Nomadic Base Station (NBS): a Software Defined Radio (SDR) based Architecture for Capacity Enhancement in Mobile Communications Networks

E. Adetiba[1], V.O. Matthews[1], S.A. Daramola[1], ,
I. A. Samuel[1], A. A. Awelewa[1], M. E.U. Eleanya[2].

[1]Department of Electrical & Information Engineering, College of Science & Technology, Covenant University, Ota, Ogun State, Nigeria.

[2]Chevron, 2,Chevron Drive, Lekki Peninsula, Lagos, Nigeria.

Abstract **- In this research work, the problem of congestion that leads to dropped calls at GSM cell sites and drastic reduction in network capacity is addressed. We designed a novel GSM base station architecture named Nomadic Base Station (NBS) which is based on Software Defined Radio (SDR) architecture and simulated the LNA for its receiver front-end. The NBS receiver LNA selects and amplifies GSM signal bursts operating at 900MHz and 1800MHz Radio Frequency Band. The later stages translate the Radio Frequency (RF) signal to Intermediate Frequency (IF) signal. This implements the SDR technology by digitizing the IF signal into bit streams that can be processed on generic Central Processing Unit (CPU) using custom written signal processing software.**

Keywords: Nomadic Base Station (NBS), GSM, LNA, MOSFET, CPU, SDR

I. INTRODUCTION

Global System for Mobile (GSM) communications, although a second generation cellular wireless technology, is still the dominant mobile communication system in Africa and so many other third world countries. Degradation of quality of service in GSM networks is a regular source of concern among consumers and regulators in these countries. This is due to factors such as capacity limitation, interference, unfavorable propagation conditions, blocking and etc.

Hitherto, to increase capacity given a limited bandwidth, Frequency Re - use is often implemented by radio frequency engineers. In Nigeria for instance, Frequency Re - use is a way of planning the re -use of the frequencies assigned to every operator by Nigerian Communications Commission(NCC). For example, the maximum available frequencies on 1800 band in Nigeria must be shared amongst MTN, Zain, Globacom, M-Tel and others, hence the need for re -use. The pattern employed by MTN GMS operator is 4 X 3 i.e. re -use frequencies after every 4 sites with 3 cells each (Fig. 1). Meanwhile, in this scheme, there is no consideration to cater for traffic congestion due to overpopulation.

However, this work focuses on capacity limitation at base stations due to overloading caused by heavy traffics that often occur during special events in GSM network cells. Such cells are sporting events at stadia, markets at big cities, Moslem praying grounds, Christian camps and etc. The heavy traffic generated at these special events usually exceed the bandwidth capacity of the existing base station, hence a high Dropped Calls Rate (DCR) is experienced. We designed the architecture and simulated the LNA for the receiver front-end of an ad hoc base station tagged Nomadic Base Station (NBS). NBS could be deployed to overpopulated cell sites to mitigate service degradation and improve the cell capacity. It is dual-band so as to cover the full GSM spectrums which are 900MHz and 1800MH. NBS architecture and design fully complies with the European Telecommunications Standard Institute (ETSI) specifications for GSM.

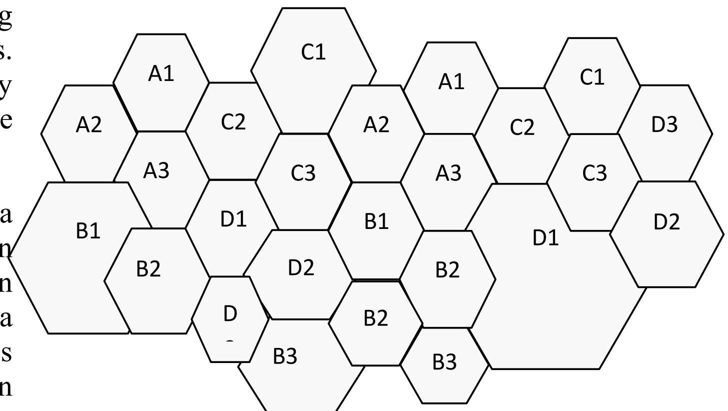

Fig. 1. MTN (Nigeria) 4 X 3 Frequency Reuse Pattern.

