Design and Implementation of Wireless Embedded Systems at 60 GHz Millimeter-Wave for Vehicular Communication

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ABSTRACT: *Globally, there is a burning desire for a communication system that provides high quality, high capacity and high speed information exchange and we need to develop an extremely spectrum-efficient transmission technology for the same. This paper describes a realistic capacity and BER comparison of a robust and secured multiple access schemes and develops a wireless embedded system at 60 GHz Millimeter-Wave using WiMAX waveform. The system is tested at the laboratory with multimedia transmission and reception but yet to be tested after mounting on the vehicles. Technical expertise are developed towards Simulink programming, methods of poring to VSG, IF and millimeter wave hardware, RTSA use, Data Acquisition and DSP. With proper deployment of this 60 GHz system on vehicles, the existing commercial products for 802.11P will be required to be replaced or updated soon. Simulation and implementation of the results will elucidate that a significant amelioration in the spectral efficiency parameter can be achieved using the proposed WiMAX at 60GHz which provides both frequency diversity and spectral efficiency to yield a powerful and affordable solution for super-high speed/4G transmission and ever-increasing requirement of high throughput in wideband multimedia communications and ITS in vehicular communication.*

Keywords: *AWG, C2C-CC, MC-CDMA, VSA, WiMAX and WMAN, 4G.*

I. INTRODUCTION

The communication and remote sensing technology are the two most important specialized sectors for electronics research today. Important developments and commercial applications are exploring those technologies. Safety and security are very important in car-to-car communication. It is even more important when wireless systems are used because it is generally perceived that wireless systems are easier to attack than wire line systems. In search of best, secured and reliable communication technology towards next generation e-car safety application, IEEE 802.16, an emerging wireless technology for deploying broadband wireless metropolitan area network (WMAN), is one the most promising wireless technology for the next-generation ubiquitous network. Though IEEE802.11P WiFi based products are commercially available for same functionality. But, disadvantages incurred in the Wi-Fi security have been addressed into the IEEE 802.16 standard and also flexibility parameters are also addressed in WiMAX. WiMAX is designed to deliver next-generation, high-speed mobile voice and data services and wireless "last-mile" backhaul connections [1].The University of Texas at Austin. IEEE 802.16e (Mobile WiMax) deals with the Data Link Layer security. The Data-Link Layer authentication and authorization makes sure that the network is only accessed by permitted users while the encryption ensures privacy and protects traffic data from hacking or spying by unauthorized users. The WiMAX 802.16e provides number of advanced security protections including:

strong traffic encryption, mutual device/user authentication, flexible key management protocol, control/ management message protection, and security protocol optimizations for fast handovers when users switch between different networks. Commercial products of vehicular networks exists viz. DENSO's Wireless Safety Unit (WSU), Hitachi-Renesas.

DENSO's Wireless Safety Unit (WSU) is the follow up envelopment to DENSO's first generation 802.11p communication module, the Wave Radio Module (WRM). The WSU is a feasibility test platform for communication protocol evaluation and application prototyping. It is specifically designed for automotive environments (temperatures, shock and vibration) and has its primary focus on safety related applications. During normal driving, the equipped vehicles anonymously share relevant information such as position, speed and heading. In a C2C environment message authorization is vital. The possibility to certify attributes and bind those to certain vehicles is particularly important for public safety.

Assuming no security, his attacker could generate valid messages for and consequently disturb the whole transportation system. While unlicensed spectrum around 2.5 GHz and 5 GHz is also available internationally; the amount of available 60G bandwidth is much higher than that around 2.5GHz and 5GHz. unlicensed spectrum surrounding the 60 GHz carrier frequency has the ability to accommodate high-throughput wireless communications. It is highly directive and can be used for long and directed link. 60GHz system enjoys the size reduction and cost reduction advantages. Additionally, due to availability of 5GHz bandwidth the data-rate for communication is more interesting. Many commercial products have been developed facing these challenges. The use of 60 GHz [2]-[8] MMW (millimeter wave) based communications for road safety is complementary to the DSRC and is currently under discussion in the C2C-CC (Car to Car Communication-Consortium manifesto). Since a vehicle can communicate with other vehicles both in front and behind it, the line-of-sight (LOS) condition is used to obtain the propagation path and able to reject multipath or jitter effects. In addition, it allows vehicle drivers and passengers several real time transactions while vehicles travel at highway cruising speed.

Thus, exploring the WiMAX 802.16e for its security, reliability and high throughput features, exploring 60 GHz millimeter wave as carrier for its size and cost reduction, wide bandwidth and highest throughput, the Car2Car communication system is required to be developed for the next generation Car for safety applications. The development of

60 GHz C2C communication system comprised of two step procedure discussed below. The MATLAB/SIMULINK is used for the design verification and simulation at the 1st stage. The final simulation result in the form of *.mdl file is ported to the ARB unit of one R&S VSG for the realization of the base band hardware. The transmit IF at 1 GHz and transmit RF at 60 GHz are realized through VSG and RTSA. The above system development efforts are discussed below. Section I will discuss the necessity of multiple antennas. Section III will discuss all about WiMAX simulation at the base band level. The successful development of section III will produce one *.mdl file which is ported to the VSG for base band hardware realization. Section III will discuss the efforts pertaining to hardware development.

