The First Millimeter-wave Point-to-Point Wireless Gigabit Ethernet Communication System at TMR&D

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Abstract: - In this paper, a millimeter-wave point-to-point (PTP) Wireless Gigabit Ethernet Communication System is presented and the first been developed by TMR&D. A 60 GHz Low Temperature Co-Fired Ceramics (LTCC) System-On-Package (SoP) Transceiver capable of gigabit data rate has been built and demonstrated with a size of 17.76 x 17.89 mm^2. A direct Amplitude-Shift Keying (ASK) modulation and demodulation scheme is adopted for the 60GHz-band transceiver. A BER of 1×10^{-12} for data rate of 1.25 gigabit-per-second (Gbps) on 2.2 GHz bandwidth at 1.4 km was demonstrated. This paper reports a new PTP link that has been installed at TMR&D site to demonstrate wireless gigabit operation and performance of its key components. The link will operate at the 57.65-63.35 GHz band incorporating TMR&D's designed millimeter-wave LTCC SoP RF Transceiver module. This LTCC SoP RF Transceiver is suitable for short-range wireless networking systems, security camera TV, video conferencing, streaming video like HDTV (high definition television) and wireless downloading systems for small power application. Outdoor wireless link test shows that the transmission range of PTP system using the SoP Transceiver is 1.4 km.

Key-Words: - PTP link, Wireless gigabit, LTCC, SoP, RF Transceiver.

1 Introduction

Every new generation of wireless networks require more and more cell-sites that are closer and closer together combined with the fast growing demand for the capacity of the transmission links. Millimeter-wave (MMW) radio has recently attracted a great deal of interest from scientific world, industry, and global standardisation bodies due to a number of attractive features of MMW to provide multi-gigabit transmission rate. Wireless broadband access is attractive to operators because of its low construction cost, quick deployment, and flexibility in providing access to different services. It is expected that the MMW radios can find numerous indoor and outdoor applications in residential areas, offices, conference rooms, corridors, and libraries. It is suitable for in-home applications such as audio/video transmission, desktop connection, and support of portable devices while for the outdoor PTP MMW systems, connecting cell-sites at one kilometer distance or closer, it will offer a huge backhaul capacity.

The increasing demands for high-data rate communications have urged to develop MMW broadband wireless systems. Demands for high-speed multimedia data communications, such as a huge data file transmission and real-time high definition TV signal streaming, are markedly increasing, e.g., Gigabit Ethernet networks are now beginning to be widely used. Wireless transmission with 1Gbps and greater data rate is very attractive [1-2]. Carrier frequencies of wireless communications are also increasing from 2.4 GHz and 5 GHz to MMW such as 60 GHz bands [3]. For wireless communication application, there has been a tremendous interest in utilising the 60 GHz band of frequency spectrum because of the unlicensed wide bandwidth available, maximisation of frequency reuse due to absorption by oxygen (O_2), and the short wavelength that allows very compact passive devices. However, commercial wireless PTP links started to become available in the 57-64 GHz band [4] and, in the 71~76 and 81~86 GHz bands. PTP links at 60 GHz can be used in wireless backhaul for mobile phone networks and able to provide up to 1 Gbps data rates. Sections of the 57~64 GHz band are available in many countries for unlicensed operation [5-6].

According to the International Telecommunication Union (ITU) Radio Regulations, the band 55.78~66 GHz, 71~76 GHz, 81~86 GHz, 92~94 GHz and 94.1~100 GHz are available for fixed and mobile services in all three

ITU regions as depicted in Fig. 1. In Europe, the 59~66 GHz band has been allocated for mobile services in general. In USA and Canada, the 57~64 GHz band is assigned as an unlicensed band. In Japan, the 59~64 GHz band has been made available on an unlicensed basis for millimeter wavelength image/data systems. In Korea, the 57~64 GHz band is assigned as an unlicensed band.

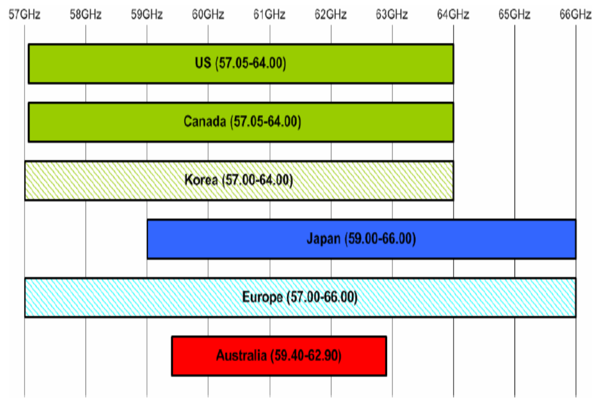


Fig. 1: Worldwide 60 GHz Band Allocation

The usefulness of 60 GHz PTP links is limited however, because of additional propagation loss due to O_2 absorption at this band. The specific attenuation characteristic due to atmospheric O_2 of 10-15 dB/km makes the 60 GHz band unsuitable for long range (>2 km) communications so that it can be dedicated entirely to short range (< 1km) communications. For a short distances to be bridged in an indoor environment (<50m) the 10-15 dB/km attenuation has no significant impact [7].