There are two possible radio architectures that could be adopted to realize the capacity enhancements, the ETSI GSM standards and functional requirements of NBS. These architectures are hardware radio architecture and software radio architecture. As communications technology continues its rapid transition from analog to digital, more functions of contemporary radio systems are implemented in software, leading towards the software radio architecture [4],[5]. Because of its flexibility, compactness, scalability, cost, portability and several other advantages over the hardware architecture counterpart, Software Defined Radio (SDR) architecture was adopted for the architectural design of NBS.

The architecture of SDR is presented in section II. A description of the system architecture of NBS is given in section III.

Section IV presents the internal and component based structure of NBS. In sub-section IV (A.), we present the analysis and design of NBS low noise amplifier while the calculations and simulations results are presented in sub-section IV (B.) Finally, the concluding remarks are presented in section V.

II. SOFTWARE DEFINED RADIO (SDR) ARCHITECTURE

SDR is the technique of getting code as close to the antenna as possible. It turns radio hardware problems into software problems. The fundamental characteristic of software radio is that software defines the transmitted waveforms, and software demodulates the received waveforms. This is in contrast to most radios in which the processing is done with either analog circuitry or analog circuitry combined with digital chips. Software radio is a revolution in radio design due to its ability to create radios that change on the fly, creating new choices for users. At the baseline, software radios can do pretty much anything a traditional radio can do. The exciting part is the flexibility that software provides us with[1],[5]. The block diagram for a Software Defined Radio Architecture (SDR) is shown in Fig. 2.

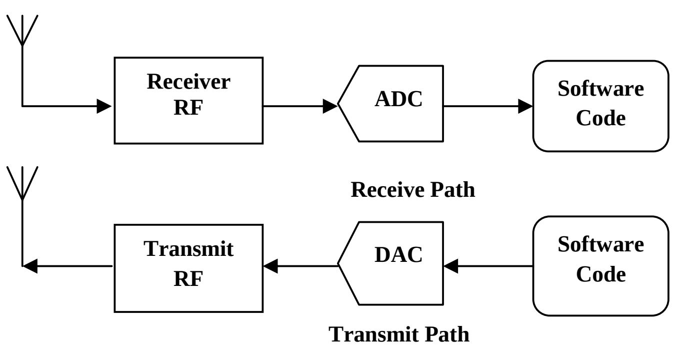

Fig. 2. Software Defined Radio (SDR) Block Diagram

III. NOMADIC BASE STATION (NBS) SYSTEM ARCHITECTURE

Given all the benefits of software radio architecture over its predecessor (i.e. traditional radio architecture), NBS adopts this architecture and design approach. The block diagram which shows the RF transceiver front end and the software code back-end is shown in Fig. 2.

Each of the blocks shown in Fig. 3 depicts a combination of signal processing functions which could be implemented with specific electronic components or software codes. The parameter of each of the components or code is tuned appropriately in order to achieve an optimum output from each block which serves as input to the next block for further processing [3]. The component level block diagram for the NBS is shown in Fig. 4.

