Circuit and Module Challenges for 60 GHz Gb/s Radio.

J. Laskar, S.Pinel, C-H.Lee, S.Sarkar. B.Perumana, J. Papapolymerou, E.Tentzeris.

Invited paper

Georgia Electronic Design Center, School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta GA 30332-0269 USA

Fax:(404) 894-0222, Email: joy.laskar@ece.gatech.edu.

***Abstract*— The recent advances of CMOS and SiGe process technologies have now made the design of low-cost highly integrated millimeter-wave radios possible in Silicon. In combination with an optimum packaging approach, this represents a unique opportunity to develop Gb/s radio that could address the increasing demand in term of data rate throughput of the emerging broadband wireless communication systems. In this paper we discuss the circuit and module challenges that will enable a successful deployment of 60GHz gigabits wireless systems.**

Index Terms— *60 GHz, Gigabit wireless, CMOS SiGe, LTCC, LCP.*

I. INTRODUCTION

The demand for ultra-high data rate wireless communication systems is increasing daily with the emergence of a multitude of multimedia applications. In particular, the needs become urgent for ultrahigh speed personal area networking and point-to-point or point-to-multipoint data link. However the conventional WLAN systems (802.11a,b and g) are limited to a data rate of 54Mb/s (in the best case). Alternative solutions such as UWB and MIMO systems are investigated to extend the speed up to 100Mb/s. Still, to achieve data throughput exceeding the Gb/s, either the spectrum efficiency or the available bandwidth have to be increased. This demand has since pushed the development of technologies and systems operating at the millimeter-wave frequencies. This trend has also been reinforced by the exponentially growth of the emerging automotive collision avoidance radar applications.

Indeed, the availability of several GHz band-width unlicensed ISM bands in the 60GHz spectrum represents a great opportunity for ultra-high speed short-range wireless communications. The FCC has allocated the 59-64 GHz band for unlicensed applications in US. In Japan, 59-66 GHz has been attributed for high speed data communications. In Europe, the 59-62, 62-63 and 65-66 GHz bands have been attributed for mobile broadband as well as WLAN systems. The specificity of the 60 GHz spectrum is the attenuation characteristic due to the atmospheric oxygen absorption in the order of 10 to 15 dB/km over a bandwidth of about 8 GHz [1]. This attenuation precludes the long-range communications but provides an extra spatial isolation that is beneficial for frequency re-use in a dense local network, reduced co-channel interferences as well as an extra safety for secure short-range point-to-point link.

Since the mid-90's, many examples of MMIC chip-set have been reported for 60 GHz radio applications using GaAs FET and InP pHEMT technologies. Despite their commercial availability and their outstanding performances, these technologies struggle to enter the market because of their prohibitive cost and their limited capability to integrated advanced base-band processing. The combination, of a low cost highly producible module technology, featuring low loss and embedded function such as antenna, is required to enable a high volume commercial use of the 60 GHz systems.

The steadily increasing frequency ranges of CMOS and SiGe process technologies has now made the design of low cost highly integrated millimeter-wave radio possible in silicon. Chip-scale package, LTCC and organic based MCM module technologies have also been demonstrated as viable solutions for low cost high performance and highly functional packaging solution for high volume market. The optimum combination and co-design of these technologies (Fig.1) is the key for the successful deployment of ultra-high speed, high capacity, 60 GHz WLAN access for very dense urban network and hot spot coverage.

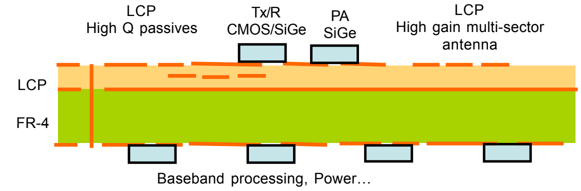

Fig.1 Concept view of a 60 GHz Gb/s radio module.

Many other commercial applications will directly benefit from this advance. This includes high data rate Wireless Multimedia Access, compact Wireless Gigabit Ethernet

0-7803-9068-7/05/$20.00 ©2005 IEEE

and Wireless FireWire/IEEE-1394 link that can be ultimately combined with a fiber or cable backhaul network.

II. SYSTEM ARCHITECTURE CONSIDERATIONS

The direct conversion architecture (as opposed to the heterodyne topology) using time-division duplexing appears to be the most attractive solution leading to the minimum cost, complexity and power. In addition, the implementation of very wide band direct modulator exhibiting very broad IF bandwidth (up to several GHz) would enable a straight forward interface to accommodate with a wide range of different scenarios such as 802.11 type and the FireWire/IEEE-1394 type of applications. Baseband filtering will help limit the transmitted power to enable channelization and meet the FCC requirement. Also, no image filtering, that could be very costly to implement at millimeter-wave frequency, is required.

