# Design and Implementation of RF Front End for Ultra Wide Band Systems

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**Abstract:** Studies conducted on design and implementation of RF front-end for UWB in the 3.1-10.6 GHz range have been based on the intrinsically wideband approach .These include distributed grounded gate and source LNA with gains of 6 and 14 dB and noise figures of 3 and 5.3 dB respectively, wideband matched LNA with a gain of 7.5 dB, DLL at 528 MHz and PLL at 3.432 GHz for realizing multi-band OFDM carriers spaced 528 MHz apart, all in 0.18μm CMOS technology. Schemes of short pulse generation studied are based on the use of distributed amplifier with feedback and SRD driven by DLL or shaped output of a ring oscillator producing sub-nanosecond pulses and realization of eigen waveforms employing sine wave synthesis. Circular disc and planar adaptation of volcano smoke antenna have been designed, fabricated and tested.

## SECTION I: INTRODUCTION

Ultra-wideband (UWB) technology has received considerable attention in recent years for high data-rate short distance communication in the 3.1 GHz to 10.6 GHz region and transmission of sensor data. To prevent interference to existing radio and wireless systems, FCC has introduced very stringent emission levels. Two approaches have emerged as a solution meeting all these requirements – a) Impulse communication following Radar technique and b) Multi-band OFDM [1].

The present work is concerned with design and implementation of RF front end for UWB systems including wideband low noise amplifier, DLL based carrier generation for multi-band OFDM, short pulse generators and wideband antennas. This paper is organized in five sections. Distributed and wideband LNAs are discussed in section II. Section III covers carrier generation for MB-OFDM using DLL. Short pulse generation techniques are briefly discussed in section IV. Section V is on wideband antenna design followed by conclusion in section VI.

## SECTION II: WIDEBAND LOW NOISE AMPLIFIER

Two types of low noise amplifiers have been designed and implemented; the first is an adaptation of conventional source inductor degenerated circuit while the second is based on the concept of distributed amplification [2, 3, 4] in grounded source or grounded gate form which can be used directly for realization of wideband LNA and power amplifier.

**Common Source Distributed Amplifier:** A four stage cascoded common source amplifier has been implemented in 0.18 μm CMOS technology using cascades T sections of impedance 50 ohm [5]. The MOSFETs are of 300μm width and 0.18 μm length with gate to source capacitance of about 490 fF. The required value of inductance is 1.25 nH. The supply voltage $V_{DD}$ is 1.8 V and gate to source bias voltage of the common source amplifiers is 0.6 V. The cascode transistors have lengths and widths same as the amplifier transistors. The S11 or the input isolation is lower than -10 dB till 9 GHz and from S21 characteristics, pass band gain is higher than 16 dB with cut off at 13.7 GHz. Variation in gain is about 1 dB at lower frequencies but the gain peaks near cut off. The noise figure NF is below 3.6dB in the band. The average power consumption is 57.9 mW.

**Common Gate Distributed Amplifier:** A three stage common gate distributed amplifier (Fig.1) has been designed to realize a very low power, broadband, impedance matched amplifier as the first section of the receiver system. Inductances and capacitances of the T-sections are so chosen that all the sections have same time delay. Each stage has a transconductance ($g_m$) equal to one-third the driving admittance. The source line of the circuit is tapered up. The circuit has a gain of 6 dB, NF of 5.3 dB and consumes 2.8 mW of power.

**Drain line-gate line inductively coupled distributed amplifier:** Simple common source distributed amplifiers suffer from feedback through gate to drain capacitance of the transistors. This causes undesired effect in frequency response commonly countered by inserting cascode transistors. In this work another method for countering the feedback is developed with mutual coupling between gate and drain lines of distributed amplifiers (Fig.4) which in combination with active matching eliminates the backward wave at each drain node. The success is manifested in an improvement of S21 characteristics of the circuits. In the designed circuit the drain line is tapered to prevent the backward traveling waves. The coefficient of inductive coupling required is approximately calculated from the gate to drain capacitance of the transistors and the capacitance in the gate line T-section and drain line T-section corresponding to that transistor. Average power consumed by the circuit is 2.8 mW.

Simulated results of the performances of CS, CG, coupled line distributed amplifier are shown in Fig.2, Fig.3 and Fig.4.