Nowadays the 60 GHz band is considered to provide wireless broadband communication and the R&D for 60 GHz technology is very competitive in worldwide. The research and development for 60 GHz band is mandatory and urgent for national broadband system in future.

2 Wireless Gigabit Research at TMR&D

TMR&D has involved several years in microwave and MMW research. We started with the GaAs PHEMT MMIC design for several frequencies from 1–36 GHz. We managed to fabricate and tested using III-V semiconductor fabrication process facility. We developed numerous MMICs for a range of purposes including MMW satellite receiver, LMDS and MVDS applications. We also developed RF Transceiver for 3G Node B Base Station and IEEE 802.16d WiMAX Subscriber Station. These projects were funded by the Telekom Malaysia under Basic Research grant.

TMR&D is developing the PTP ultra broad-bandwidth wireless link up to 1.25Gbps data rate on 2.2 GHz bandwidth (BW) using MMW 60GHz frequency band. This Wireless Gigabit Ethernet link has a function of a media converter to connect a fiber link to a full duplex wireless link seamlessly with 1.25 Gbps data rate for both directions. The data input and output interface is a 1000BASE-SX optical transceiver module with LC connectors. Millimeter waves can permit more densely packed communication links, thus it provides very efficient spectrum utilisation, and they can increase spectrum efficiency of communication transmissions within restricted frequency band.

We completed our first wireless gigabit ethernet system (PTP link demonstrator) incorporating with TMR&D's LTCC SoP RF Transceiver module in December 2008. It operates at 57.65-63.35 GHz band and is suitable for ASK data rates of 1 Gbps and a maximum line of sight (LOS) path of 1.4 km for BER<10^{-12}. Outdoor propagation data has been collected since January 2009. Three sites have been tested at different locations, i.e. 0.8km, 0.9 and 1.4km. The V-band transceiver modules include GaAs MMICs together with the IF baseband in a metal housing attachment. The entire LTCC SoP RF Transceiver module was designed by TMR&D's Researchers; the LTCC fabrication was outsourced to third party. The transmitter output is 10 dBm and the receiver NF is 8 dB. The antennas were commercially purchased, low-cost Cassegrain type with 48 dBi gain and beamwidth of 0.6 deg (figure 2).

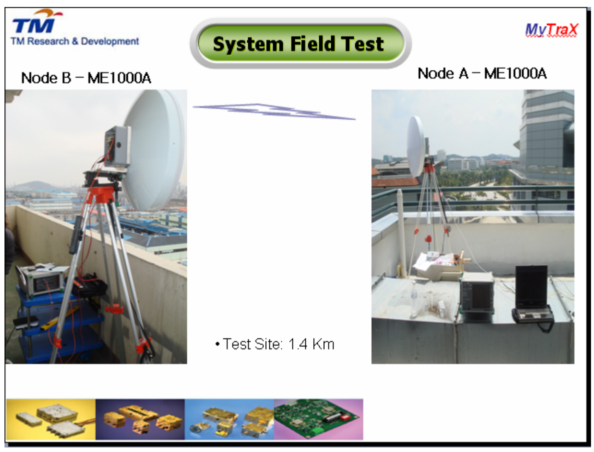


Fig. 2: Millimetre wave links at the TMR&D Innovation Centre, Cyberjaya. A pre-commercial 60 GHz link

Table 1: TM MMW PTP Wireless Gigabit Ethernet Communication System Specification

Parameters		Specifications		Remarks
		Type A	Type B	
TX	Frequency Range	57.65GHz~59.85GHz	61.15GHz~63.35GHz	
	Band Width	2200MHz		
	Output Power	+10dBm typ.		
	LO Frequency	58.75GHz ±[illegible]	62.25GHz ±[illegible]	
	Spurious Output	53dBc		58.75GHz/62.25GHz PLO Spurious
	Phase Noise	85dBc/Hz		
	Stability	±0.01ppm		
	Signal Input VSWR	2.0:1		
RX	Frequency Range	61.15GHz~63.35GHz	57.65GHz~59.85GHz	
	Band Width	2200MHz		
	Min Input Level	-47dBm		
	Max Input Level	-20dBm		
	Gain Flatness	±1.5dB		
	Noise Figure	10.0dB typ.		
	RF Input VSWR	2.0:1		
Common	RF Port	WR-15		
	Signal IN/OUT Port	SMA(f)		
	Temperature Range	-30℃ ~ 70℃		
	Modulation	ASK		
	Data Rate	1.25Gbps		
	Max Coverage	0.8 - 1.4 km		
	Bias	+5V/3000mA		

Table 1 shows the system specification of the TM MMW PTP Wireless Gigabit Ethernet Communication System.

This system can be used as PTP link, and establishing high-speed backbone networks, such as backbone link or wireless backhaul. This system is also used for satellite, broadcasting and observation purposes. Figure 3 illustrates the PTP system suitable for applications which can serve high capacity PTP up to 1.25Gbps Wireless Gigabit Ethernet link. Thus, the outdoor units are optimised for Ethernet radio links or mobile communication backhauls.

