# A 60GHz Line-of-Sight 2x2 MIMO Link Operating at 1.2Gbps

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## Abstract

We report first experimental results from a hardware prototype of a millimeter wave line-of-sight (LOS) 2x2 MIMO link. The proposed architecture uses antenna element spacing derived from the principles of diffraction limited optics to establish multiple parallel data channels. Operation at millimeter wave carrier frequencies reduces the antenna array size to reasonable dimensions. The proposed system architecture is scalable to larger one dimensional and two dimensional arrays supporting data rates >160Gbps. This paper presents the design and characterization of a hardware prototype 2x2 LOS MIMO link operating at 1.2Gbps.

## Introduction

MIMO communication links support increased data rates without simultaneously increasing channel bandwidth. Multiple closely spaced transmitter and receiver elements establish parallel communication channels. The conventional approach to low frequency (2-5GHz) MIMO exploits multipath signals in non line-of-sight (NLOS) environments [1]. We will show in the next section that a LOS MIMO link is possible with antenna element spacing given by $D = \sqrt{R \cdot \lambda / n}$ [2]. Using this result, a 16 element square antenna array of dimensions 3.4m x 3.4m operates at 1km link range using a 60GHz carrier frequency, while an indoor linear 4 element link at 10m range would require a 34cm array. This system architecture is compatible with other methods for achieving LOS MIMO links [3]. This paper presents the experimental results from a hardware prototype of a 60GHz 2x2 MIMO LOS link operating at 1.2Gbps.

## Millimeter Wave MIMO Architecture

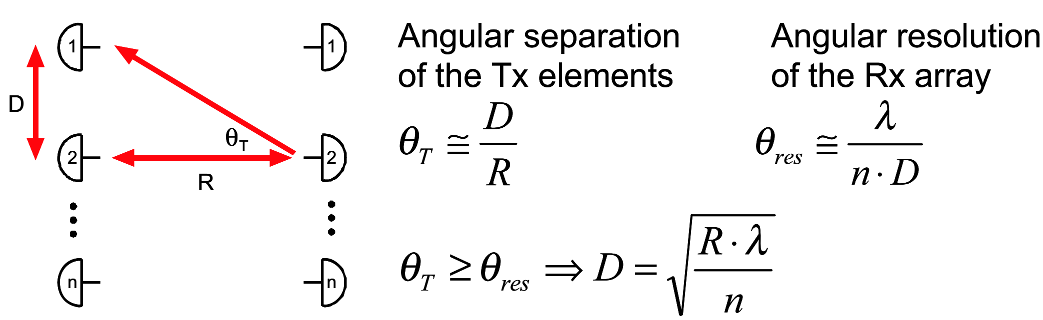


Figure 1: LOS MIMO system analysis using imaging theory

A LOS MIMO link can be analyzed using the principles of diffraction limited optics [2]. Perfect separation of transmitted channels at the receiver array requires the angular

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separation of the transmitter elements to be larger than the angular resolution of the receiver array (Fig. 1), leading to the $D = \sqrt{R \cdot \lambda / n}$ criterion.

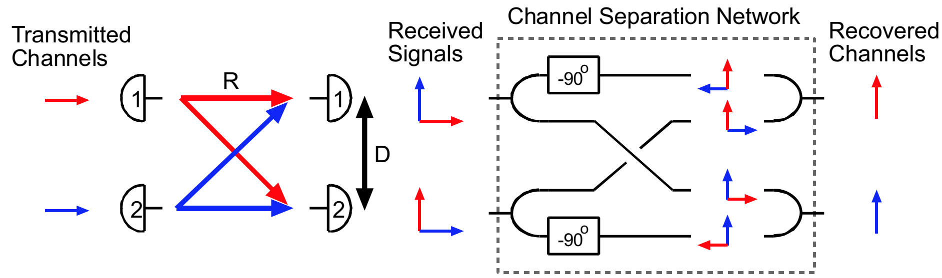



Figure 2: 2x2 LOS MIMO architecture; signals vectors shown in the I/Q plane

Fig. 2 shows a two element LOS MIMO link. The system consists of antenna elements separated by the distance D derived in Fig. 1 and a channel separation network at the receiver. The design of the channel separation network is independent of link range R and carrier wavelength λ, assuming λ << R.

