Software Defined Integrated RF Frontend Receiver Design

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Abstract. Software Defined Radio (SDR) technology uses a generic hardware platform supported by software modules to accommodate different communication standards, frequency bands and modulation schemes. In today's world, integration of various mobile communication standards like Code Division Multiple Access (CDMA), Global System for Mobile communication (GSM), Wideband CDMA (WCDMA) and Worldwide Interoperability for Microwave Access (WIMAX) is the need of the hour. This paper deals with the concepts and procedures involved in designing software defined integrated radio frequency (RF) frontend receiver which can be configured to support different technologies like GSM, CDMA and WCDMA. In a three band case, a new band pass sampling algorithm is proposed to evaluate valid sampling frequency ranges and corresponding intermediate frequencies for multiple standards. The simulation results show that the algorithm developed and the software defined integrated RF frontend receiver design proposed in this paper give good performance.

Keywords: Band Pass Sampling, Base Transceiver Station, Interoperability, Modulation, Numerically Controlled Oscillator, Reconfigurable architecture and Software Defined Radio.

1 Introduction

Software Defined Radio (SDR) is a term adopted by the international Software Defined Radio Forum to describe radios that provide software control of a variety of modulation techniques, variable bandwidth, security functions and waveform requirements of current and evolving standards. The main aim of SDR is to design a reconfigurable hardware which can support different technologies just by changing the software. Quite often this is done with general purpose Digital Signal Processors (DSP) or Field Programmable Gate Arrays (FPGA).

In this paper, a reconfigurable SDR based integrated RF frontend receiver design is given for multiple standards, i.e. GSM, CDMA and WCDMA. The main challenge in designing reconfigurable frontend receiver is to find out valid sampling frequency and corresponding intermediate frequencies. The band pass sampling algorithm for three band case is given in this paper and valid sampling frequency ranges are obtained for these standards. The intermediate frequencies for the system considered are calculated and given.

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2 Band Pass Sampling

The central idea behind the SDR architecture is to place analog to digital and digital to analog convertors as near to the antenna as possible, leaving the implementation of the most radio functionality to a programmable micro or signal processor. One way to accomplish this in a radio receiver front end is by directly down converting the desired radio frequency (RF) signal to a target intermediate frequency (IF) using band pass sampling. In band pass sampling method, initially, all possible orders of spectral replicas in the spectrum of the sampled signal are determined. For each case, valid sampling frequency range in terms of parameters such as bandwidth, centre frequency, the upper/lower cutoff frequency of RF signals is derived. The challenge is to determine a valid sampling frequency closest to the bandwidth of RF signal that will translate the band pass signal into sampled bandwidth without aliasing. The value of the IF for the down converted signals is given as follows [2].

$$f_{IF} = \begin{cases} rem\ (f_c, f_s) & if \left\lfloor (f_c/(f_s/2)) \right\rfloor \ is\ even \\ f_s - rem\ (f_c, f_s) & if \left\lfloor (f_c/(f_s/2)) \right\rfloor \ is\ odd \end{cases} \tag{1}$$

Where, f_c is the centre frequency of the RF signal, f_s is the sampling frequency and rem (f_c , f_s) is reminder of f_c / f_s.

2.1 Procedure to Determine Valid Sampling Frequency Range

Consider three RF signals with frequency ranges given by f_{L1} - f_{H1}, f_{L2} - f_{H2} and f_{L3} - f_{H3}, with bandwidths as B_1, B_2 and B_3 and centre frequencies as f_1, f_2 and f_3 respectively. The centre frequencies are related by $f_2=R_1f_1$ and $f_3=R_2f_2$, where R_1 and R_2 are positive real numbers calculated and used in the algorithm.

For the sampled signal to be without aliasing, the spectrum of each signal must not straddle any integer multiple of $f_s/2$. Therefore, the positive spectra of the three signals '1', '2' and '3' must lie inside some segments n_1, n_2 and n_3 respectively. Since n_1 is the number of segment where spectrum '1' is located, the largest value of n_1 is determined by $n_1 = \lfloor (f_{L1}/f_s) \rfloor$.