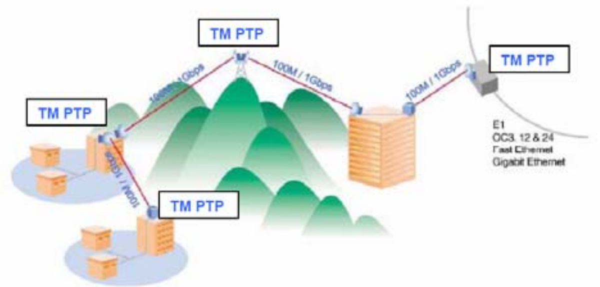


Fig. 3: 60GHz PTP Wireless Gigabit Ethernet Link

This PTP system is the fastest wireless solutions for PTP wireless in IP network such as Fast and Gigabit Ethernet applications. The interconnection between two endpoints apart from last mile can be easily deployed and installed.

This system can be deployed with full-duplex security systems, and it can be used for wireless link between buildings in downtown or campus area where higher speed is required. Backup link for optical fiber is easily installed when a system is needed to replaced. Therefore, services can continue seamlessly even though any problems are on the link path.

Other applications of 60 GHz are as below.

a. Wireless high-definition multimedia interface (HDMI). Uncompressed video can be wirelessly transmitted from a DVD player to a flat screen [8].
b. Fast up and download of high-definition movies. Users can download high-definition movies from a video kiosk onto their mobile device or at home can download a movie from their mobile device onto the computer.
c. Wireless docking station. A laptop computer can be wirelessly connected to the network, the display, an external drive, the printer, a digital camera etc.

3 Millimeter-Wave Front End Design

In this paper, LTCC SoP modules for a 60GHz ASK transceiver were designed. First, a ASK transceiver was briefly introduced and using Link Budget Analysis, link parameters for ASK Tx and Rx were extracted and the transceiver was designed. And then, selection method of RF components using commercial Monolithic Microwave Integrated Circuits (MMICs) was presented. Second, LTCC design rules (DR) were introduced. Following the LTCC DR, active single LTCC modules to construct the ASK Tx and Rx and their functional blocks were designed. Lastly, the Tx and Rx block were also designed.

Using multi-layer LTCC based SoP technology, various research efforts have been made for SoP ASK transceiver applications. 60GHz transmitter (Tx) and receiver (Rx) modules were downsized into 13.82 x 6.55 mm^2 and 11.02 x 4.31 mm^2 respectively, for 1.25 Gbps wireless Ethernet link.

3.1 ASK Transceiver Design

There are a wide variety of RF communication system architectures such as a super-heterodyne, a direct conversion and a self-heterodyne scheme. They are distinguished by purpose of usage and system requirements. Also, they are mainly affected by integration technology, size, cost, power consumption and many components. A super-heterodyne scheme needs a local oscillator (LO) to pump a mixer and down-convert a RF signal into an intermediate frequency (IF). Even though it is complicated and expensive topology due to several components, it has high performance and easy implementation. A direct conversion (zero IF) scheme [9] convert directly RF signal into base band signal with out IF signal. It is simple architecture, but it has a little benefit except cost effectiveness. For self-heterodyne detection scheme [10, 11], the transmitter transmits a RF signal together with a LO signal to the receiver, which down-converts the RF signal by mixing the received RF signal with a LO signal.

3.1.1 Link Budget Analysis

Link Budget Analysis establishes when Tx and Rx can communicate with each other through free space. The transmit power (P_{TX}), communication range (R), antenna gains (G_T and G_R) considering loss terms and other items are specified as shown in figure 4. According to the environment and transmit speed, the communication range, receiver and transmitter power can be estimated.

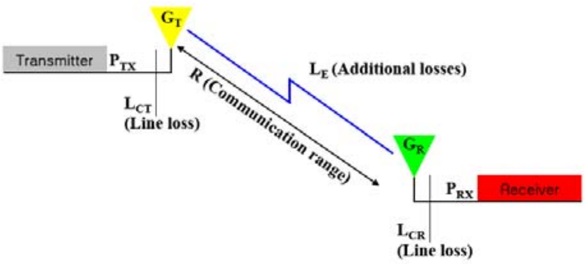


Fig. 4: Wireless Link

For an ideal system, the bit error rate (BER) will approach zero if the data transmission rate is below the channel capacity. In the real world, the degree to which a practical system can approach this limit is dependent on modulation technique and receiver noise.