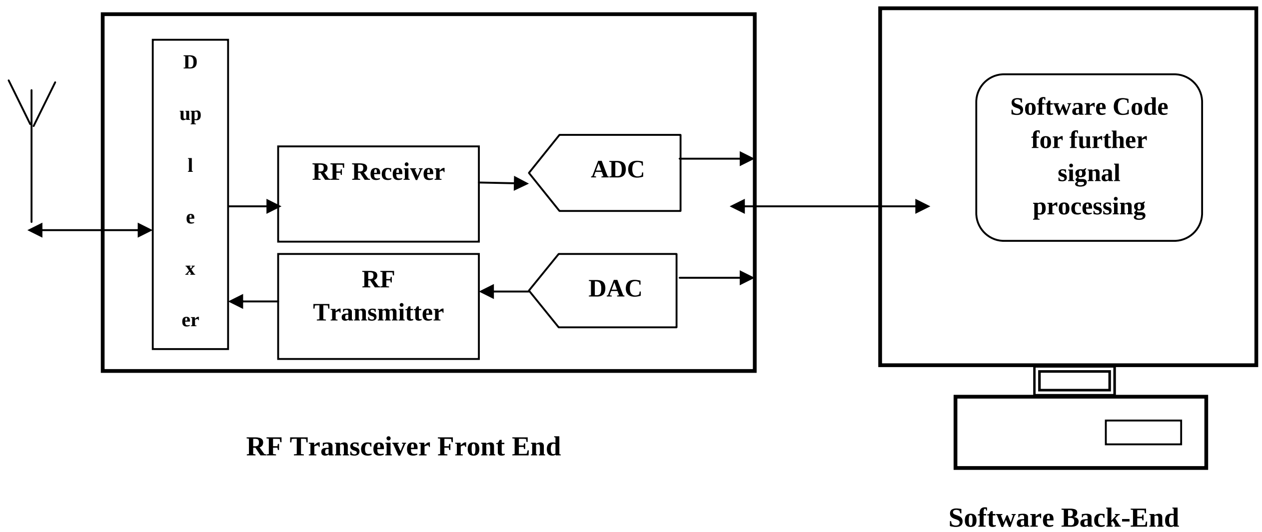

Fig. 3. Nomadic Base Station (NBS) System Architecture

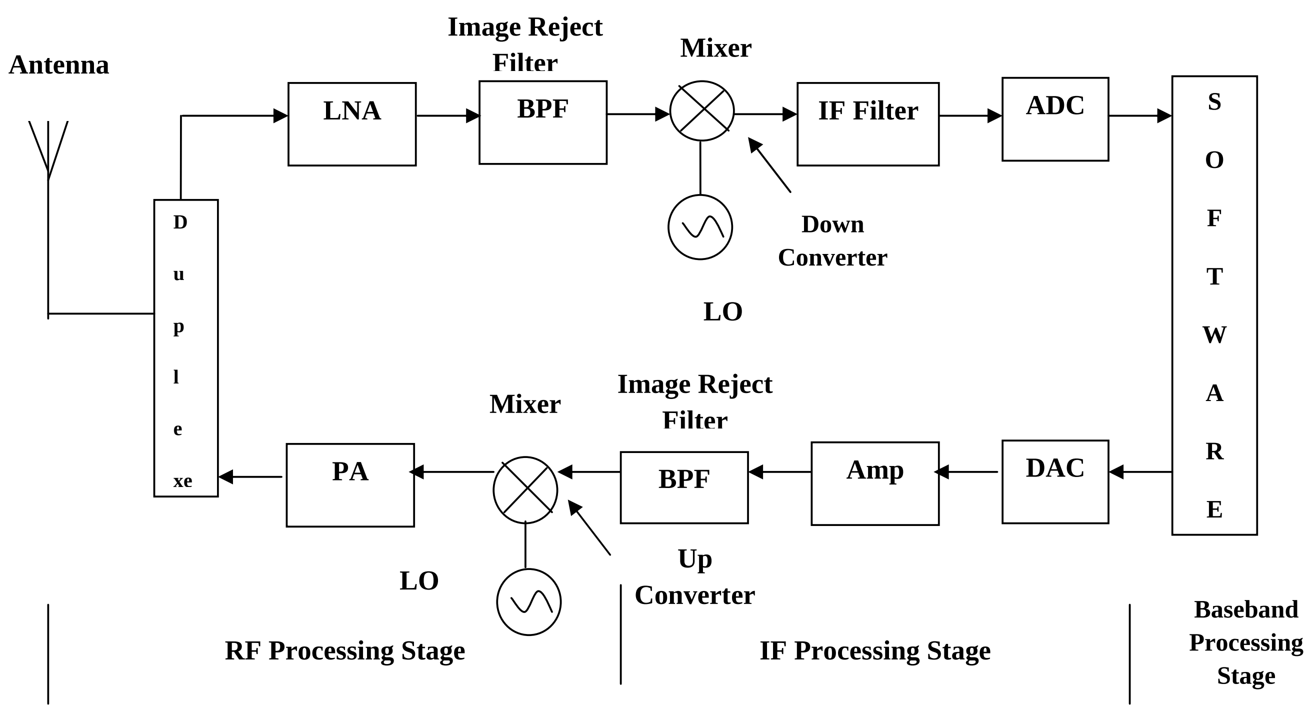

Fig. 4. Nomadic Base Station (NBS)

Component Level Blocks

IV. NOMADIC BASE STATION (NBS) TRANSCEIVER STRUCTURE

The system has two major signal paths which are Receive Path and Transmit Path as shown in Fig. 4. The Receiver front-end LNA is designed, simulated and varying amplification levels achieved for different drain currents (Id) in the amplifier.

