Approach Towards Energy Efficient Power Amplifier for 4G Communications

Approach Towards Energy Efficient Power Amplifier for 4G Communications

Abubakar Sadiq Hussaini[#*1], Raed Abd-Alhameed[#2], Jonathan Rodriguez[*3]

[#]School of Engineering, Design and Technology, University of Bradford, UK
Email: [1]ashussaini2@bradford.ac.uk, [2]r.a.a.abd@bradford.ac.uk

[*]Instituto de Telecomunicações – Aveiro, Portugal
Email: [1]ash@av.it.pt, [3]jonathan@av.it.pt

***Abstract*—The biggest challenge for future 4G systems is the need to limit the energy consumptions of battery-powered and base station devices, with the aim to prolong their operational time and avoid active cooling in the base station. The green wireless communications requires research in areas such as energy efficient RF front end, MAC protocol, networking, deployment, operation, and also the integration of base station with renewable power supply. In this paper, the design concept of energy efficient RF front end is considered in terms of RF power amplifiers at which it represents the workhorse of modern wireless communication systems and inherently nonlinear. The approach of output power back off is to amplify the signal at the linear region to avoid distortion, but this approach suffers from significant reduction in efficiency and power output. To boost the efficiency at wide range of output power and keep the same margin for signal with high crest factor, the load modulation technique with new offset line are employed to operate over the frequency range of 3.4GHz to 3.6GHz band. The performances of load modulation power amplifier are compared with balanced amplifier. The results of 42dBm output power and 62% power added efficiency are achieved.**

***Index Terms*— Balanced amplifier; load modulation RF power amplifier; OFDM; 4G**

I. Introduction

The approach towards energy conservation and CO_2 reduction in 4G communications will require a lot of effort form physical layer to upper layers. As of today information and communication technology accounted for 3% and 2% global power consumption and global CO_2 emissions respectively. Corporate social responsibility for international efforts against climate change, targets set to reduce carbon emissions and environmental impacts of networks. Therefore, there's need at both terminal and base station, to take a more holistic approach for improving or achieving green communications, right from radio operation, functionality, up to the implementation. 4G devices should be reconfigurable for multi-standard radios; that will scan the available spectrum and change its network parameters (frequency, bandwidth, modulation) for maximum data transfer, highly integrated, power efficient, and low cost. The 4G networks will provide mobility and connectivity at all the time, putting the priority of data over voice; as a result of this it needs higher modulation scheme to accommodate data. However, 4G adopts Orthogonal Frequency Division Multiplexing (OFDM), with modulations from QPSK to 64-QAM, and has crest factor around 9dB-12dB. This wideband digital modulation scheme offers high data rates and resilience to multipath effects. However, the scheme is critically dependent on linearity in the hardware system due to its inherently high crest factor and also affects the RF power amplifier efficiency. To support the proposed data services, the base station and the user terminal itself must be able to handle higher data rates. Achieving high efficiency and good linearity simultaneously in power amplifier design are the most challenging task.

The 4G offers a higher data rate but unfortunately at the expense of more power consumption. The transmitted power of base station increase exponentially as the data rate increase, from the baseband unit, the radio and the feeder network, the radio consumes more than 75% energy of the base station's energy need and 60% consumed by power amplifier alone. The power amplifier consumes the highest power at the base station and converts more than 50% of what it consumed into heat as a waste. This paper explores the energy efficient power amplifier. The efficiency and the output power of the load modulation power amplifier have been achieved and the results show significant improvement over balanced RF power amplifier.

II. Conventional Balanced and Load modulation circuit architecture

The conventional balance and load modulation amplifiers exploit the Freescale N-Channel Enhancement-Mode Lateral MOSFET MRF7S38010HR3 transistor. The balanced amplifier was first proposed to improve efficiency of 3G base station, is designed to work over a given dynamic range where the amplifier should behave linearly. Conventional balanced amplifier was commercially successful 2G/3G base station amplifiers. However, there are some problems that limit the balanced amplifier for use as power amplifier for 4G communications. Balanced amplifier can be realized by combining two class AB amplifiers as shown in Figure 1. The splitter divides the input signal equally with 90 degree phase-shift, after the input matching circuitry the signals are fed to the transistors' gates. With the proper biasing of VGS both class AB amplifiers are set to conduct in the positive cycles, the signals from the drain of the transistors are also

90 degree in phase and feed into the combiner and at the output, combiner combines the signals un-phase-shift, and full sine wave. While load modulation can be realized by combining carrier class AB and peaking class C amplifiers as shown in Figure 2. The splitter divides the input signal into two equal magnitude but 90 degree phase difference. At the output a microstrip quarter wave impedance inverter combines the signals. The concept of load modulation technique has been fully explained by the present authors of their previous work in [2]. Load modulation power amplifier improves the efficiency and the linearity by complementing the saturation class AB amplifier with the turn on characteristic of class C amplifier.