3.1.2 ASK Modulation

Modulation technique is a key consideration. Selection of modulation method determines system bandwidth, power efficiency, sensitivity, and complexity. For the purposes of link budget analysis, the most important aspect of a given modulation technique is the Signal-to-Noise Ratio (SNR) necessary for a receiver to achieve a specified level of reliability in terms of BER. Relation of probability of error (bit error rate) and bit energy-to-noise density ratio is as following:

▪ Coherent ASK

$$P_b = Q\left(\sqrt{\frac{E_b}{N_0}}\right),\ Q(x) \approx \frac{1}{x\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right)$$

▪ Noncoherent ASK

$$P_b = \frac{1}{2}\left\{\exp\left(-\frac{1}{2}\frac{E_b}{N_0}\right) + Q\left(\sqrt{\frac{E_b}{N_0}}\right)\right\} \approx \frac{1}{2}\exp\left(-\frac{1}{2}\frac{E_b}{N_0}\right)$$

- Eb: Energy required per bit of information
- No: Thermal noise in 1Hz of bandwidth

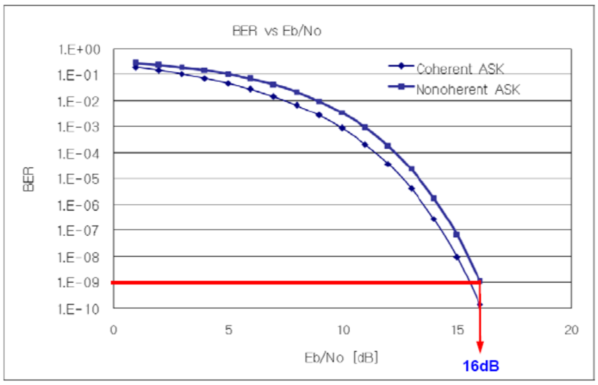


Fig.5: Probability of bit error for ASK modulation method

For high-speed data rate, BER of 1E-9 is required. For non-coherent ASK, Eb/No of 16dB is required at the BER value as shown in figure 5.

3.1.3 SNR and Bandwidth

$$S/N = (E_b/N_o) \times (R/B_T)$$

- E_b: Energy required per bit of information
- N_o: Thermal noise in 1Hz of bandwidth
- R: System data rate
- B_T: System bandwidth

Example.

$E_b/N_o = 16\text{dB} = 39.81$, $R = 1.2\text{Gbps}$, $B_T = 2.2\text{GHz}$

$S/N = (39.81) \times (1.2/2.2) = 21.7 = 13\text{dB}$

3.1.4 S/N Ratio

S/N ratio is a factor to determine the receiver performance. As it increases, the communication quality also improves. In general, S/N ratio is determined in most communication systems and it is presented as following equation.

$S/N = P_{RX} - N$ [dB]

- S/N: Signal to noise ration [dB]
- P_{RX}: Input power of the Rx [dBm]
- N: Noise power [dBm]

3.1.5 Input Power Level of the Rx - Friis Equation

Friis equation is the fundamental result for radio system links. It expresses the receiver power in terms of transmitted power, antenna gain, rage, and frequency, and thus forms the basis for all wireless system design.

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - \overbrace{20\log\frac{4\pi\pi}{\lambda}}^{\text{Path loss}} - L_E - L_{CT} - L_{CR} - \text{Fade Margin [dBm]}$$

- P_{RX}: Input power of the Rx [dBm]
- P_{TX}: Output power of the Tx [dBm]
- G_{TX}: Antenna gain of the Tx [dBi]
- G_{RX}: Antenna gain of the Rx [dBi]
- λ: Wavelength [m]
- R: Communication range [m]
- L_{CT}: Cable or W/G loss between Tx and antenna [dB]
- L_{CR}: Cable or W/G loss between Rx and antenna [dB]
- L_E: Additional loss [dB] due to oxygen, rainfall, fog/cloud,

3.1.6 Path Loss and Range

$$L = 20\log\frac{4\pi R}{\lambda}[\text{dB}]$$

As radio waves propagate in free space, power falls off as the square of range. For a doubling of range, power reaching a receiver antenna is reduced by a factor of four. This effect is due to the spreading of the radio waves as they propagate. This equation describes line-of-sight, or free space propagation.

3.1.7 Additional Path Loss - Oxygen (O_2)/Moisture

Signals in space can be absorbed by oxygen or water vapor because of resonant effects. Especially, at 60 GHz the attenuation is severe, 16dB/Km.

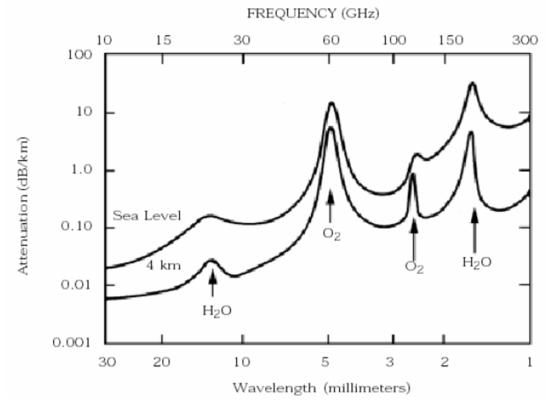


Fig. 6: Loss characteristics due to oxygen and moisture

Transmission losses occur when millimeter waves traveling through the atmosphere are absorbed by molecules such as oxygen, water vapour, and other gaseous atmospheric constituents. These losses are greater at certain frequencies, containing with the mechanical resonant frequencies of the gas molecules. The H_2O and O_2 resonance have been studied extensively for purposes of predicting millimeter propagation characteristics. Figure 6 shows the atmospheric absorption versus frequency at altitudes of 4 km and sea level for water content of 1g/m3 and 7.5g/m3, respectively [12]. The former value represents relatively dry air while the latter value represents 75% humidity for 10^{o}C. As the result, the attenuation of the 60 GHz carrier signal shows 16dB/Km due to the oxygen. Table 2 shows the summary of the loss due to oxygen at different frequencies.