TABLE II STANDARD SPECIFICATIONS FOR GSM LNA

(Source: http://www.etsi.org)

S/N	PARAMETERS	SPECIFICATION
1	Operating Frequency	900MHz and 1800MHz bands
2	Gain	>20dB
3	Noise Figure	< 4dB
4	IIP3	≈-8dBm
5	Input Matching	50 Ohms
6	Stability factor	Should be unconditionally stable

A. Low Noise Amplifier (LNA) Analysis and Design

LNA is the first stage of radio receiver whose main function is to amplify the signal while adding as little noise as possible[2]. Table 1 shows the standard specifications for GSM receiver's LNA.

In LNA receiver, signal coming from antenna is very small which is -100dBm (3.2µV) to -70dBm(0.1mV). Based on this, amplification is needed for the mixer stage to handle a reasonable signal magnitude. The received signal should have certain SNR to be reliably detected. Noise comes from the environment and the circuit itself. Noise floor is determined by thermal noise and system bandwidth (see equation 1.0) and the noise that is added by the LNA circuit should be as small as possible. Also, large signal or blocker can occur at the input of LNA and large signal performance of LNA should be good enough so as to minimize distortion of the desired signal. Active RF devices like LNA can be considered non-linear in operation and it can generate undesirable spurious signal when driven by large input signal. Non-linearity result in intermodulation distortion, desensitization, blocking and cross modulation [2], [7].

Gain and low noise are critical parameters in LNA design because its noise factor directly appears in the total noise factor of the receiver and ultimately impacts the sensitivity of the receiver (see equation 4.0). Also, LNA's gain suppresses the noise in the subsequent stages in the receiver's chain.

$$\text{NoiseFloor (dBm)} = -174\text{dBm} + 10\log BW \quad (1.0)$$

Noise factor (F) of receiver with cascaded sub-components is given as:

$$F_{total} = F_{LNA} + F_{afterLNA} / G_{LNA} \quad (2.0)$$

$$\text{Noise Figure}_{total} = 10 \log_{10} F_{total} \quad (3.0)$$

$$\text{Receiver Sensitivity} = \text{Noisefloor (dBm)} + \text{SNR} + \text{Noise Figure}_{total} \quad (4.0)$$

For GSM communications; Narrow Band (NB) LNA are typically used. The inductive source degenerated MOSFET LNA which is a narrow band LNA is considered the optimum choice due to its low noise figure and good gain**.** The impedance matching and power gain of this LNA are usually optimized at one frequency. Also, the output load stage and the input matching of inductive source degenerated MOSFET LNA usually involve LC networks hence low noise figure is attainable. To enhance the performance of our design, differential cascade source-degenerated LNA topology, which uses the inductive source degenerated MOSFET LNA is adopted. This topology is shown in Fig. 4. [2],[6].