For a three band case, the bandwidth of a segment should at least accommodate all non overlapping replicas (replicas '1', '-1', '2', '-2', '3', and '-3'). This means that $f_s \geq 2(B_1 + B_2 + B_3)$. Therefore, the value of n_1 is upper bounded by

$$n_1 \leq \left\lfloor \left(\frac{f_{L1}}{2(B_1 + B_2 + B_3)} \right) \right\rfloor \tag{2}$$

In addition, since spectrum of '1' is in segment n_1, we can write

$$n_1 f_s \langle f_1 \langle (n_1 + 1) f_s \tag{3}$$

Multiplying (3) by R_1/f_s and using the relation of $f_2 = R_1f_1$, we get

$$R_1 n_1 \langle (f_2 / f_s) \langle R_1 (n_1 + 1) \tag{4}$$

Taking 'floor' function on (4) leads to

$$\lfloor (R_1\, n_1) \rfloor \;\langle\; n_2 \;\langle\; \lfloor (R_1\,(n_1+1)) \rfloor \tag{5}$$

Similarly, we get

$$\lfloor (R_2\, n_2) \rfloor \;\langle\; n_3 \;\langle\; \lfloor (R_2\,(n_2+1)) \rfloor \tag{6}$$

Table 1. Boundary constraints for a three band case

Case	Boundary Constraint	
	Spectrum '1' or '2'	Spectrum '2' or '3'
1	$f_{L1} \geq n_1 f_s$	$f_{H2} \leq (n_2 + ½) f_s$
2	$f_{L1} \geq (n_1 + ½) f_s$	$f_{H2} \leq (n_2 + 1) f_s$
3	$f_{L1} \geq n_1 f_s$	$f_{L2} \geq (n_2 + ½) f_s$
4	$f_{L1} \geq (n_1 + ½) f_s$	$f_{L2} \geq n_2 f_s$
5	$f_{H1} \leq (n_1 + 1) f_s$	$f_{H2} \leq (n_2 + ½) f_s$
6	$f_{H1} \leq (n_1 + ½) f_s$	$f_{H2} \leq (n_2 + 1) f_s$
7	$f_{H1} \leq (n_1 + 1) f_s$	$f_{L2} \geq (n_2 + ½) f_s$
8	$f_{H1} \leq (n_1 + ½) f_s$	$f_{L2} \geq n_2 f_s$
9	$f_{L2} \geq n_2 f_s$	$f_{H3} \leq (n_3 + ½) f_s$
10	$f_{L2} \geq (n_2 + ½) f_s$	$f_{H3} \leq (n_3 + 1) f_s$