Table 2: Summary of the loss due to oxygen at different frequencies

Freq.[GHz]	<10	10~50	60
L [dB/km]	<0.02	<0.5	16

3.1.8 Additional Path Loss – Rainfall

At mm-wave wireless communications, attenuation due to rainfall is very critical problems. At low frequencies around 5GHz, loss due to rainfall is less than 1dB/Km and thus its effect on wireless communications is insignificant. However, loss due to rainfall at 60GHz is 3~31dB/Km (as shown in figure 7). So, it can be an obstacle to communications. Table 3 shows the summary of loss due to amount of rainfall.

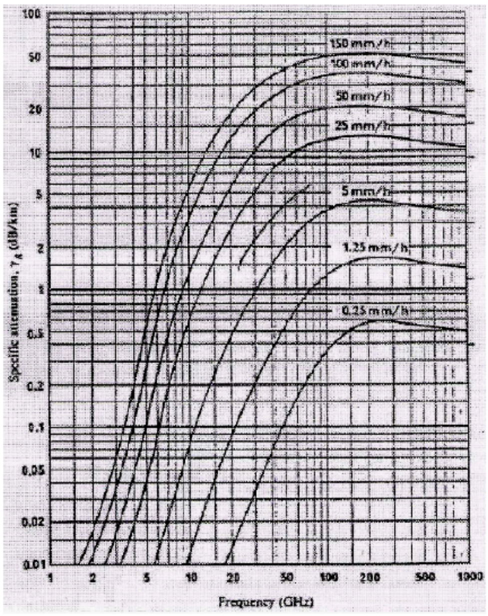


Fig. 7: Loss characteristics due to rainfalls

Table 3: Summary of loss due to amount of rainfall

A rainfall	<5GHz	Ku-Band	26GHz	40GHz	60GHz	77GHz
1.25 [mm/h]	0.01dB/Km	0.03 dB/Km	0.3 dB/Km	0.4 dB/Km	0.8 dB/Km	1.0 dB/Km
5.0 [mm/h]	0.01 dB/Km	0.15 dB/Km	1.5 dB/Km	1.5 dB/Km	3.0 dB/Km	3.5 dB/Km
25 [mm/h]	0.05 dB/Km	1.0 dB/Km	6.0 dB/Km	8.0 dB/Km	10 dB/Km	12 dB/Km
50 [mm/h]	0.15 dB/Km	2.0 dB/Km	12 dB/Km	14 dB/Km	17 dB/Km	18 dB/Km
100 [mm/h]	0.3 dB/Km	5.0 dB/Km	20 dB/Km	25 dB/Km	31 dB/Km	34 dB/Km

3.1.9 Additional Path Loss – Fog/Cloud

Attenuation due to fog or cloud is 0.04dB/Km at 5GHz, 0.8dB/Km at 26GHz, 1.5dB/Km at 40GHz, and 3dB/Km at 60GHz on the basis of a dense fog or cloud in the ground.

3.1.10 Additional Path Loss – Leaves

Attenuation due to leaves should be considered at mm-wave communications. Total attenuation is calculated by the following eq. when penetration is less than 400m.

$L = 0.2 \times f^{0.3} \times R^{0.6}\ [dB]$
- f: frequency [MHz]
- R: penetration [m]

3.1.11 Summary of Total Additional Path Losses

Table 4: Summary of Total Additional Path Losses

Loss Factors		Frequency [GHz]					
		< 3	26	38	40	60	77
Rain fall	5 [mm/h]	0	< 1.5	< 1.5	< 1.5	< 3	< 3.5
	25 [mm/h]	< 0.01	< 6	< 7	< 8	< 10	< 12
	50 [mm/h]	< 0.02	< 12	< 13	< 14	< 17	< 18
	100 [mm/h]	< 0.04	< 20	< 22	< 25	< 31	< 34
Oxygen absorption		0	0.15	0.15	0.17	16	0.5
Fog / Cloud		< 0.01	0.8	1.2	1.3	3	4.5
Leaves		< 2.2	4.2	4.7	4.8	5.4	5.8
Totall Loss		< 2.25	21.15	28.05	31.27	55.4	44.8

Loss due to leaves: Assumption of total penetration of 1m.

Total loss is calculated by considering the worst case of the rain fall of 100mm/h (as shown in table 4). In outdoor application, the additional losses should be considered in the link budget analysis in the RF system design.

