Multi-Gigabit Wireless Link Development

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Abstract - CSIRO ICT Centre is developing millimetre wave point-to-point links suitable for multi-gigabit wireless connectivity. Suitable spectrum for this purpose is allocated at the 60 GHz band and above. This paper reports a new point-to-point link that will be installed at Marsfield site to demonstrate multi-gigabit operation and performance of its key components. The link will operate at the 81-86 GHz band incorporating CSIRO designed millimetre wave MMICs and multi-gigabit modems.

I. Introduction

Computer and networking speeds continue to increase (Gigabit Ethernet is now common and 10-Gigabit Ethernet is becoming more available) but wireless data rates have been lagging behind, mainly because of lack of wide-band spectrum at the traditional radio frequencies. But recently, commercial wireless point-to-point links started to become available in the 57-64 GHz band [1] and, in the 71-76 and 81-86 GHz bands. Point-to-point links at 60 GHz are already being used in wireless backhaul for mobile phone networks and they provide up to 1 Gbps data rates. Sections of the 57-64 GHz band are available in many countries for licence free operation. The usefulness of 60 GHz point-to-point links is limited however, because of additional propagation loss due to oxygen absorption at this band. The recently allocated 71-76 and 81-86 GHz bands in the USA provide opportunity for links with longer range (no oxygen absorption) and higher data rates (more bandwidth available). Up to 10 gigabits-per-second (Gbps) are promised in the near future by some commercial ventures [2].

As the cost of gigabit wireless comes down, high volume consumer applications such as Wireless Gigabit Ethernet, WLAN and WPAN will be commercially viable. The research efforts for gigabit wireless components and for reducing their cost have been increasing. Several research organisations have started to report their new technologies on multi-gigabit wireless links and networks [3-6]. The technology being developed for the 77 GHz automotive radar is also relevant because the key technologies are similar [7]; the automotive sector is worth watching as they may be quicker in cost reduction of millimetre wave components. Key components such as the GaAs MMICs are becoming commercially available [8] and their lower cost SiGe and Si CMOS counterparts are being developed by many researchers [9-10].

II. Multi-Gigabit Wireless Research at CSIRO

CSIRO has quite a long history in microwave and millimetre wave research. We established a III-V semiconductor fabrication facility about 20 years ago and developed our own GaAs Schottky and PHEMT MMIC processes. We developed numerous MMICs for a range of purposes including mmwave radio astronomy, mmwave optics and for projects funded by Australian Defence. We obtained the first access to the TRW (now Northrop Grumman) InP process from outside the USA in 1998 and developed MMICs up to 200 GHz. Our 85-110 GHz MMICs from these runs were installed in cryogenically cooled receivers of the Australia Telescope to form the first mmwave interferometer array using MMICs at this frequency. In 2001 we closed our GaAs MMIC fabrication facility due to the ready availability of foundries elsewhere and focused on system-oriented research.

We completed our first gigabit wireless system (a point-to-point link demonstrator) in December 2003 [11]. It operates at 83.5 GHz and is suitable for ASK data rates of 0.03-0.96 Gbps and maximum line of sight path of >1km for BER<10^{-6}. Outdoor propagation data has been collected since February 2004. The W-band transceiver modules include GaAs and InP MMICs in a conventional metal housing with wire bond attachments. All the MMICs were designed by CSIRO, the amplifiers were manufactured by Northrop Grumman and the mixers were manufactured by CSIRO. The transmitter output is 0 dBm and the receiver NF is 6 dB. The antennas were commercially purchased, low-cost Cassegrain type with 39 dBi gain (Figure 1).

We are now developing a 6-10 Gbps link demonstrator operating in the 81-86 GHz band (Figure 2). We are building the RF front ends using a similar approach to the previous transceivers [12-13] but we are optimising their performance for wider band operation. We are designing the IF modules using commercially available surface-mount components and multi-layer printed circuit boards. We are following the existing standards and adopting commercially available solutions for the modem where it is possible. For example we are using the 10 Gigabit Ethernet standards being developed by the 10 Gigabit Ethernet Alliance (10GEA). Each modem will function as a bridge between a wired 10 Gigabit Ethernet network and the wireless network.