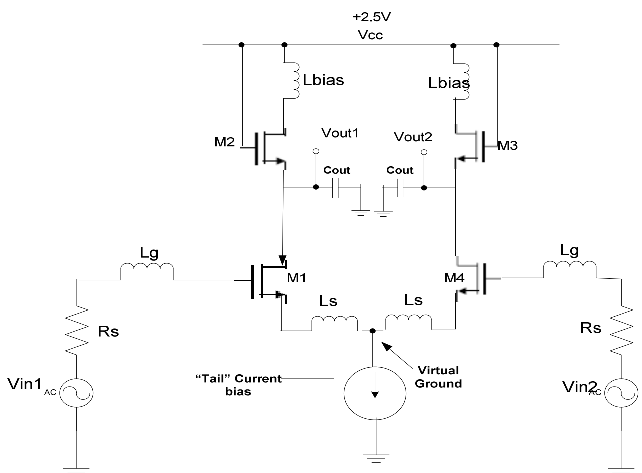

Fig. 5. Differential Cascade Source-Degenerated LNA Topology

TABLE 2 LNA CALCULATED COMPONENTS' PARAMETERS

S/N	**LNA Components' Parameters**	**GSM 900 Values**	**GSM 1800 Values**
1	Zin	50 ohms	50 ohms
2	ω_T(Cut-Off Frequency)	1.0×10^{11} rad/sec	11.81×10^{9} rad/sec
3	ω_0(Center Frequency)	5.8×10^{9} rad/sec	11.28×10^{9} rad/sec
4	Q_L(Optimal Q of inductor)	2.02	2.02
5	Ls	0.5nH	4.2nH
6	Lg	0.17nH	4.75nH
7	Cgs	0.44pF	87.81pF
8	Lmin(CMOS minimum length)	0.18µm	0.18µm
9	W(CMOS minimum Width)	43.55nm	0.87nm
10	gm	0.04A/V	0.04A/V
11	Veff	0.6mV	0.03V
12	Vg	521mV	550mV
13	I_D	0.012mA	0.6mA
14	NF(Noise Figure)	1.76dB	2.03dB
15	L_{bias}	0.74nH	0.2nH
16	A_{LNA} (Gain)	40.26dB	34.52dB

B. Calculations and Simulation Result

Table 2 summarizes the calculated parameters for the components shown in Fig. 5. for GSM at both 900MHz and 1800MHz. The simulation output of the LNA (i.e.Vop versus Frequency with varying Id-30mA-60mA) using Multism circuit simulation software is shown in Fig. 6.

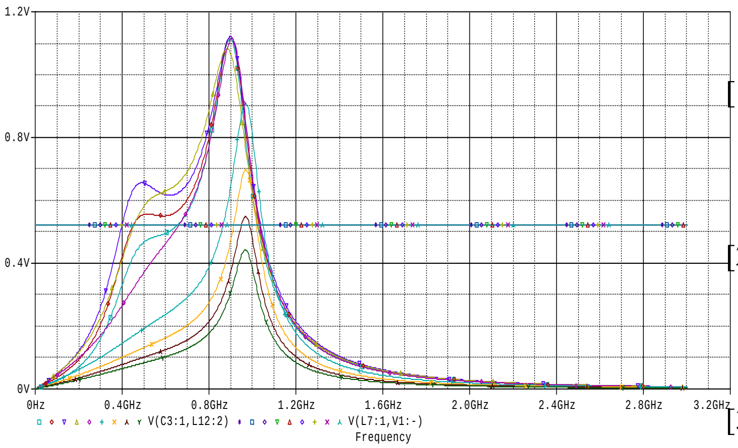

Fig. 6. Simulation Output of the LNA (Vop versus Frequency with varying Id-30mA-60mA)

V. CONCLUSION AND FUTURE WORK

In this research work, the LNA of the receiver front-end of NBS (a novel system that can reduce Dropped Calls Rate (DCR) has been designed and simulated. Since an appreciable amplification is obtained, this impacts sufficiently on the network capacity when NBS is introduced to a congested GSM network cell. The design fully complied with ETSI GSM standards so as to achieve interoperability with existing GSM infrastructure in any part of the world and by any manufacturer. Software Defined Radio (SDR) approach helped to achieve a highly modular architecture which permits continuous development of other modules of NBS and extension of the functionalities to cater for 3G/4G standards and still maintain backward compatibility with GSM. The simulation result of the designed LNA shows that varying degree of amplifications are obtained when the drain current is varied, hence, the LNA is tunable to achieve a desired level of amplification.

REFERENCES

[1] Adetiba E. Design and Simulation of Nomadic Base Station Receiver Front-End for GSM, May 2007. M.Eng. Thesis, Covenant University, Ota, Nigeria.

[2]Agboje E. Mobile and Personal Communications. Unpublished M.Eng. Lecture Note, Covenant University, Ota, 2006.

[3] Ericsson, *GSM RBS 2000 Basics*, Student Text EN/LZT 123 3805 R2A. 1998.

[4] ETSI SMG Tdoc SMG2 UMTS D 9/97, Concept Group Delta Wideband TDMA/CDMA Evaluation Report-Part v0.2

[5] Joe Mitola 1995. The Software Radio Architecture. IEEE Communications Magazine. 33 (5), 26-38.

[6] Michel D. Y. WIRELESS TECHNOLOGY Protocols, Standards, and Techniques. CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida, 2002.

[7]Theodore S. R. Wireless Communications Principles and Practice. Publishing House of Electronics Industry, Beijing, 1998.