3.1.12 Fade Margin

Multi-path occurs when waves emitted by the transmitter travel along a different path and interfere destructively with waves traveling on a direct line-of-sight path. This is sometimes referred to as signal fading. This phenomenon occurs because waves traveling along different paths may be completely out of phase when they reach the antenna, thereby canceling each other (as shown in figure 8).

Since signal cancellation is almost never complete, one method of overcoming this problem is to transmit more power. In an indoor environment, multi-path is almost always present and tends to be dynamic (constantly varying).

Several fading due to multi-path can result in a signal reduction of more than 30dB. It is therefore essential to provide adequate link margin to overcome this loss when designing wireless system.

The amount of extra RF power radiated to overcome this phenomenon is referred to as Fade Margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule-of-thumb is 20dB to 30dB.

One method of mitigating the effects of multi-path is antenna diversity. Since the cancellation of radio waves is geometry dependent, use of two (or more) antenna separated by at least half of wavelength can drastically mitigate this problem.

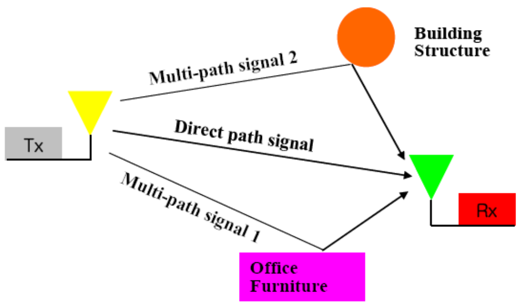


Fig. 8: Multi-path

3.1.13 Channel Noise

For all communications systems, channel noise is intimately tied to bandwidth. All objects which have heat emit RF energy in the form of random (Gaussian) noise. The amount of radiation emitted can be calculated by:

$$\boxed{N = kBT\ [W]}$$

- N: Noise power [W]
- k: Boltzman's constant (1.38 x 10^{-23} J/k)
- T: System temp., usually assumed to be 290oK (=17°C)
- B: Channel bandwidth (Hz)

3.1.14 Noise Floor

N (noise power) represents a theoretical noise floor for an ideal receiver. A real receiver noise floor will always be higher, due to noise and losses in the receiver itself. NF (noise figure) is a measure of the amount of noise added by the receiver itself. NF must be added to the thermal noise to determine the receiver noise floor:

$$\boxed{N = 10\log kBT + NF\ [dBm]}$$

TMR&D's advanced ASK (Amplitude Shift Keying) transceiver module has the best quality and superior performance to transmit ultra high speed digital data in millimeter wave. The maximum data rate is 1.25Gbps on 2.2 GHz of bandwidth for Gigabit Ethernet applications. We have developed low-cost multi-chip modules (MCMs) based on the multilayer LTCC technologies; 60GHz-transmission lines (CPW, MSL, eMSL), BPFs, patch antennas [13], active modules (PA, LNA, multiplier (MTL), Tx, and Rx), and L-band LPFs. Utilising these technologies, we have developed 60 GHz mmwave band broadband wireless transceiver namely MyTraX (LTCC SoP Transceiver). The block diagram shown in figure 9 includes the antenna, diplexer and ASK LTCC SoP Transceiver with the optical transceiver being connected. Its carrier center frequencies are 62.24 and 58.75 GHz for Tx (up) and Rx (down) links, respectively. ASK modulation method is used for simple transceiver architecture.

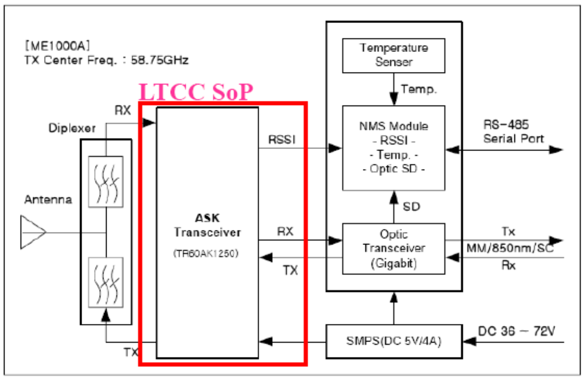


Fig. 9: 60GHz Point-to-Point Transceiver block diagram

In this ASK LTCC SoP Transceiver module, it consists of receiver (Rx) and transmitter (Tx) block. The ASK has a carrier wave which either switched ON or OFF. For the Rx block, it consists of high gain low noise amplifier (LNA) block, demodulator (detector) and low pass filter (LPF) whereas for the Tx block, it consists of frequency doubler (MTLs), modulator (up-converter Mixer) and power amplifier (PA).

At Rx block, the signal received coming from antenna is downconverted to Intermediate Frequency (IF) signals and then to the original signals via baseband. For Tx block, the IF signals from the baseband are fed to the Tx block and upconverted to 60 GHz band, then transmit through antenna (Figure 10). The LO signal of the Tx is supplied by multiplying the external VCO source of 7.78 GHz by 8 to the mixer.

