheme of direct RF sampling in MATLAB is discussed.

II Conceptual Design of Direct RF Sampling Schemes:

According to band pass sampling theorem when a bandpass signal is sampled slower than its Nyquist rate, the samples are indistinguishable from samples of a low-frequency alias of the high-frequency signal. That is often done purposefully in such a way that the lowest-frequency alias satisfies the Nyquist criteria, because the bandpass signal is still uniquely represented and recoverable. Such under sampling is also known as bandpass sampling, harmonic sampling, IF sampling, and direct IF to digital conversion.

1 First Scheme

In this scheme, a high speed ADC, with sampling frequency (f_s) of 580 MSPS, samples the input L-band RF signals 1.2 - 1.4 GHz having instantaneous bandwidth of 10MHz. The L-band RF signal when sampled with 580 MSPS falls in the 5^{th} Nyqyist zone which will be aliased into 1^{st} Nyquist zone (0 to $f_s/2$). The lowest RF signal (1.2GHz) after sampling with ADC will be at 40 MHz whereas the highest RF signal (1.4 GHz) will be at 240 MHz as shown in the Fig 3. A tunable NCO with sampling rate of 580 MSPS and center frequency varying from 40 MHz to 240 MHz, depending upon the frequency of the input RF signal, down converts the signal to baseband. Since the instantaneous band width of the signal is 10 MHz, the number of samples in the base band data has to be brought down to 10. This is achieved by down sampling the base band data by 58 times.

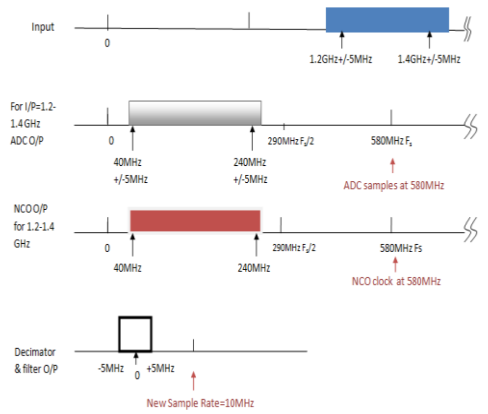

Fig: 3. Direct RF sampling with single sampling frequency.

2 Second Scheme

In this scheme, a high speed ADC, with two sampling frequencies (f_{s1}) 290 MSPS if input RF frequency is from 1.2 to 1.3 GHz and (f_{s2}) 320 MSPS if input RF frequency is from 1.3to 1.4 GHz, samples the input L - band RF signals having instantaneous bandwidth of 10 MHz. The L - band RF signal when sampled using f_{s1} and f_{s2}, sampling frequency selected depending upon the input RF frequency of the signal, falls in the 9^{th} Nyqyist zone which will be aliased into 1^{st} Nyquist zone (0 to $f_{s1}/2$ or $f_{s2}/2$). The RF signals (1.2 – 1.3 GHz) after sampling with ADC having sampling frequency f_{s1}will be at 40 MHz and 130 MHz corresponding to the input RF frequency of 1.2 GHz and 1.3 GHz respectively. Whereas the RF signals (1.3 - 1.4 GHz) after sampling with ADC having sampling frequency f_{s2} will be at 20 MHz and 120 MHz corresponding to the input RF frequency of 1.3 GHz and 1.4 GHz respectively as shown in the Fig 3. A tunable NCO with sampling rate off_{s1} and center frequency varying from 40 MHz to 130 MHz or sampling rate of fs2, and center frequency varying from 20 MHz to 120 MHz, depending upon the frequency of the input RF signal, down converts the signal to baseband. Since the instantaneous band width of the signal is 10 MHz, the number of samples in the base band data has to be brought down to 10. This is achieved by down sampling the base band data by 29 or 32 times for f_{s1} or f_{s2} respectively.