Figure 1: Millimetre wave links at the ICT Centre test bed at Marsfield. A commercial 60 GHz link (top) and an CSIRO built Gigabit link at 83 GHz.

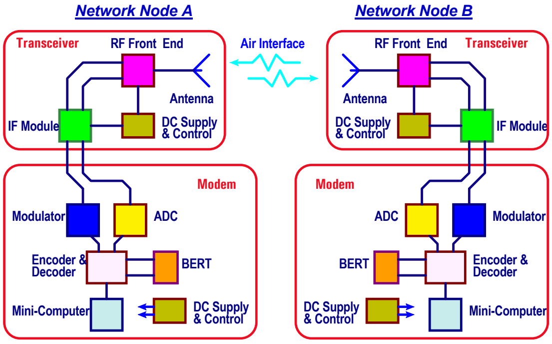

Figure 2: Simplified Diagram for the Multi-Gigabit Link

III. Millimetre-Wave Front Ends

The transceivers include the wide-band RF front-ends and the IF modules (Figure 2). The requirement for higher order digital modulation for increased spectral efficiency results in tighter specifications for the RF front ends. To achieve this, low noise amplifier (Figure 3), medium power amplifier and transceiver modules have been developed. Performance characteristics of individually packaged low noise amplifiers (LNA) and medium power amplifiers (MPA) are shown in Figure 4. Adjustable microstrip-to-waveguide transitions at the input and output allowed minimization of the gain ripple and achievement of a desirable frequency response. Tuning options are indicated by indexes A and B appended to the module numbers in Figure 4. Gain variations were less than 1.5 dB over the specified bandwidth.

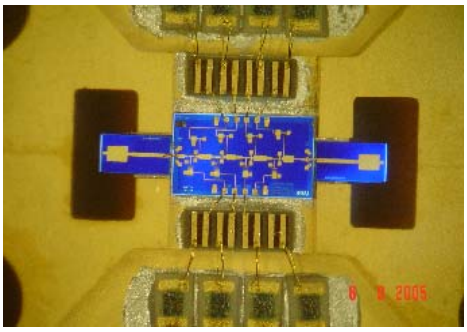

Figure 3: Photograph of the CSIRO-developed low noise amplifier MMIC in package.

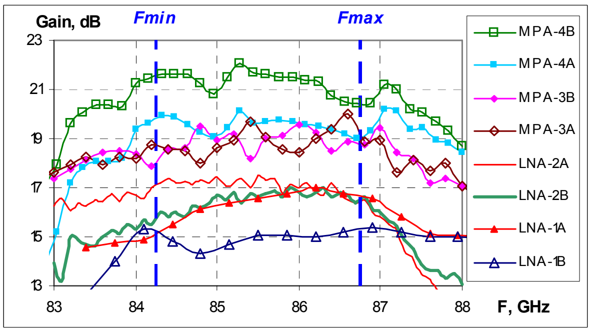

Figure 4: Measured performance of the low noise amplifier and medium power amplifier modules.

The conversion gain variations for all the transceiver front-ends were within 1.5 – 2.2 dB over the specified bandwidth (See Figures 5 and 6). The measured conversion gain and the output P1dB of the complete transmitter front end (that included modules Tx7, MPA-4B, a commercial W-band band-pass filter and a commercial PIN attenuator at fixed zero bias) were 9.6 ± 1.16 dB and 4.5 ± 1.5 dBm respectively. For the receiver front end (that consisted of module Rx9) the conversion gain variations and the input P1dB were ±1 dB and -22 ± 2 dBm respectively.

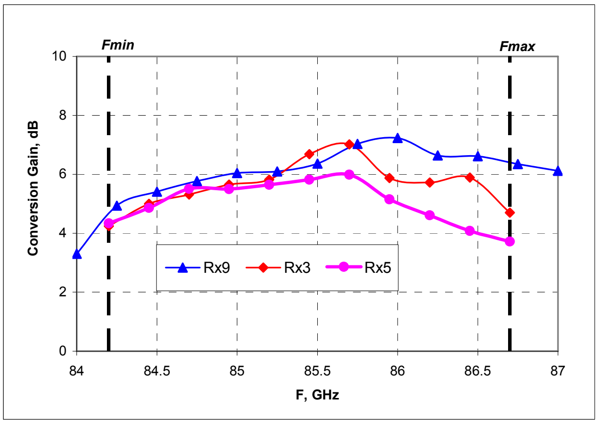

Figure 5: Measured performance of the receiver front ends.