The design comprises of step-by-step procedure for the optimum design of energy efficient power amplifier, the proposed additional of 90 degree offset lines at the output and input matching network for which will prevents power leakage at the output junction between the output impedance transformer and peaking Class C amplifier. The gate biases and the individually matchings of class AB and class C amplifiers are further optimized to achieve high efficiency, linearity and wideband characteristics. The peaking amplifier allows the load modulation amplifier to respond to the high input levels of short duration, by amplifying the signal peaks, and to dynamically change the load impedance of the main class AB amplifier.

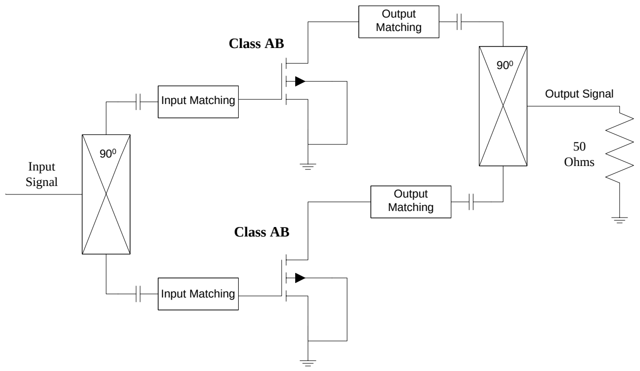


Figure 1. Balanced amplifier configuration

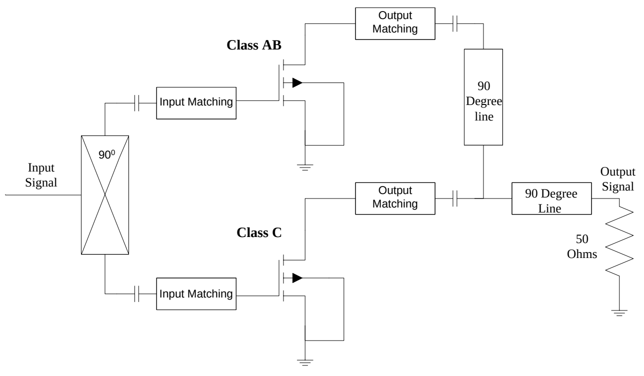


Figure 2. load modulation amplifier configuration

III. Design Layout and Results

The conventional balanced and load modulation amplifiers are fabricated with RT 5880 substrates, H=0.5mm and relative permittivity of 2.2. Figure 3 and 4 shows the layout of conventional balanced amplifier and load modulation amplifier respectively. Figure 5 and 6 shows the simulated linear performance of the balance and load modulation amplifier respectively, the gain is flat in the range of 3.47 to 3.53 GHz with excellent input and out put return losses.

The non-linear simulations and the comparisons of conventional balanced and load modulation amplifiers are performed. The bias conditions used in this experiment are shows in table 1, for balanced amplifier while in table 2; represent that of load modulation amplifier. The drain bias voltage VDS = 30V for both two transistors of balanced and their gate voltage is VGS = 3V. The drain bias voltage of load modulation amplifier is VDS = 30V for both carrier and the peak transistors, while their respective gate bias voltages are VGS (Carrier) = 3V and VGS (Peaking) = 2.2V. Figure 7 represent the comparison of the variation of the input power versus output power of both balanced and load modulation amplifiers. It clearly shows that 42dBm output power is achieved at the linear region of both amplifiers. Figure 9 represent the transducer power gain versus output power. The load modulation has less gain compared to balanced amplifier; this is due to the fact that the peaking amplifier of load modulation is biased in Class C mode. Figure 10 shows the power added efficiency (PAE) versus output power of balanced and load modulation amplifier. From the graph one can be seen that the load modulation amplifier has a higher efficiency over the wide range of output power than conventional balanced amplifier. The PAE of 62% is obtained at 1dB compression point of 42dBm output power of load modulation amplifier while the PAE of 50% is obtained at 1dB compression point of 42dBm output power of conventional balanced amplifier.

The load modulation offers improved efficiency at the whole range of output power compared to conventional balanced amplifier. The heart of the load modulation is the load modulation output combiner and that is the fascinating part of the design, while the input behaves the same as a conventional balanced amplifier.