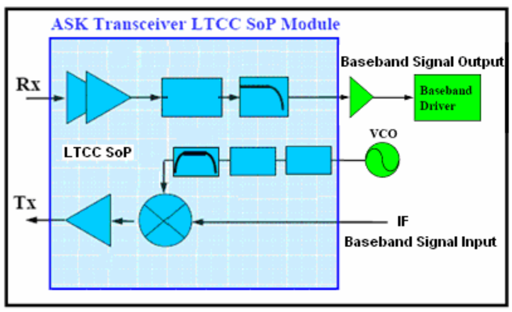


Fig. 10: Block diagram of the ASK LTCC SoP Transceiver

4 Measured Results

TMR&D develops several kinds of LTCC (Low Temperature Co-Fired Ceramics) MMW modules in 60GHz band. These LTCC modules have superior RF performance so that the whole systems equipped with the module can operate more stable.

Using 6-layer LTCC substrate based on SoP technology [14], various research efforts have been made for compact SoP RF systems. For 1.25Gbps wireless Ethernet link, fabricated 60GHz using a commercial Foundry RN2 [15], the Tx and Rx modules were downsized into 13.82 x 6.55 mm^2 (Figure 11) and 11.02 x 4.31 mm^2 (Figure 12), respectively. The integration of Tx and Rx will produce the LTCC SoP Transceiver with a size of 17.76 x 17.89 mm^2.

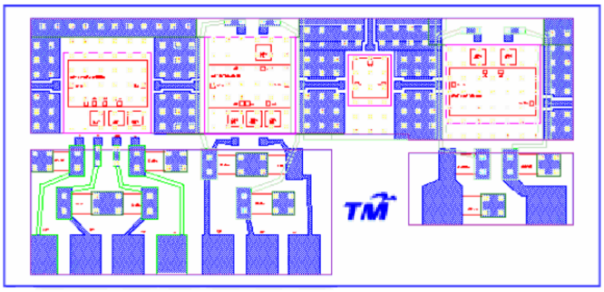


Fig. 11: LTCC SoP Transmitter module

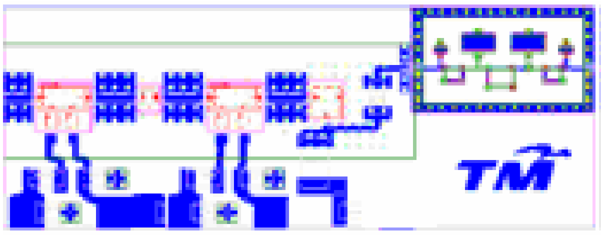


Fig. 12: LTCC SoP Receiver module

Figure 13 shows frequency response for the Tx output power with IF sweep from 10-1500 MHz and LO at 58.752 GHz. The peak output power for the ASK modulated 60GHz band signal is plotted versus frequency. The output power is 13dBm. There is no resonance and oscillation problems occur at Tx module. The measured frequency spectrum of the LTCC Tx module is shown in figure 14.

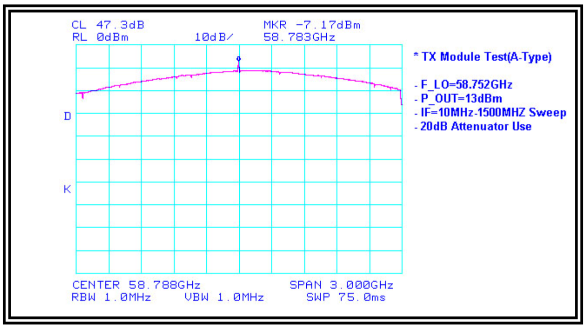


Fig. 13: Frequency response of peak output power for Tx module

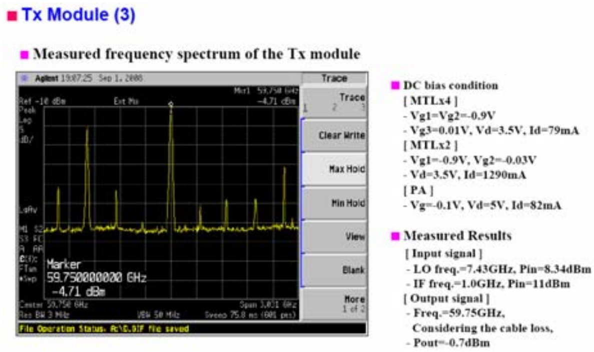
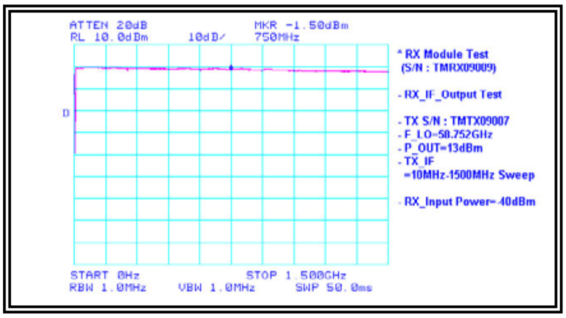
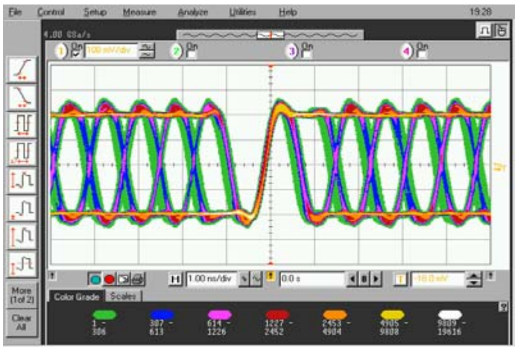