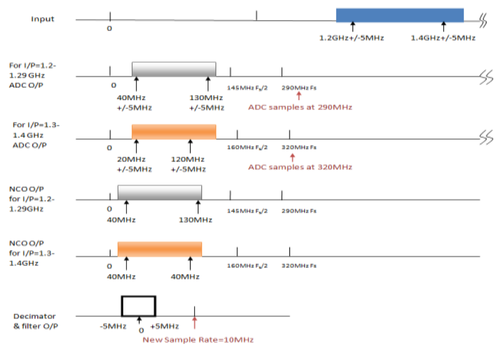

Fig: 4. Direct RF sampling with single sampling frequency.

III Implementation:

First scheme is considered for the implementation of direct RF sampling for our L-band Radar case. ADC evaluation board ADC12b1800RB is used to sample the RF signal directly. The RF input signal to this ADC is fed using Pulse building software of Agilent Function generator and clock of 580 MHz is fed using signal source which is further converted to a differential clock of 580 MHz using BALUN.

The ADC used is ADC12b1800RF from Texas Instruments. It is based on calibrated folding and interpolating architecture and has an input bandwidth of 2.7 GHz in non-DES mode and 1.2 GHz in DESI and DESQ mode, maximum sampling rate of 3.6 GSPS in interleaved mode and 1800 MSPS in dual ADC mode, 12 bit of output. ENOB of 8.7 bits, SNR of 54.3 dB, SFDR of 64 dBC for I/P = 1448 MHz @ -0.5 dBFS.

Linear Frequency Modulated (LFM) waveform with 10us pulse width and center frequency of 1.3 GHz is generated using Pulse building software which is fed to the ADC. Output of the ADC is captured using Wave Vision software the data is exported to text file. A MATLAB program is implemented which reads the text file and down converts the ADC data to baseband. It also does low pass filtering with cut off frequency at 5 MHz, down samples the data from 580 MSPS to 10 MSPS and performs pulse compression on the down sampled base band data.

Fig 5 and Fig 6 shows the input data after sampling using ADC in time domain and frequency domain respectively. As we can see from Fig 6 that after sampling with ADC of sampling frequency 580 MSPS the input RF signal at 1.3 GHz will be at 140 MHz (f_{out}=f_c-2*f_s). A tunable NCO with center frequency of 40 MHz to

240 MHz and sampling rate of 580 MSPS, implemented in MATLAB, is tuned to corresponding RF signal frequency which in this case is 140 MHz. Using this NCO the signal at 140 MHz is down converted to base band. Fig 7 shows the down converted base band data in time domain. The base band data is then passed through the low pass FIR filter, implemented in MATLAB, of order = 59, sampling frequency = 580 MSPS, Fpass = 5 MHz and Fstop = 30 MHz to remove any unwanted frequency components. Output of the low pass filter is shown in Fig 8. Output of the filter is then down sampled from 580 MSPS to 10 MSPS which is the required base band data rate for this application. Fig 9 shows the down sampled I and Q output in time domain. Pulse compression is implemented on the base band down sampled data in time domain. The coefficients to the pulse compression filters are the complex conjugate of the input signal. Fig 10 shows the I and Q pulse compressed output and Fig 11 shows the pulse compressed output in dB.

IV Results:

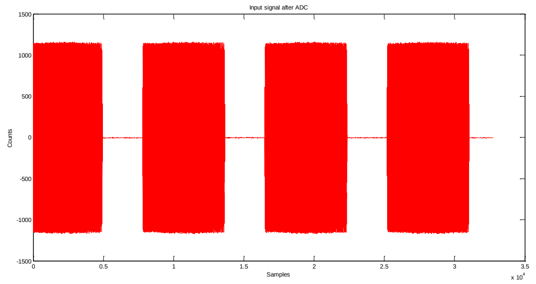

Fig: 5. RF signal after sampling using ADC in time domain.