Table 1: Bias point setting for balanced amplifier

Drain Voltage (V)	**Class AB 1 VGS (V)**	**Class AB 2 VGS (V)**
30	3.0	3.0

Table 2: Bias point setting for load modulation

Drain Voltage (V)	**Carrier VGS (V)**	**Peaking VGS (V)**
30	3.0	2.2

Table 3: Performances of load modulation and balanced amplifiers

	Gain (dB)	**PAE (%)**
Balanced	19.5	50
Load Modulation	16.5	62

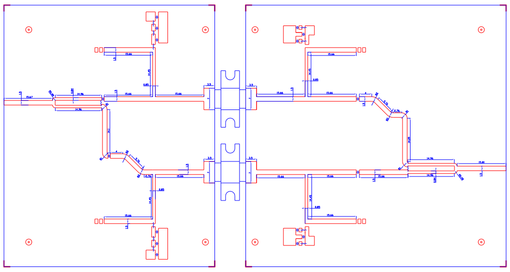


Figure 3. Design layout of Balance amplifier

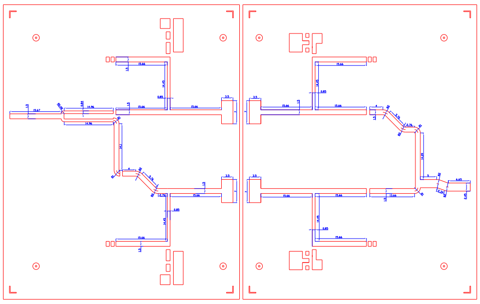


Figure 4. Design layout of load modulation amplifier

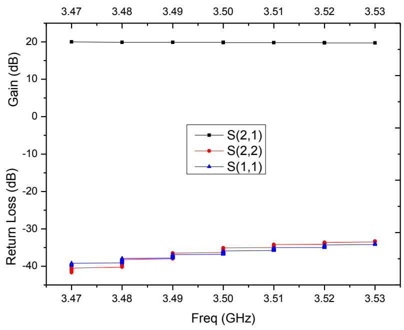


Figure 5. Linear similation of Balance amplifier

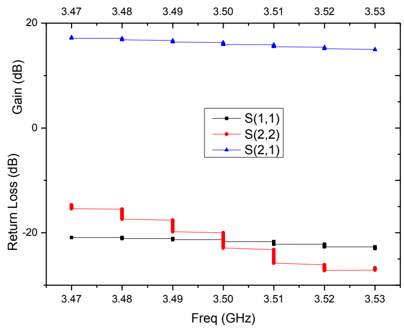


Figure 6. Linear simulation of load modulation amplifier

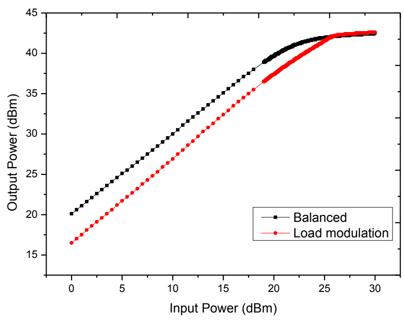


Figure 7. AM-AM responses

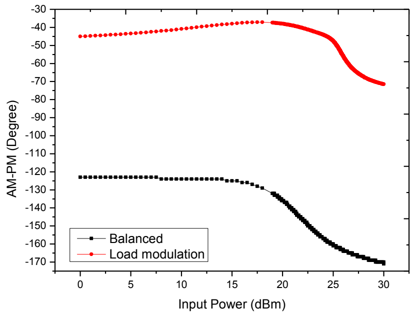


Figure 8. AM-PM responses

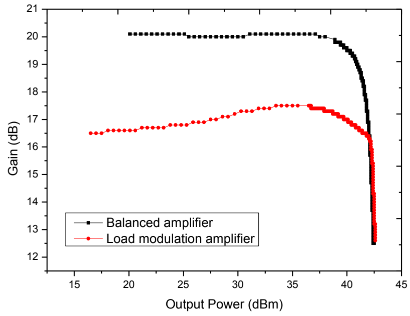


Figure 9. Transducer power gain

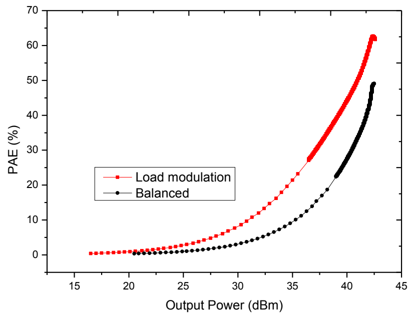


Figure 10. Power-Added Efficiency

IV. CONCLUSION

The performance comparisons between load modulation power amplifier and conventional balanced power amplifier are performed. The achieved results of the proposed design process have shown an excellent efficiency and power performances. The proper phasing of input signal splitter effectively contributed to the total efficiency of the system. The load modulation amplifier offers improved efficiency over wide range of output power compared to conventional balanced amplifier. The load modulation has less gain compared to balanced amplifier due the arrangement of lower biasing of Class C peaking transistor of load modulation. The operation of this design was strongly influenced by the coupling factor of the splitter, biasing of class AB and C amplifiers. Applying load modulation technique can significantly reduce the CO_2 emission and power consumption in the transceiver. The self-managing characteristic of the load modulation power amplifier has made its implementation more attractive.

ACKNOWLEDGMENT

This work has been performed in the framework of the C2POWER project (FP7/2007-2013) under the European Community, funded through the Seventh Framework programme (project n. 248577) and MOBILIA project (CP5-016) under the Eureka Celtic Framework, funded through the QREN Framework – PO Centro (project n. 5555).

REFERENCES