Fig. 14: Measure frequency spectrum of the LTCC Tx module

For high sensitivity of the Rx, low-noise and high-gain components should be chosen. The Rx IF output test is plotted versus frequency. The sweep frequency is from 10 MHz–1500 MHz. The IF output is marked at -1.33 dBm with input power at -40 dBm. There is no resonance and oscillation problems occur at Rx module. The Rx performance is shown in figure 15. The NRZ Eye-Pattern is shown at the IF output level with data rate of 1.25 Gbps.



IF Output (Input Power=-40dBm)



IF Output Level
(Input Power=-40dBm, 1.25Gbps NRZ Eye-Pattern)

Fig. 15: LTCC SoP Rx with 7 order LPF module

Isolation for Tx and Rx position need to be considered as it is required to avoid any signal losses during transmitting. Isolation of greater than 80 dBc is required between the Tx and Rx block [16]. Figure 16 shows the EM distribution of two RF paths. When the Tx and Rx block is placed in the same area of the transceiver module, the isolation requirement should be satisfied. There is no resonance and oscillation problems occur at Transceiver (TxRx) module. Figure 17 shows the TxRx module test result and figure 18 shows the ASK 60 GHz transceiver module assembled in a metal housing with DC bias circuits.

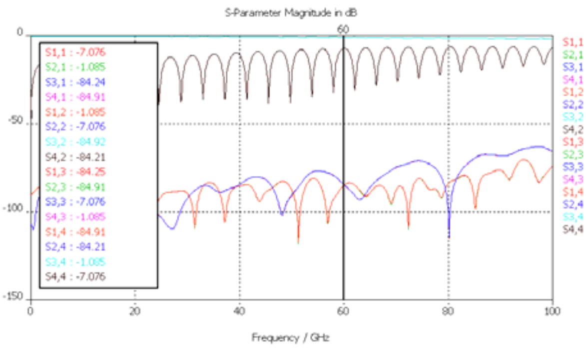
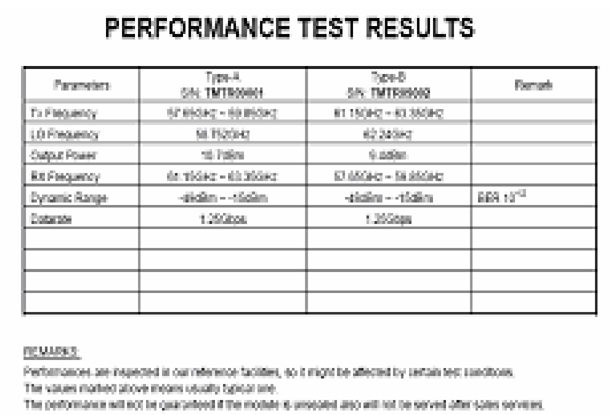


Fig. 16: Simulated s-parameters results with via fence



PERFORMANCE TEST RESULTS

Parameters	Type-A S/N: TMTR00001	Type-B S/N: TMTR00002	Remark
Tx Frequency	57.65GHz ~ 59.85GHz	61.15GHz ~ 63.35GHz	
LO Frequency	58.75GHz	62.24GHz	
Output Power	10.7dBm	6.0dBm	
Rx Frequency	61.15GHz ~ 63.35GHz	57.65GHz ~ 59.85GHz	
Dynamic Range	-49dBm ~ -15dBm	-45dBm ~ -15dBm	BER 10^{-12}
Datarate	1.25Gbps	1.25Gbps	

REMARKS:
Performances are inspected in our reference facilities, so it might be affected by certain test conditions.
The values marked above means usually typical one.
The performance will not be guaranteed if the module is unsealed also will not be served after-sales services.

Fig. 17: LTCC SoP Transceiver module test result

Fig. 18: LTCC ASK 60 GHz transceiver module in a metal housing with DC bias circuits

5 Conclusion

MMW technologies are becoming important for the high data rate communications of the future and research efforts are placed to reduce the cost of MMW front ends. TMR&D has developed key components to make PTP Wireless Gigabit Ethernet Communication System possible. It is now integrating the RF LTCC components into a complete link demonstrator for pilot testbed to test Wireless Gigabit Ethernet link, streaming video like HDTV (high definition television) or TiVo systems and obtain outdoor propagation data. Again, the 60 GHz band is available unlicensed worldwide.

This 60 GHz technology can provide new businesses and business models such as corporations and wireless hot spots which may provide Gigabit Ethernet connectivity, as well as video, to its customers. One of the main applications of these radios is replacement of fiber at the last mile.

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