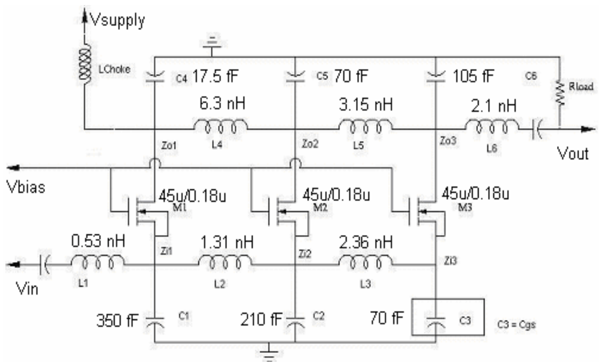


Fig.1. Common-gate DA schematic

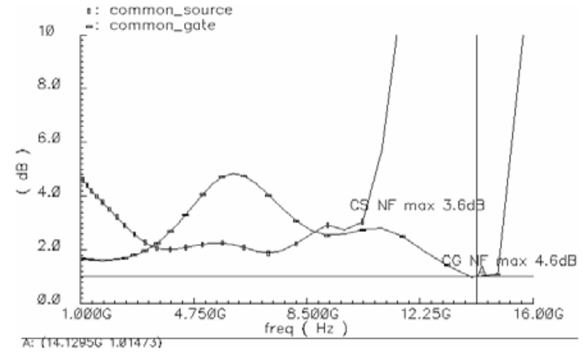


Fig.3. NF for CS and CG distributed amplifier

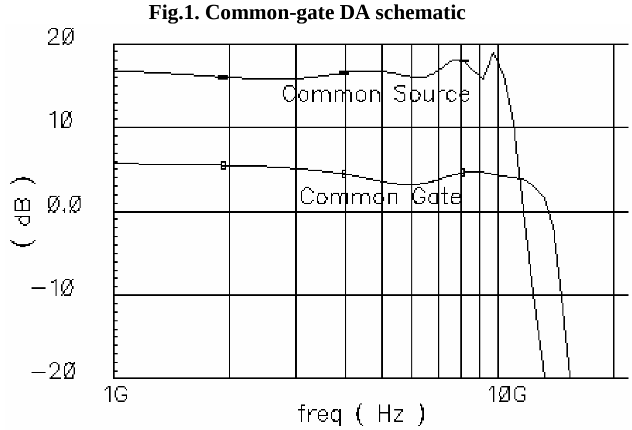


Fig.2. Comparison of S21 of CS and CG distributed amplifier gain

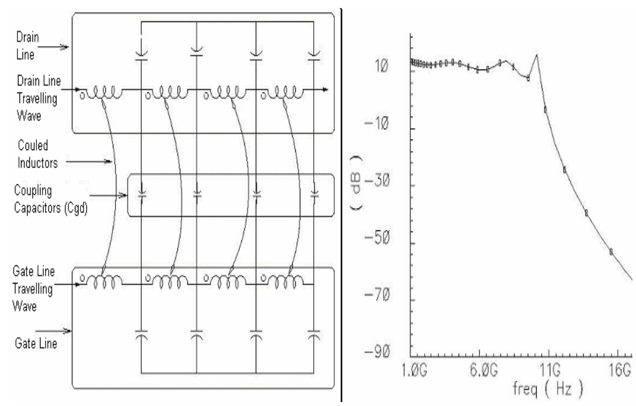


Fig.4. Coupled transmission line and corresponding S21 response

**Wideband matched LNA:** In the LNA architecture shown in Fig.5, input is matched by a third order band-pass filter of bandwidth 3-5 GHz. The output of the LNA is tuned by a π-type stagger tuned band-pass network. The alternative of using one output network per channel has also been studied. The simulated LNA has a gain about 7.5 dB (Fig.6) over a range of 3 to 5 GHz drawing a current of 5 mA from a 1.8V supply. S11 is less than -12dB and the noise figure lies between 2 to 4 dB.

## SECTION III: CARRIER GENERATION FOR MULTI-BAND OFDM

Multi-band OFDM [1] is one of the emerging choices to implement UWB systems. While there has been a deluge of publications on the communication aspects, few deal with the front-end design and even fewer with the problem of multi-carrier generation. The standard divides the entire UWB band ranging from 3.1 to 10.6 GHz into 14 sub-bands each 528 MHz wide, supporting data rates of 53.3, 80, 106.7, 160, 200, 320, 400 and 480 Mb/s. While the first three bands are mandatory, rest are kept optional to provide flexibility to cope with regulation standards worldwide.