[1] W. H. Doherty, "A New High Efficiency Power Amplifier for Modulated Wave", Proc. IRE, Vol. 24, No. 9, PP. 1163– 1182, September, 1936.

[2] A. S. Hussaini, R. A. Abd-Alhameed, J. Rodriguez, "Implementation of Efficiency Enhancement Techniques in the Linear Region of Operations of Power Amplifier", 7th Conference on Telecommunications (Conftele2009), pp. 105-108, Santa Maria de Feira, Portugal, May 2009.

[LINK: http://www.av.it.pt/conftele2009/Papers/103.pdf]

[3] F. H. Raab, "Efficiency of Doherty RF Power Amplifier System", IEEE Trans. Broadcasting, Vol. BC-33, No 3, PP. 77-83, September, 1987.

[4] S.C. Cripps, Advanced Techniques in RF Power Amplifier Design, Norwood, MA: Artech House, 2002.

[5] S.C.Cripps, RF Power Amplifier for Wireless Communications, Norwood, MA: Artech House, 1999.

[6] D. M. Upton, P. R. Massey, "A New Circuit Topology to Realize High Efficiency, High Linearity and High Power Microwave Amplifiers", RAWCON '98 Proceedings, PP. 317– 320, August, 1998.

[7] S. M. Wood, R.S. Pengelly, M. Suto, "A high power, high efficiency UMTS amplifier using novel Doherty Configuration," in Proc. IEEE Radio Wireless Conf., Boston, MA, Aug. 2003, pp. 329-332.

[8] Y. Zhao, M. Iwamoto, L. E. Larson, P. M. Asbeck, "Doherty amplifier with DSP control to improve performance in CDMA operation", in IEEE MTT-S Int. Microwave Symp. Dig., 2003, pp. 687-690

[9] C. T. Burns, A. Chang, D. W. Runton, "A 900 MHz, 500 W Doherty power amplifier using optimized output matched Si LDMOS power transistors", IEEE MTT-S Int. Microw. Theory Tech., Symp. Dig., PP. 1557 – 1580, June, 2007.

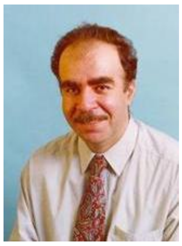
[10] Raab F.H., Asbeck P., Cripps S., Kenington P.B., Popovic Z.B., Pothecary N., Sevic J.F., Sokal N.O., "Power amplifiers and transmitters for RF and microwave", IEEE Transactions on Microwave Theory and Techniques, Vol. 50, No 3, PP. 814 – 826, March, 2002.

[11] K. J. Cho, J-H. Kim, and S. P. Stapleton, "A Highly Efficient Doherty Feed-Forward Linear Power Amplifier for W-CDMA Base-Station Applications," IEEE Trans. on MTT, Vol. 53, pp. 292 - 300, Jan. 2005.J. Groe, "Polar transmitters for wireless communications", IEEE Communications Mag., Vol. 45, No 9, PP. 58 – 63, Sept. 2007.

[12] P. B. Kenington, High- Linearity RF Amplifier Design, Norwood, MA: Artech House, 2000.

[13] C. F. Campbell, "A fully integrated Ku-band Doherty amplifier MMIC," IEEE Microw. Wireless Compon. Lett., vol. 9, no. 3, pp. 114–116, Mar. 1999.