## 2x2 MIMO Hardware Prototype

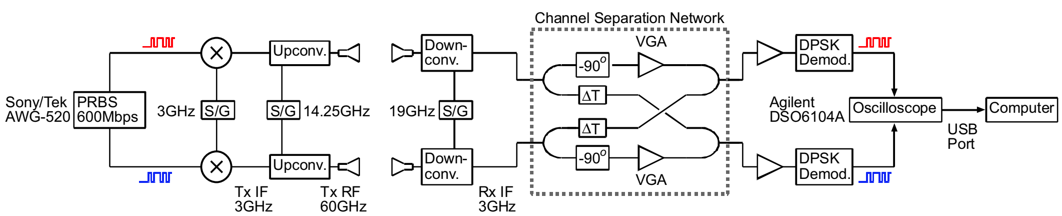
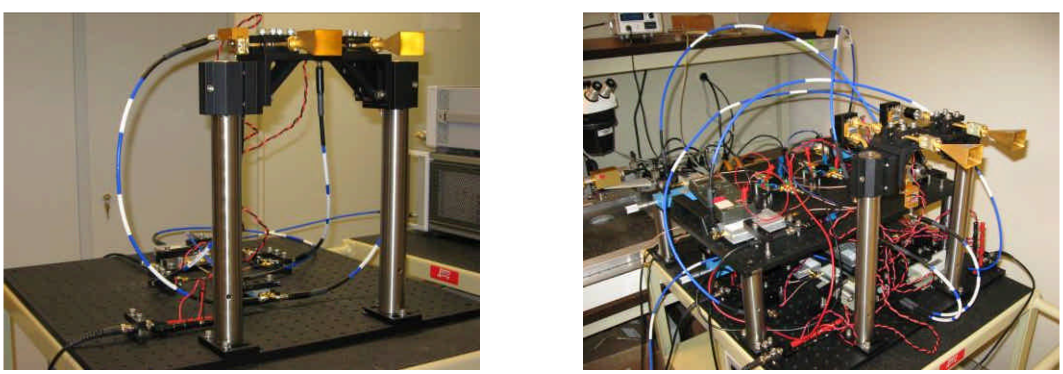



Figure 3: Hardware prototype block diagram

We constructed a two channel MIMO hardware prototype operating at 600Mbps per channel from commercially available millimeter wave and RF components (Fig. 3). A programmable signal source generated the two channel PRBS data. The PRBS signal source operated at 600Mbps with sequence length $2^{17}$-1. Two PRBS data streams were generated using different maximal length shift register feedback configurations.



(a) (b)

Figure 4: Prototype photographs: (a) transmitter; (b) receiver

The transmitter (Fig. 4a) used two upconversion stages to generate BPSK encoded data. The receiver (Fig. 4b) consisted of downconversion stages from 60GHz to a 3GHz IF, a channel separation network and Differential PSK (DPSK) demodulators. The prototype used signal vector summation to separate the channels at the IF frequency. Variable gain amplifiers and tunable delay lines optimized cross channel interference nulling. An oscilloscope captured time domain data for offline data processing.

## Wireless Link Characterization

The MIMO hardware prototype was tested in an indoor office environment at a range of 6.15m. The transmitter and receiver antenna pairs were separated by 12.4cm, based on the antenna spacing equation derived in Fig. 1. Horn antennas were used in the transmitter and receiver arrays.

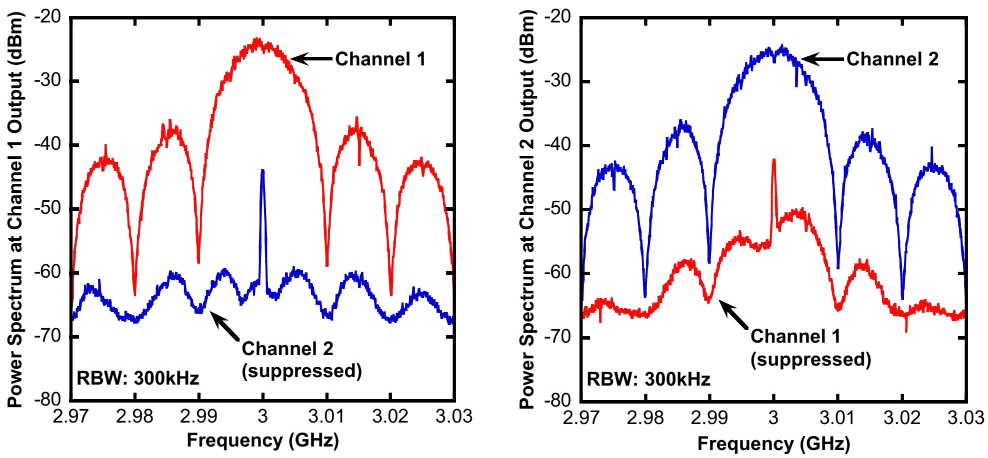



Figure 5: Channel suppression network performance at 10Mbps

The receiver channel separation network was tuned by operating the PRBS source at 10Mbps. The spectrum of each output of the channel separation network was observed on a spectrum analyzer. Gain and time shift elements were iteratively tuned to minimize the undesired transmitter signals. Fig. 5 is a plot of the channel suppression at 10Mbps.