Multi-band OFDM requires generation of a set of frequencies spaced by 528 MHz(=2*264 MHz) starting from 3.432 GHz. Additionally the carrier generation scheme must support band to band switching time of less than 9.5 nS. This low switching time requirement discards a single PLL based implementation. Using dedicated PLLs [6] for each band followed by multiplexers provide spectrally clean carriers but at the cost of more hardware and power consumption. A proposed solution uses multiple dividers and SSB mixers following a PLL to generate the required carriers for the first three mandatory bands [7]. But at high frequency the dividers and the mixers consume a lot of power. Also extending this to other bands will require more hardware and problems of I-Q imbalance will appear after the signal passes through a number of mixers. An alternative scheme

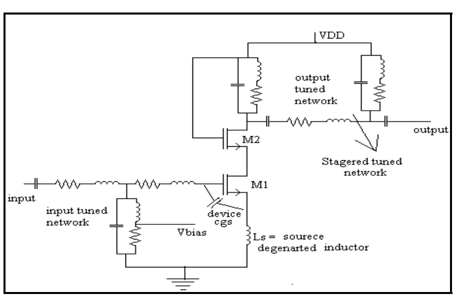


Fig.5. Wideband LNA schematic

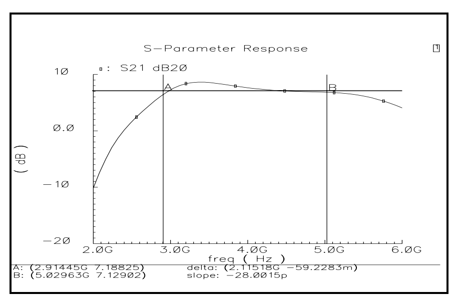


Fig.6. S21 response of the wideband matched LNA

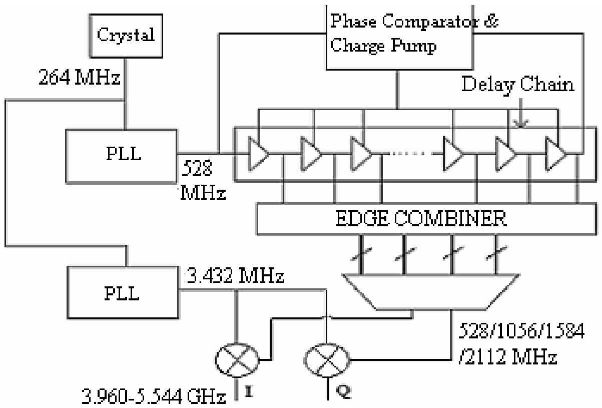


**Fig.7. Block Diagram of the carrier generation scheme for OFDM**

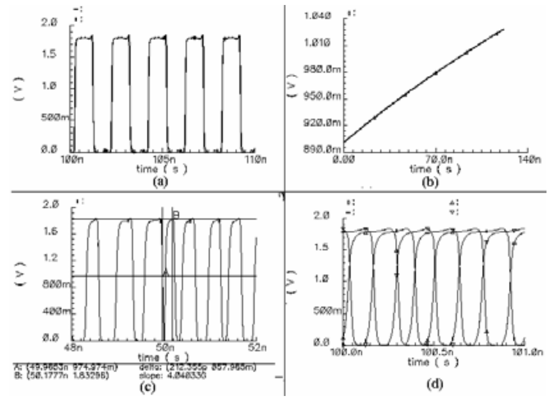


**Fig.8. Transient responses**

based on two PLLs operating at 3.432 GHz and 528 MHz and frequency multiplying DLL (MDLL) at 528 MHz has been implemented (Fig.7). The DLL has 24 differential delay stages. The output from the delay chain is locked with the input clock, effectively generating 24 equally phase shifted signals within the 0 to 2π range. These signals are then combined using an edge-combining circuit to produce signals with frequencies which are multiples of the input frequency. The delay cell is implemented using CML logic [8] and uses replica biasing to get better rise fall time symmetry. Moreover, quadrature signals for each output frequency are generated by combining different phase shifted versions of the signals. But for this the number of delay cells has to be a multiple of four. Using the present scheme, quadrature signals at 3.432 GHz, 3.960 GHz, 4.488 GHz, 5.016 GHz and 5.544 GHz can be produced conveniently. This choice is for the ease of subsequent filter implementation. A better choice is the mid-band frequency for up and down conversion as necessary, covering almost the entire UWB band.