Another key aspect of the front-end architecture is the frequency planning, i.e. the frequency synthesis combined with the mixing scheme. The direct mixing where the LO frequency is generated at around 60 GHz, or at a lower frequency and then multiplied, is now widely used. However, this approach has to face serious issues related to LO pulling and DC offset due to increased substrate and radiation coupling at the LO power level and frequency involved. A sub-harmonic mixing (X2 or X4) approach would avoid this issue while keeping the advantage of a low frequency synthesis and an easier PLL implementation.

The very wide bandwidth available at 60 GHz has enabled many examples of very high date rate wireless system using some very simple and low spectrum efficiency modulation such as ASK [2]. These systems offer many advantages such as low complexity and low cost implementation, less stringent specifications on the MMIC chipset (linearity, phase noise, etc…) and ease the interfacing to wire or to fiber data network. However, this approach suffers from limited receiver sensitivity, relatively poor SNR performances for a given data rate, and a poor immunity to received power drops occurring in LOS path obstructions. Hence, the BSPK and QPSK modulation schemes could partially overcome these disadvantages at the moderate cost of a slightly more complex architecture. In addition, the OFDM technique presents some advantageous properties beside a higher spectrum efficiency, such as an improved reliability of high speed transmission for a given Rms delay spread and Doppler effect compared to single carrier system. It also benefits of reduced co-channel interferences at 60 GHz due to the inherent free-space losses. The complexity of an OFDM modem to support a gigabits data rate is theoretically lower than the complexity of a single-carrier system with an equalizer, but its practical implementation still has to be demonstrated.

III. DEVICE TECHNOLOGY

The SiGe technology has advanced to a point that a complete chipset for 60 GHz application can be implemented using silicon. In a 0.12-μm SiGe technology it is now possible to achieve F_t ~ 205 GHz and F_{max} ~290 GHz [3]. A 60 GHz SiGe transceiver chipset has been reported recently [4] fully demonstrating the potential of this technology.

In parallel, recent modeling and circuits for millimeter-wave in 90-nm CMOS have shown that a successful implementation up to 60 GHz is possible for some circuits [5]. In a front-end architecture using a sub-harmonic approach, it appears that the 90-nm CMOS technology has the potential to be reasonably used for some circuits operating up to 30 GHz.

A. LNA

The SiGe HBT technology has demonstrated the best microwave noise performances of any bipolar technology to date. It is a natural candidate for the implementation of 60 GHz LNA. Single and multistage circuit topologies are required. The cascade topology using bipolar devices and the inductive degeneration technique leads to the best compromise between maximum gain and minimum noise figure. The input and output matching network are efficiently implemented using on-wafer transmission lines, open and shorted stubs in micro-strip or CPW configuration. The typical specifications are a gain of 15 dB, for a noise figure NF $\leq$ 4.5 dB, a DC power consumption $\leq$ 10 mW, and a linearity IIP3 $\geq$ -10dBm. In the receiver, a double or triple stage LNA may be required to provide enough gain and therefore enough sensitivity to the system.

B. MIXER AND VCO.

Both passive and active mixers can be considered for 60GHz systems. The active mixer approach benefits of an inherent gain that helps balancing the gain distribution along the transceiver chain. On the other hand, the APDP topology presents the inherent advantage of a very wide IF bandwidth (enabling a very high date rate transmission) and no power consumption, for a reasonable conversion loss (~10dB) in the x2 sub-harmonic scheme. This conversion loss remains acceptable and could be globally compensated, since the sub-harmonic approach does not require power consuming and noisy multiplier.

The implementation of 60 GHZ VCO has been demonstrated [6]. However, this approach will suffer from the LO pulling and DC offset due to increased substrate and radiation coupling at the LO power level and frequency involved. A sub-harmonic mixing approach might then be preferred and a VCO design below 30 GHz becomes sufficient. Also, the sub-harmonic approach requires a narrower tuning range of the VCO to cover the 60 GHz spectrum. Therefore, the VCO design can be better optimized for a low phase noise performance at low power consumption.

The recent advances in modeling and circuits for millimeter-wave in 90-nm CMOS [5] indicate that the implementation a wideband modulator and de-modulator integrated with 30 GHz VCO would be possible.

C. DRIVER AMPLIFIER AND POWER AMPLIFIER

The implementation of a 60 GHz driver and power amplifier in SiGe technology is one of the most challenging and critical designs of a gigabits radio transceiver. The typical performances achievable in SiGe technology are a gain of 10 dB, for a P1dB between 7 and 9 dBm, and DC power consumption below 250 mW.
A two stages topology, combined with an emitter ballasting technique to prevent thermal runaway appears as the most suitable approach. In the case of high data rate transmission, the linearity requirements are very stringent. In particular, if a modulation scheme such as OFDM is used, a differential architecture may be required to accommodate the large peak-to-average ratio. At last, due to the high frequency of operation the interconnection length (using wire-bonds) to the module is a very critical packaging issue, resulting in mismatches and losses.