Table 2. The valid ranges of sampling frequency

Case	Range of valid f_s
1	$\frac{f_{H2}}{(n_2+\frac{1}{2})} \leq f_s \leq \min(\frac{f_{L1}}{n_1}, \frac{f_{L2}-f_{H1}}{n_2-n_1}, \frac{f_{L3}-f_{H2}}{n_3-n_2})$
2	$\frac{f_{H2}}{(n_2+1)} \leq f_s \leq \min(\frac{f_{L1}}{n_1+\frac{1}{2}}, \frac{f_{L2}-f_{H1}}{n_2-n_1}, \frac{f_{L3}-f_{H2}}{n_3-n_2})$
3	$\frac{f_{H1}+f_{H2}}{(n_1+n_2+1)} \leq f_s \leq \min(\frac{f_{L1}}{n_1}, \frac{f_{L2}}{n_2+\frac{1}{2}}, \frac{f_{L3}}{n_3+1})$
4	$\frac{f_{H1}+f_{H2}}{(n_1+n_2+1)} \leq f_s \leq \min(\frac{f_{L1}}{n_1+\frac{1}{2}}, \frac{f_{L2}}{n_2}, \frac{f_{L3}}{n_3-\frac{1}{2}})$
5	$\max(\frac{f_{H1}}{n_1+1}, \frac{f_{H2}}{n_2+\frac{1}{2}}, \frac{f_{H3}}{n_3}) \leq f_s \leq \frac{f_{L1}+f_{L2}}{(n_1+n_2+1)}$
6	$\max(\frac{f_{H1}}{n_1+\frac{1}{2}}, \frac{f_{H2}}{n_2+1}, \frac{f_{H3}}{n_3+\frac{3}{2}}) \leq f_s \leq \frac{f_{L1}+f_{L2}}{(n_1+n_2+1)}$
7	$\max(\frac{f_{H1}}{n_1+1}, \frac{f_{H2}-f_{L1}}{n_2-n_1}, \frac{f_{H3}-f_{L2}}{n_3-n_2}) \leq f_s \leq \frac{f_{L2}}{(n_2+\frac{1}{2})}$
8	$\max(\frac{f_{H1}}{n_1+\frac{1}{2}}, \frac{f_{H2}-f_{L1}}{n_2-n_1}, \frac{f_{H3}-f_{L2}}{n_3-n_2}) \leq f_s \leq \frac{f_{L2}}{n_2}$
9	$\frac{f_{H3}}{(n_3+\frac{1}{2})} \leq f_s \leq \min(\frac{f_{L2}}{n_2}, \frac{f_{L3}-f_{H2}}{n_3-n_2}, \frac{f_{H3}-f_{L1}}{n_3-n_1})$
10	$\frac{f_{H3}}{(n_3+1)} \leq f_s \leq \min(\frac{f_{L2}}{n_2+\frac{1}{2}}, \frac{f_{L3}-f_{H2}}{n_3-n_2}, \frac{f_{H3}-f_{L1}}{n_3-n_1})$

The boundary constraints and ranges of valid sampling frequency for some of the possible cases are given in Table 1 and 2 respectively. Some of the valid sampling frequency ranges for a three band case are calculated and given in Table 3. The corresponding IFs are calculated using (1) and given in Table 4.

Table 3. Valid sampling frequency ranges for three band case

Standard	Channel Range (MHz)	Sampling Frequency Range (MHz)
CDMA-IS 95 GSM-900 WCDMA	824-825.25 895-895.2 1920-1925	12.919463-12.924812
		13.099206-13.122137
		13.336822-13.358209
		13.461654-13.46890
		13.528689-13.535433
		13.563636-13.568905
		13.961386-13.963636
		14.109589-14.117647

Table 4. Sampling frequency and down converted IF

Sampling Frequency (MHz)	IF1 (MHz)	IF2 (MHz)	IF3 (MHz)
12.924812	2.5630	3.2880	3.2970
13.099206	0.6250	4.3540	3.0833
13.358209	3.5840	0.10	1.0821
13.4689	3.0221	6.1526	3.5527
13.528689	0.6250	2.2065	1.4262
13.568905	3.0782	0.4477	4.2845
13.963636	0.7705	1.4273	4.4818
14.117647	5.8015	5.6882	2.50

3 Software Defined Integrated RF Frontend Receiver

Digital front end of a BTS is shown in the figures 1 and 2. The configurable part in an SDR is its digital front end. The digital front end consists of digital band pass filters, ADC, Numerically Controlled Oscillator (NCO) and anti aliasing filters. Numerically controlled Oscillator (NCO) is the digital version of local oscillator. This paper focuses on the sampling frequency for the ADC which in turn determines the down converted IF and the NCO frequency.