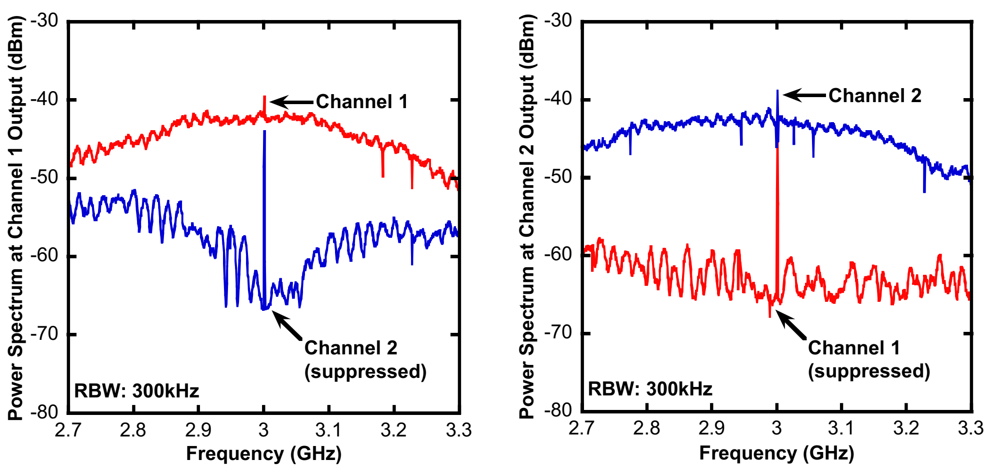



Figure 6: Channel suppression network performance at 600Mbps

After tuning the channel separation network, the system was operated at 600Mbps. Fig. 6 is a plot of the channel suppression at 600Mbps. Channel separation network performance was limited by frequency dependent gain and phase variations between the signals at each receiver array element. These variations were caused by component mismatches between the two receiver channels and by the multipath signals inherent in an indoor propagation environment. Given these channel mismatches, the channel suppression ratio is 12.1dB (Fig. 6).

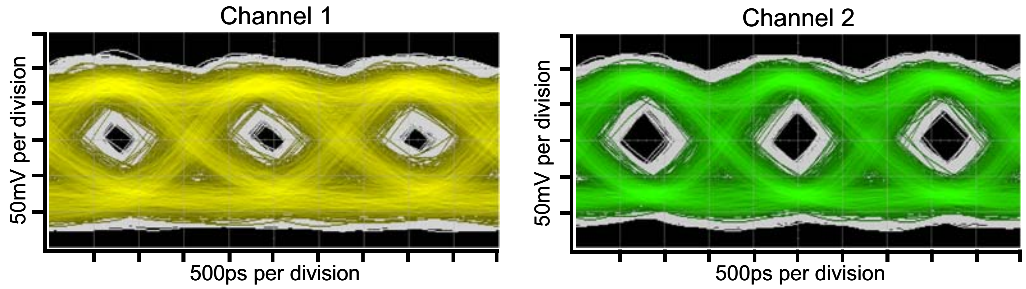


Figure 7: Eye patterns at 600Mbps

Table I
Summary of Indoor Measurements

| | Channel Number | 1 | 2 |
|---|---|---|---|
| BER | Single Active Transmitter | $<10^{-6}$ | $<10^{-6}$ |
| | Two Active Transmitters | $<10^{-6}$ | $<10^{-6}$ |
| Channel Suppression Ratio (dB) | 10Mbps per channel | 28.6 | 23.8 |
| | 600Mbps per channel | 12.1 | 17.6 |

Receiver eye patterns are shown in Fig. 7. Bit error rate (BER) measurements were performed offline on signals captured by the oscilloscope (Table I). Measurements were made with both transmitters active and with only one transmitter active at a time. There was no measurable difference in the system BER for the two operating modes.

## Conclusion

We have demonstrated a system architecture for millimeter wave LOS MIMO wireless links based on antenna element spacing derived from the principles of diffraction limited optics. Further work on characterization of the system at longer link range, larger one dimensional and two dimensional arrays, and additional system enhancements are underway.

## References: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[2] E. Torkildson, B. Ananthasubramaniam, U. Madhow and M. Rodwell, “Millimeter-wave MIMO: Wireless Links at Optical Speeds,” *Proc. of 44th Allerton Conference on Communication, Control and Computing*, Sept. 2006.

[3] Y. Palaskas, A. Ravi, S. Pellerano, B. Carlton, M. Elmala, R. Bishop, G. Banerjee, R. Nicholls, S. Ling, P. Seddighrad, S. Suh, S. Taylor, K. Soumyanath, "A 5GHz, 108Mb/s 2x2 MIMO CMOS Transceiver," *2007 IEEE Radio and Wireless Symposium,* pp.239-242, 9-11 Jan. 2007.