IV. ANTENNA AND MODULE TECHNOLOGY

At 60 GHz the free space loss are much more severe than at the frequencies usually used for cell phone and wireless applications. According to the Friss formula, the link budget at 60 GHz is 21dB less than the one at 5GHz under equal conditions. This drawback can be compensated for by the use of a high gain, high directivity antenna. However, due the high absorption and the weak diffraction properties of millimeter-wave frequencies, such antennas become very sensitive to any LOS path obstructions that can result in a drastic drop of the received power and interrupt the communication. Omni-directional antennas offer an advantage in a reflective indoor environment. However, they usually exhibit a low gain that makes them inefficient for 60 GHz applications. An attractive solution to insure a robust wireless link suitable for an indoor WLAN scenario is the use of medium to high gain multi-sectors antenna [7].

At last, the packaging of the 60 GHz radio represents a major challenge. The LTCC technology has been used for many years and has demonstrated its potential for low-cost, high performance millimeter-wave module implementation. However in the case of the 60 GHz system, the co-integration on LTCC substrates of 60 GHz front-end chipsets with a multi-sectors antenna system would require a large area of ceramic substrate and therefore lead to a prohibitive cost. The Liquid Crystal Polymer has emerged as a promising low-cost alternative for millimeter-wave module implementation [8]. It combines uniquely outstanding microwave performances, low cost and large area processing capability. It appears as a platform of choice for the packaging of the future 60 GHz gigabit radio.

IV. CONCLUSION

We discussed in this paper the circuit and module challenges for the next generation gigabits radio operating at 60 GHz. We highlighted the technology issues and choices based on application, system architecture, circuit and packaging considerations. The recent advances of CMOS and SiGe process technologies have now made the design of low-cost, highly integrated millimeter-wave radios possible in Silicon. In combination with an optimum packaging approach, such as a Liquid Crystal Polymer platform, these advances could have a major impact on the cost and the performances of the future high speed systems and lead a to a successful deployment of the 60GHz gigabit wireless radio.

REFERENCES

[1] P. Smulders,, "Exploiting the 60 GHz band for local wireless multimedia access: prospects and future directions", *Communications Magazine, IEEE* ,Volume: 40 , Issue: 1 , Jan. 2002, pp. 140 – 147.

[2] K. Ohata, et al., *"Wireless 1.25 Gb/s Transceiver Modules utilizing Multilayer Co-fired Ceramic technology",* ISSCC digest, February 7-9, 2000.

[3]B. Jagannathan et al, "Self aligned SiGe NPN Transistors with 285 GHz fmax and 207 GHz Ft in a manufacturable technology", *IEEE Electron Device Letters*,Volume: 23 , Issue: 5 , May 2002, pp. 258 – 260.

[4] S.K. Reynolds, B.A. Floyd, T. Zwick, "60 GHz transceiver circuits in SiGe bipolar technology", *IEEE ISSCC Dig. Tech. Papers*, Feb. 2004, pp 442-443.

[5] M. Ferndahl, H.Zirath, et al, "CMOS MMICs for microwave and millimeter wave applications", Microwaves, Radar and Wireless Communications, 2004. MIKON-2004.

15th, International Conference on ,Volume: 1 , 17-19 May 2004, pp 247 - 248.
[6] W. Winkler, J. Borngraber, B. Heinemann, P. Weger, “60GHz and 76GHz oscillators in 0.25/spl mu/m SiGe:C BiCMOS”, Solid-State Circuits Conference, 2003. Digest of Technical Papers. ISSCC, 2003 IEEE International , 2003, pp.454 – 507.
[7] T. Ihara, et al. ‘Switched four-sector beam antenna for indoor wireless LAN systems in the 60 GHz band”, Topical Symposium on Millimeter Waves, 7-8 July 1997, pp 115 – 118.
[8] MM. Tentzeris, J.Laskar, J.Papapolymerou, S.Pinel, V.Palazzari, R.Li, G.DeJean, N.Papageorgiou, D.Thompson, R. Bairavasubramanian, S.Sarkar, J-H Lee, “3-D-integrated RF and millimeter-wave functions and modules using liquid crystal polymer (LCP) system-on-package technology”, IEEE Transactions on Advanced Packaging and Manufacturing Technology, Volume: 27, Issue: 2 , May 2004, pp. 332 – 340.