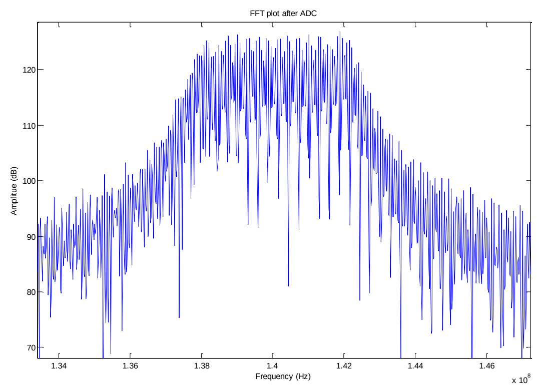

Fig: 6. RF signal after sampling using ADC will be at 140 MHz (in frequency domain).

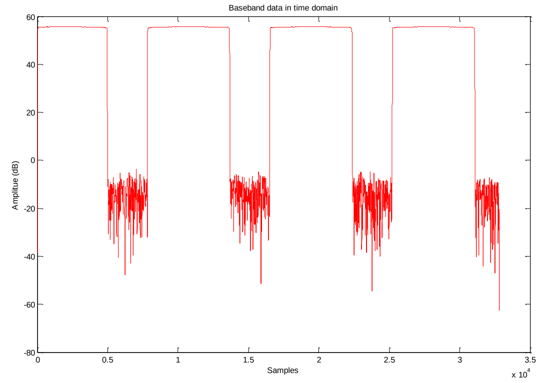

Fig: 7. Signal after down conversion in time domain.

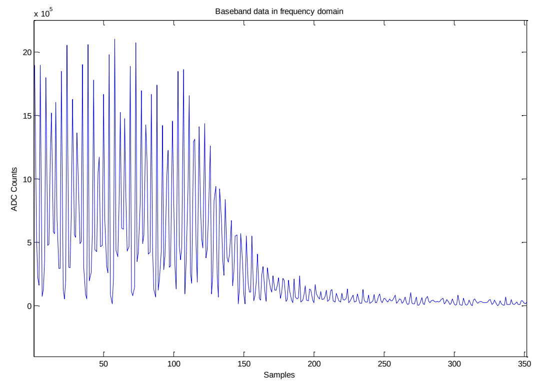

Fig: 8. Signal after down conversion in frequency domain.

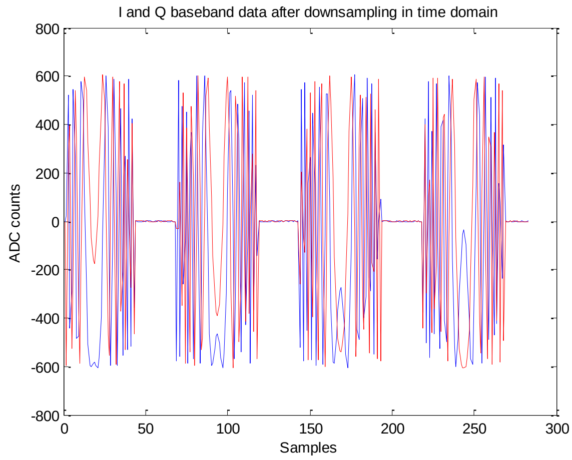

Fig: 9. I and Q baseband data after down sampling in time domain.

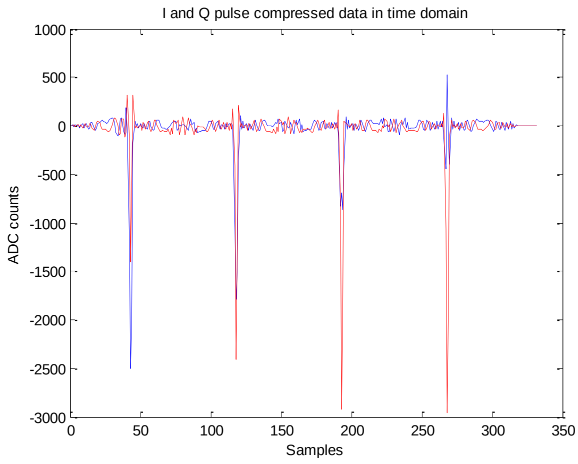

Fig: 10. I and Q pulse compressed output in time domain.