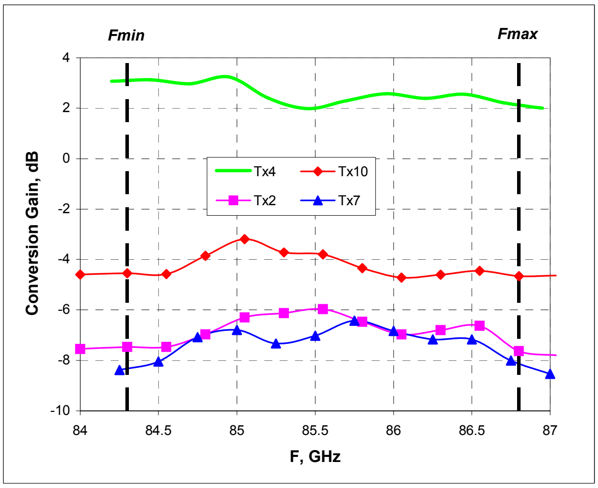

Figure 6: Measured performance of the transmitter front ends.

IV. Multi-Gigabit Modems and IF Modules

The modems for the link are designed to transmit data rates in excess of 10 gigabits per second in less than 5 GHz of bandwidth. Commercially available analogue-to-digital and digital-to-analogue converters are currently limited to Nyquist bandwidths of 1 GHz or less. Frequency multiplexing waveforms using multiple analogue-to-digital and digital-to-analogue converters are required as sown in Figure 7. The analogue filters need to be realized with small dispersion in group delay and sharp amplitude response. Combined digital and analogue filtering allows the group delay of the analogue filters to be tightly controlled and the amplitude response of the analogue filter to be relaxed while the digital filters provide a tightly controlled amplitude response.

The initial goal for the multi-gigabit modem is to achieve a spectral efficiency of 2.4 bits per Hertz in 2.5 GHz of bandwidth using 4 frequency multiplexed carriers then extend it to 5 GHz bandwidth (by adding more channels) to permit the testing of phase-shift, quadrature-amplitude and spread-spectrum modulation techniques.

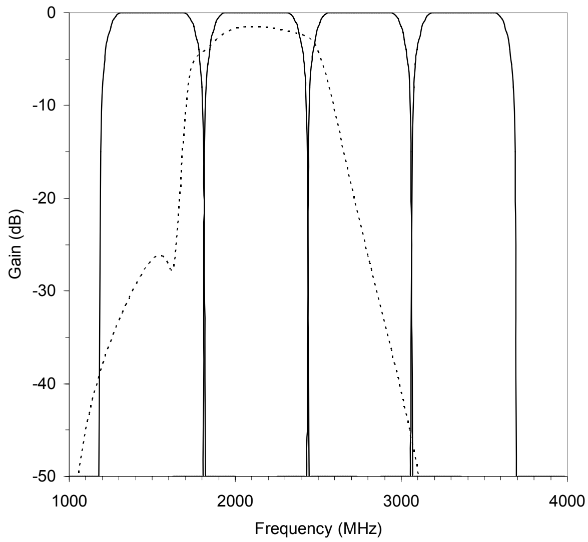

Figure 7: Four channels of the modem in 2.5GHz bandwidth. Each carrier has a root-raised-cosine spectrum. There are no guard bands separating the carriers. Dashed line shows the pass band of the analogue filter.

V. Reducing the Cost of Multi-Gigabit Connectivity

We will use fixed lens antennas for the multi-gigabit link initially but portable low-cost antennas (such as shown in Figure 8) will be essential for consumer oriented gigabit wireless applications of the future. Therefore we are investigating methods of manufacturing microstrip antennas on low-cost soft substrates such as Rogers Duroid 5880 and Liquid Crystal Polymer [14]. A potential 20 element microstrip array (Figure 8) gives a maximum simulated gain of 16.7 dB, efficiency of 50% and E and H plane beamwidths of 18° and 26° respectively.