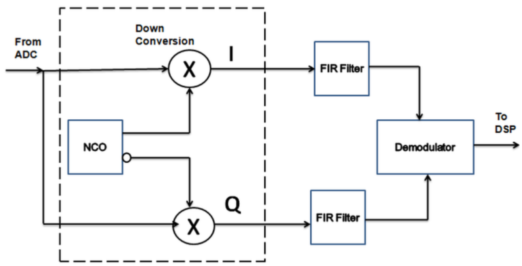

Fig. 1. Digital Frontend Receiver

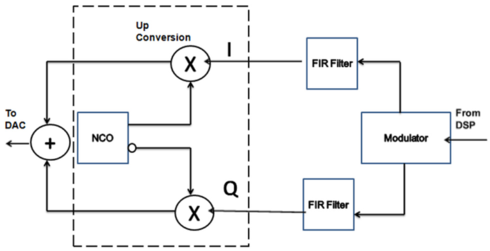

Fig. 2. Digital Frontend Transmitter

Software defined integrated RF frontend receiver architecture for GSM, CDMA-IS95A and WCDMA technologies for the uplink band is shown in Fig. 3. In the absence of actual input signal, we simulate the incoming signal using the Gaussian noise generator. The output of the generator is filtered into required uplink bands of CDMA (824-849 MHz), GSM (890-915 MHz) and WCDMA (1920-1980 MHz) using digital band pass filters.

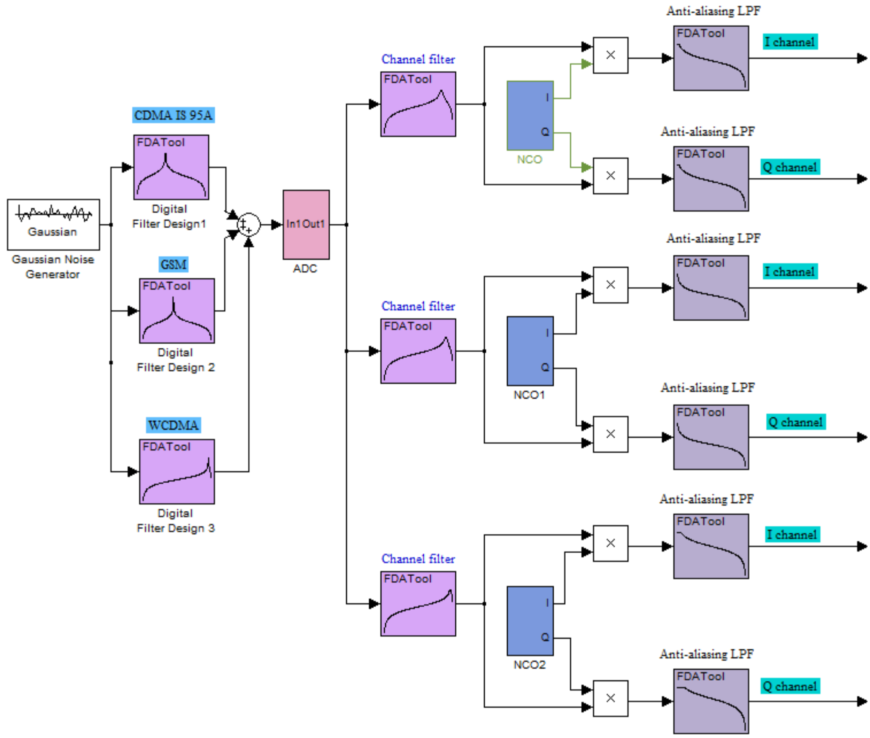

Fig. 3. Software based RF Frontend Receiver

The outputs from the digital filters are added and given to the ADC block. The ADC block also carries out the functions of amplification and gain control in addition to the analog to digital conversion. The sampling frequency of ADC is determined by the band pass sampling algorithm as given in sec.2. Direct down conversion of these RF signal bands to the respective baseband frequency is carried out using digital down converter. The carrier frequency for Numerically Controlled Oscillator (NCO) is taken from the valid Intermediate Frequencies as calculated in sec.2. These digital down convertors will give the output as the CDMA, GSM and WCDMA baseband signals. These baseband signals are then fed to the respective demodulator.