Fig.8.(a) shows the DLL input and output in locked condition, (b) is the plot of the delay control voltage with time, switching from 1.5 GHz to 2 GHz is shown in (c) and (d) shows the quadrature signal waveforms. Since all the signals are being generated simultaneously, the switching time from one frequency to another is primarily dominated by the multiplexer and is below 1 ns. The total power consumed is around 50 mW. The scheme also can easily be extended to cover the entire UWB band with required number of multiples of the input frequency. The design was based on a tested MDLL chip.

SSB mixing ideally requires sinusoidal inputs for proper operation. Harmonics present in the square waveforms available from the DLL give rise to undesired components at the output of the up-converter. The DLL outputs can be passed through a frequency selective network to cut off the harmonics [8]. But that again requires lot of hardware and die-area for on-chip implementation. Fortunately most of the undesired components fall outside the 3.1 – 10.6 GHz band and hence can be filtered out producing near sinusoid carriers at the output.

## SECTION IV: SHORT PULSE GENERATION

Pulse generators for UWB impulse radio are designed to meet requirements of wide specified spectral mask and short duration to ensure high time resolution. The pulses may be designed directly at RF or at video for modulating a carrier at the mid-band frequency. For multi-user applications a set of low cross-correlation signals may be generated by computing the correlation function corresponding to the spectrum desired and finding the eigen vectors with large eigen values [9]. For the video case the modulating waveforms are derived by using weighted sums of the outputs of differential amplifier with thresholds chosen to ensure necessary zero crossings or sine wave synthesis. Direct RF generation is based on summation of Fourier terms and cancellation using delayed replica, all utilizing lumped equivalents of short circuited or open circuited transmission lines [10].

Perhaps the simplest way to generate a short duration pulse is to excite a step recovery diode by a sine wave or a wider pulse obtained from a DLL, a ring oscillator and pulse shaper, a tunnel diode pulse shaper or a distributed amplifier pulse regenerator. As is well known, the transition from the conducting to non-conducting states of the reversed biased step diode occurs in a time of typically less than 100 ps and the current waveform has a high harmonic content and can be used for generating short pulses. Fig.9 shows the waveform obtained using a shaped square pulse input and a short circuited line in parallel with the load. The equivalent pulse duration of the bipolar pulse can be controlled by varying the length of the short circuited line.

Distributed amplifier based pulse regenerator deserves special mention as it in conjunction with a counter operating a gate enables realization of PPM. The pulse generation consists of a distributed amplifier with a short circuited transmission line as load and a delay line feeding the reverse output to the gate line [3,11]. An excitation by a short trigger pulse to an auxiliary transistor produces a negative going output in the drain line. This is inverted by the short circuited line. The positive going

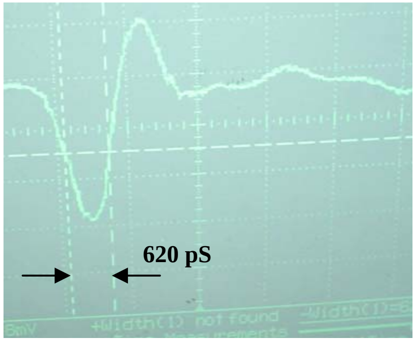


Fig.9. Pulse generated by SRD

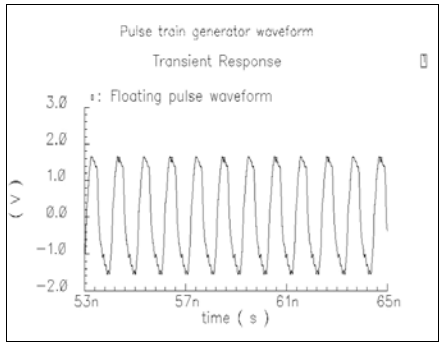


Fig.10. Waveform from pulse regenerator

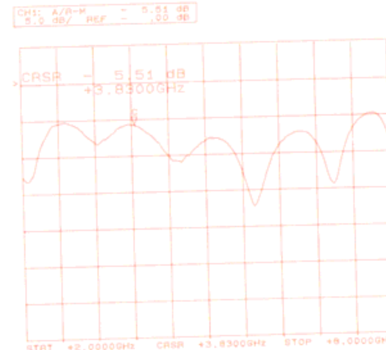

Fig.11. S11 of wideband antenna

output drives the gate line thus ensuring regeneration when the gain is adequate. Time span between regenerated pulses depends on the delay. A typical simulated waveform is shown in Fig.10.