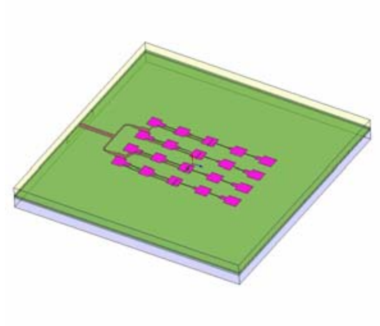

Figure 8: 20 Element Microstrip Array on Duroid

It is also essential to reduce the cost of millimetre wave front ends. The millimetre wave integrated circuits are becoming commercially available and getting cheaper, single function chips costing $20 - $200 each. Multi-function chips are not yet available for 60 GHz or above. Research is being conducted on lower cost multi-function chips on Si and SiGe and these will be available in the future. But currently, integration is still costly and challenging. A millimetre wave module may cost more than $10K. This is too expensive for large volume acceptance.

A solution may be to use a low-cost thin-film process to integrate commercially available millimetre wave MMICs without the use of bond-wires or flip-chip bonds. This method is cheap and reliable because a number of modules can be processed at the same time on a single wafer.

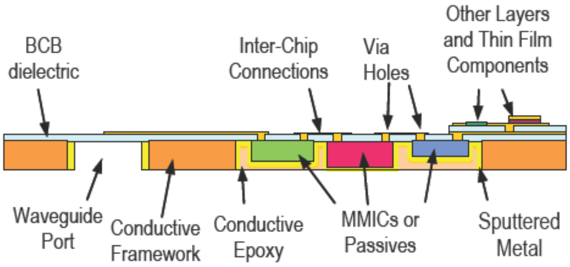

Figure 9: Schematic cross-section of CSIRO's thin-film multi-chip-module technique with embedded commercial MMICs.

We have developed a new technique, specifically for integrating commercial MMICs and passive chips for operation up to 110 GHz or more. We have used standard wafer scale thin-film processes to enable transfer of the technology to a commercial foundry in the future. A schematic cross-section of the multi-chip-module is shown in Figure 9.

We proved that this technique is suitable for millimetre wave integration by developing and testing 60 GHz amplifier prototypes (Figure 10 and Reference [15]). A major advantage of this approach is the possibility of predicting the package performance easily and accurately. An Australian provisional patent application No. 2005901655 was filed on 4 April 2005.

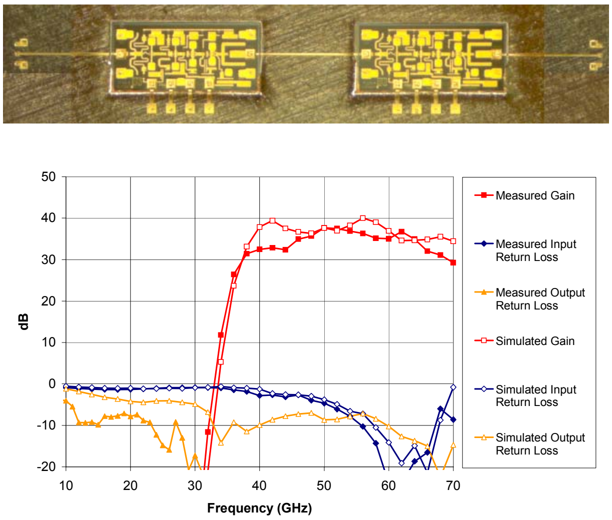

Figure 10: Performance of 60 GHz low noise amplifiers (ALH382-0) purchased from NGST and embedded into the low-cost multi-chip-module prototype by CSIRO.

VI. Conclusions

Millimetre wave technologies are becoming important for the high data rate communications of the future and research efforts are increasing both in Australia and overseas. As a result, it is expected that cost of the millimetre wave systems will decrease to enable consumer applications in the not too distant future.

CSIRO ICT Centre has developed key components to make multi-gigabit point-to-point communication possible. It is now integrating these components into a complete link demonstrator to test more advanced modulation techniques, new types of key modules and antennas and to obtain outdoor propagation data.

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