II. Channel Capacities of MIMO Multiplexing and Multiple SIMO

The channel capacity of MC-CDMA and OFDM are compared in Fig. 1 as a function of the average Es/N0 with the number of transmitter or receiver antenna as a parameter. Fig. 1 shows that MC-CDMA always provides higher channel capacity as compared to OFDM systems irrespective of the number of transmitter or receiver antennas. As the number of antennas increases, capacities of MC-CDMA and OFDM increase. However, the capacity difference between MC-CDMA and OFDM for a fixed SNR becomes larger. From Figure 1, it is observed that MIMO multiplexing provides lower channel capacity than SIMO in a lower Es/N0 region. However, the channel capacity of MIMO multiplexing increases substantially in a large Es/N0 region owing to the spatial diversity and multiplexing. The capacity difference between MC-CDMA and OFDM is found to be smaller for SIMO and STBC than for MIMO multiplexing. The advantage of MC-CDMA over OFDM is the frequency diversity gain obtained from frequency domain spreading. However, the frequency diversity gain becomes relatively small compared to the spatial diversity gain when SIMO or STBC-MISO is used.

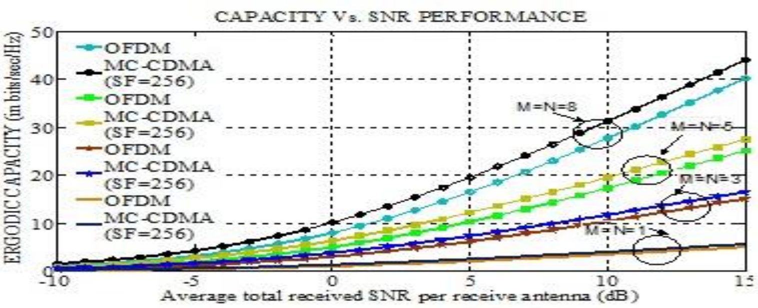

Fig. 1. Impact of number of antennas.

III. End-to-End Simulation of 60 GHz WiMAX Communication

The full WiMAX simulation is shown in the Fig. 2.The descriptions of some important blocks are as follows:

A. Data generator [MAC PDU] block under 'data' block:

The 802.16 standard is designed with the network and communication security keeping in considerations. Over the wireless link the robust security aspects are to be considered as the most important to control the confidentiality during data communication. In 802.16 standards, the security keys and encryption techniques are involved as shown in the Fig. 3. It has the similarity in concepts of adopting the security parameters as of IP sec. After the authorization from Security Association, the X.509 certificate, consists of an authorization key (AK), a key encryption key (KEK), and a hash message authentication code (HMAC) key, which are used for authorization, authentication, and key management [6] Here in the following model, we have 10 blocks utilized for message authentication and security management.

From the top to bottom, those blocks are: (i) HT: Header Type, (ii) EC: Encryption Control, (iii) Type: Payload Type, (iv) RSV: Reserved, (v) CI: CRC Identifier, (vi) EKS: Encryption Key Sequence, (vii) RSV: Reserved, (viii) LEN: Length of Packet, (ix) CID: Connection Identifier and (x) HCS: Header Check Sequence.

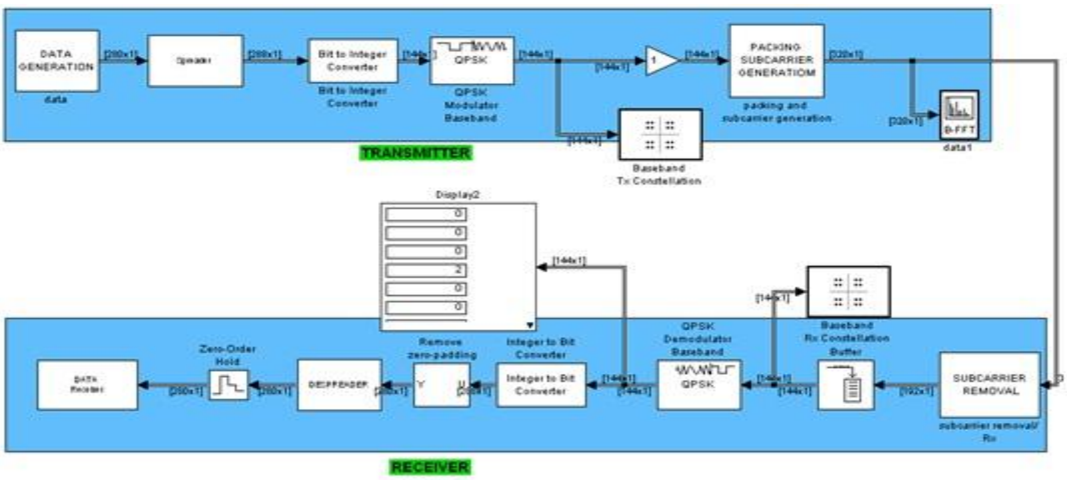

Fig. 2: The Simulink model of WiMAX transmitter and receiver.