## SECTION V: WIDEBAND ANTENNA

Wideband antennas are an integral part of both impulse carrier and multi-band OFDM. A planar wideband monopole antenna which was modeled on a volcano-smoke antenna was fabricated on a glass epoxy substrate with thickness of 1/16 inch and a dielectric constant of 3.4. The feed to the structure was a coplanar waveguide. The measured S11 in the 2-8 GHz range is shown in Fig.11. The gain pattern was also measured in two planes with this antenna as a radiating antenna and a horn antenna as receiver. A circular disc monopole was also designed fabricated and tested .The return loss has been found to be less than 11 dB over the frequency range of interest and the radiation pattern meets the specifications.

## SECTION VI: CONCLUSION

The present study on RF front-end is based on intrinsically wideband circuits suitable for both impulse radio & multi-band OFDM. Design and CMOS implementation of wideband LNA for UWB and simulation results have been presented. An approach for implementing carrier generator for multi-band OFDM has been described. Results of studies relating to short pulse generation and antenna for UWB have also been presented. It may be worthwhile to compare the design of OFDM carrier generator and LNA described in [6] with the present work. The intrinsically wideband grounded gate LNA and matched LNA described in this work have better noise performances. The scheme for carrier generation in this work requires two PLLs at 528 MHz and 3.432 GHz and a DLL; and switching takes place at the output of the DLL. These features together with the ease of extension to multiple bands make the design attractive.

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**References:**

[1] Multiband OFDM Alliance, http://www.multibandofdm.org
[2] T.T.Y. Wong,"Fundamentals of Distributed Amplification",*Norwood, MA: Artech* (1993).
[3] A. Ghosh, B.G. Perumana, A. Dutta, P. Sen, Y. Kumar, V. Garg, T.K. Bhattacharyaya, N. B. Chakrabarti, "Design and Implementation of 935 MHz FM Transceiver for Radio Telemetry and 2.45 GHz Direct AQPSK Transmitter in CMOS" *17th IEEE International VLSI Design Conference*, Mumbai, 2004.
[4] Y. Kumar, N.B. Chakrabarti, "Design and Implementation of CMOS Distributed Mixers and Oscillators for Wide-band RF Front-end", *IEEE International Symposium on Circuits and Systems (ISCAS)*, 2004.
[5] R. C. Liu, C. S. Lin, K. L. Deng, H. Wang, "A 0.5-14 GHz 10.6 dB CMOS Cascode Distributed Amplifier," in *Symposium on VLSI Circuits Digest of Technical Papers*, 2003, pp. 139-140.
[6] B. Razavi, T. Aytur, H. C. Kang et al., "A 0.13µm CMOS UWB Transceiver", *IEEE ISSCC 2005*,
[7] A. Batra, J. Balakrishnan and A. Dabak, "Multi-Band OFDM: A new approach for UWB," in *Proceedings ISCAS,* May 2004, Volume 5, pp. 365-368.
[8] G. Chien and P. Gray, "A 900MHz local oscillator using a DLL-based frequency multiplier technique for PCS applications," *IEEE JSSC*, vol.35, No.12 December 2000, pp. 1996–1999.
[9] D.Slepian & H.O.Pollock "Prolate Spheroidal Wave-function, Fourier Analysis & Uncertainity", *Bell Systems Tech. Journal*, January 1961.
[10] N.B.Chakraborti, "Generation of pulse-like functions by means of lumped equivalents of delay lines", *IEE Monograph* No 471E, Oct 1961.
[11] L. Divina, Z. Skvor, "The Distributed Oscillator at 4 GHz," in *IEEE Transactions on Microwave Theory and Techniques"*, December 1998, pp. 2240-2243.