4 Simulation and Results

For simulation, we chose the frequencies as 890-890.2 MHz for GSM, 824-825.25 MHz for CDMA and 1920-1925 MHz for WCDMA. The sum of these three signals is given as input signal to the ADC whose sampling frequency is selected from the frequency ranges given in Table 3. We have considered 13.568905 MHz as the sampling frequency and the results are obtained. The input signal to the ADC consisting of the spectrum of CDMA, GSM and WCDMA bands is shown in Fig. 4. The corresponding intermediate frequencies are given in Table 4 as 3.0782 MHz, 0.4477 MHz and 4.2845 MHz for CDMA, GSM and WCDMA standards respectively. These down converted IFs are generated by NCO, NCO1 and NCO2. The baseband spectra of GSM, CDMA, and WCDMA are shown in figures 5, 6 and 7 respectively. These results show that the band pass sampling algorithm developed and the Software Defined Integrated RF Frontend Receiver Design proposed in this paper give good performance.

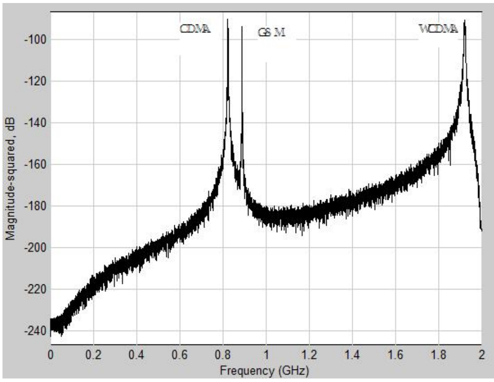

Fig. 4. The spectrum of simulated GSM, CDMA and WCDMA bands

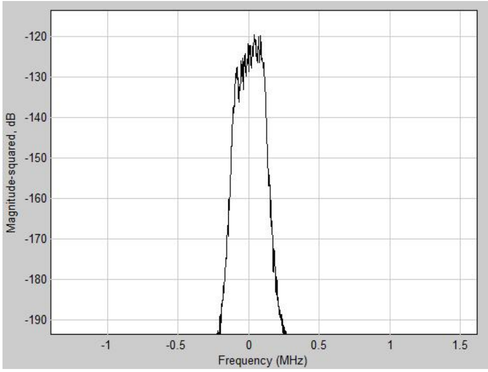

Fig. 5. The baseband spectrum of GSM

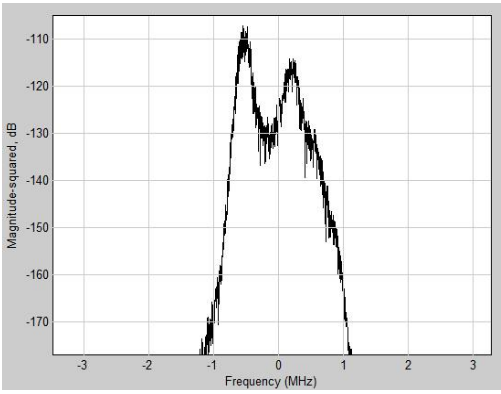

Fig. 6. The baseband spectrum of CDMA

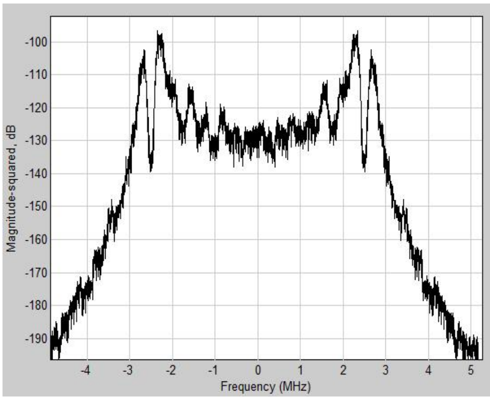

Fig. 7. The baseband spectrum of WCDMA

5 Conclusion

In this paper, a new receiver model for the Software Defined Integrated RF Frontend Receiver to interoperate amongst GSM, CDMA and WCDMA is given. This architecture multiplies the cell capacity by a factor of three. The band pass sampling algorithm developed in this paper for a three band case can be extended for N bands. The Software Defined Integrated RF frontend receiver model developed in this paper can be upgraded to interoperate amongst N standards. In a similar way, the transmitter model also can be developed.

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