Abubakar Sadiq Hussaini (S'05) Research Scientist / PhD in view: Instituto de Telecomunicações - Pólo de Aveiro / University of Bradford, United Kingdom; MSc in Radio Frequency Communication Engineering, University of Bradford, United Kingdom, 2007; Post Graduate in Electrical/Electronic Engineering, Bayero University, Kano, Nigeria 2003; Specialization in Microwave/RF power amplifiers design and Tunable Filters.
Technical Education: SDH Network Configuration Siemens (Information and Communication Network Training Institution Siemens), 2002; Telecomm Engineer, Nigerian Telecommunications Limited, Abuja, 2000; where I was responsible for the operations and maintenance of SRT 1F, SRT 1S, SRT 1 (Siemens Radio), Planning and implementing the provision and utilization of microwave radio transmission systems. Contribute article to numerous publications.
Award: Best Student, Newton Institute, Jos, 1993; Nominated in the 26th Edition of Who's Who in the World 2009; Member: Senate Committee of the University of Bradford-2007, IEEE, IET, Optical Society of America (OSA); Involved in European and CELTIC research projects. His research interests include Radio Frequency System Design and High-Performance RF-MEMS Tunable Filters with specific emphasis on energy efficiency and linearity.
Achievements: participation in process to produce energy efficient Power Amplifier at 3.5GHz (Mobile WiMAX Frequency); Designed and developed "Radio over Fiber" Optical transmitter and Optical Receiver (1550nm Wavelength) where investigated radio over fiber technology in which the frequency limitations of quantum well lasers in direct RF to Light transponding was investigated.



Professor Raed A. Abd-Alhameed received his PhD from Electrical and Electronic Engineering, Bradford University, UK, in 1997. From 1997 to 1999 he was a Postdoctoral Research Fellow at the University of Bradford, specialisation in computational modelling of electromagnetic field problems, microwave nonlinear circuit simulation, signal processing of preadaption filters for adaptive antenna arrays and simulation of active inductance. From 2000 to 2003 he has been a lecturer in the University of Bradford. In August 2003 he was appointed as a senior lecturer in applied Electromagnetics and then Sept 2005 to a Reader in Radio Frequency Engineering at the same University. Since Nov 2007 he was appointed as Professor of Electromagnetics and Radio Frequency Engineering in the school of Engineering, Design and technology, Bradford University. Abd-Alhameed is the Director of Mobile and Satellite Communications Research Centre, Leader of Communications Research group, and the head of the Radio Frequency, Antennas, Propagations and Computational Electromagnetiscs Research group including his appointment as a research visitor for Wrexham University, Wales, UK since 2009. He has worked on several funded projects from EPSRC, Dept. of Health, Mobile Telecommunications and Health Research Programme, EU FP5 and a number of industrial KTPs. He has published over 300 technical Journal and Conference papers including several book chapters. In addition, he holds two patents work on RF antenna designs. He has invited as keynote speaker for ITA 09, Mobimedia 2010, and he chaired the 1st EERT 2010 workshop and several sessions at many international conferences. He is also appointed as guest editor for IET SMT Journal special issue on EERT for 2011. In addition, he is invited to several IEEE, IET and International Journals for his successful research in radio frequency engineering. His current research interests include hybrid electromagnetic computational techniques, EMC, antenna design, low SAR antennas for mobile handset, bioelectromagnetics, RF mixers, active antennas and MIMO antenna systems. Prof Abd-Alhameed is Fellow of the Institution of Engineering and Technology, a Chartered Engineers and Fellow of Higher Education Academy.

Jonathan Rodriguez (M' 04) received his Masters degree in Electronic and Electrical Engineering and Ph.D from the University of Surrey (UK), in 1998 and 2004 respectively. In 2002, he became a Research Fellow at the Centre for Communication Systems Research at Surrey and responsible for managing the system level research component in the IST MATRICE, 4MORE and MAGNET projects. Since 2005, he is a Senior Researcher at the Instituto de Telecomunicações, Pólo de Aveiro (Portugal), where he is the project coordinator for the C2POWER project, technical manager of COGEU and technical workpackage leader in WHERE, HURRICANE, PEACE and MOBILIA. He was also the project coordinator of the Celtic LOOP Project. He is leading the 4TELL Wireless Communication Research Team at IT, author of several conference and journal publications, and has carried out consultancy for major manufacturers participating in DVB-T/H and HS-UPA standardisation. His research interests include Radio Access Networks for current and beyond3G systems with specific emphasis on Radio Resource Management, Digital Signal Processing and PHY/MAC optimization strategies.