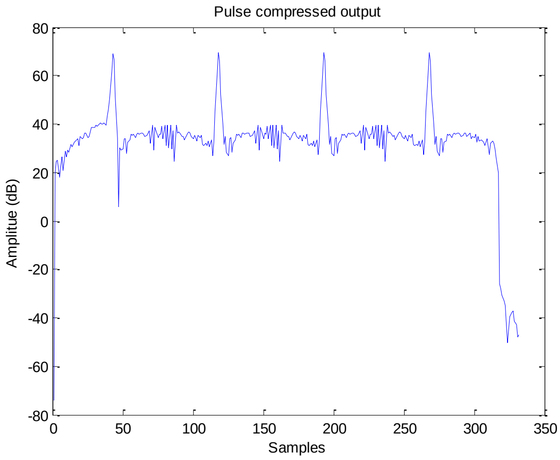

Fig: 11.Pulse compressed output for 10us LFM pulse.

V Conclusion:

Direct RF sampling front ends for Radar receivers have been studied analytically, experimentally, and via simulation. This type of front end samples at more than twice the information bandwidth of the signal, but at much less than twice the carrier frequency. Such a front end uses intentional aliasing to map the signal band around the Radar carrier frequency into the Nyquist bandwidth of the sampling system. Bandpass filters ahead of the analog-to-digital converter are used to avoid the loss of carrier-to-noise ratio that otherwise would result from aliased folding into the Nyquist bandwidth of out-of-band noise and interference.

The principal goal of this study has been to investigate two different sampling schemes for direct RF sampling of Radar signals in L-band, performing down conversion, filtering, down sampling and pulse compression.

References:

1. Mark L. Psiaki, Steven P. Powell, Hee Jung, and Paul M. Kintner "Design and Practical Implementation of Multi-frequency RF Front Ends Using Direct RF Sampling", IEEE IRC 2005.
2. Mark L. Psiaki, Dennis M. Akos and Jonas Thor "A Comparison of Direct RF Sampling and Down-Convert & Sampling GNSS Receiver Architectures.
3. www.ti.com/gigadc

Bio Data of Authors

G DurgaSrinivas born on 2nd June 1986 obtained B.Tech degree in Electronics and Communication from NIT Warangal in 2008. He is currently working as a scientist at Electronics and Radar Development Establishment (LRDE), Bengaluru. Area of specialization is in Digital Receiver systems.

K Sreenivasulu received his Diploma in Electronics and Communication Engineering from S.V. Government Polytechnic, Tirupati, Andhra Pradesh in the year 1987. He received his B.Tech degree in Electronics and Communication Engineering from Jawaharlal Nehru Technological University, Hyderabad in the year 1995. He received M.E. degree in Micro Electronics Systems from Indian Institute Of Science, Bangalore in 2004. He started his professional career as Electronic Assistant in Civil Aviation Department where he worked from 1990 to 1995. Since 1996 he has been working as Scientist in Electronics and Radar Development Establishment (LRDE), Bangalore. His area of work has been design and development of RF and Microwave sub-systems, Digital Radar system, Beam Steering Controller for Active Aperture Array Radars. His interests include VLSI Systems and Programmable Controllers.

Mohit Kumar born on 7th October 1980 obtained B.Tech degree in Electronics and Communication from NIT, Jalandhar in 2002. He has completed his MTech from IIT Delhi in Communication Engg. in 2010. He is currently working as scientist at Electronics and Radar Development Establishment (LRDE), Bengaluru. Area of specialization is in Digital Radar Receiver design.

Vishal Maheshwari born on 18th December 1990 obtained his B.Tech degree in Electrical Engineering stream from IIT,Gandhinagar in 2012. He is currently working as scientist at Electronics and Radar Development Establishment (LRDE), Bengaluru. Area of specialization is in Digital communication and optical realization.