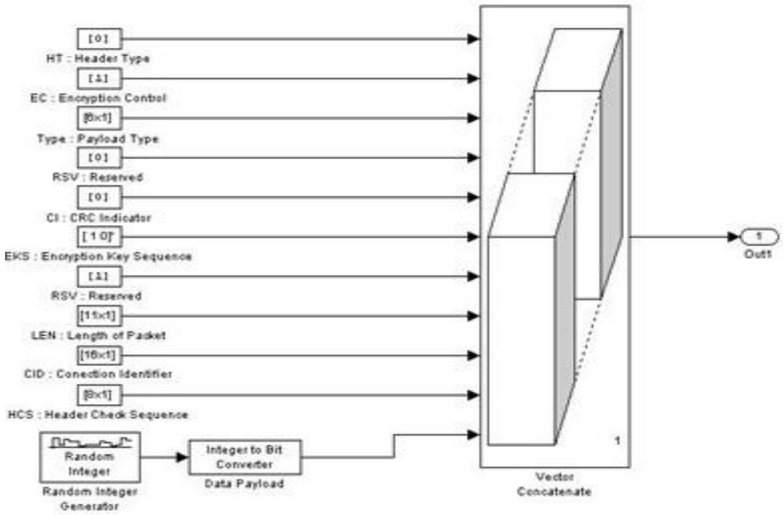

Fig. 3: The MAC PDU generator including header scheme and payload.

In terms of message authentication, there are some important shortcomings in IEEE 802.16 standard implemented at the MAC Layer. To avoid the serious threats arise from its authentication schemes, the WiMAX involves a two-way sequential transactions for controlling, authorization and authentication. During the basic and primary connection, MAC management messages are sent in plain text format which is not a robust type of authentication and so can be easily hijacked over the Air and this can be done by the attacker once again. So, as per the X.509 Certificate, the Public Key Infrastructure (PKI) defines a valid connection path to identify a genuine Security Systems. It uses RSA Encryption with SHA1 hashing. The certificate, as pre-configured by the specific manufacturer and embedded within the system must be kept secret so that it cannot be stolen by other users/vendors. A Security System that is certificated by a particular manufacturer is implemented in a Base Station (BS) and the particular BS cannot know the internal standards priory. Since, mutual authentication verifies the genuineness of a BS, it should be present in any wireless communication as it is virtually open to all. Extensible Authentication Protocol (EAP) is mostly utilized in any WiMAX Base Stations as to protect IEEE 802.16 / WiMAX against masquerading parties. Fig. 4 represents the base band spectrum. The incoming signal is XOR'd with the bit pattern generated by a PN sequence generator. This is further zero padded to increase the frame size to 288×1. The Chip sample time is 1/1000 S, so the chip rate is 1 KHz. The spectrum after spreading looks like as shown in the figure 8 below: The bit pattern generated after this is fed into a bit to integer converter and then to a QPSK modulator. Fig. 5 shows spectrum after spreading.

After the QPSK modulation, pilot is inserted which helps in channel estimation. Here 192×1 input stream is broken down into 10 different data pipes and pilots inserted in between them according to the above figure. All the rows of the resulting data are combined before feeding it to the IFFT block for sub carrier generation in time domain and then cyclic prefixing to add guard time.

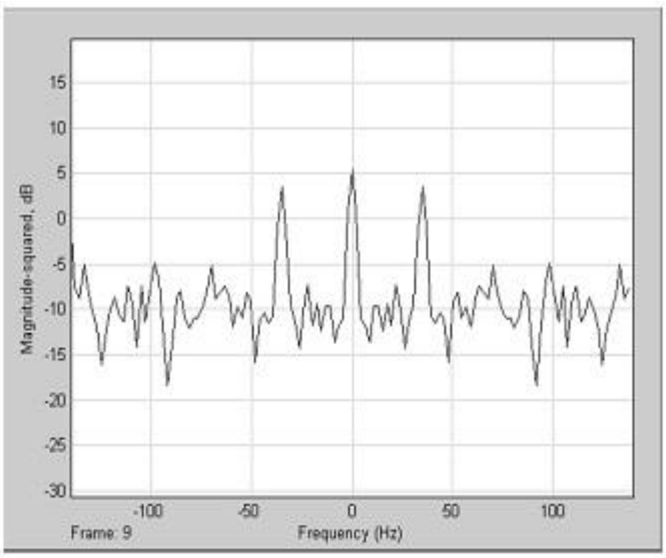

Fig. 4: Base band spectrum.

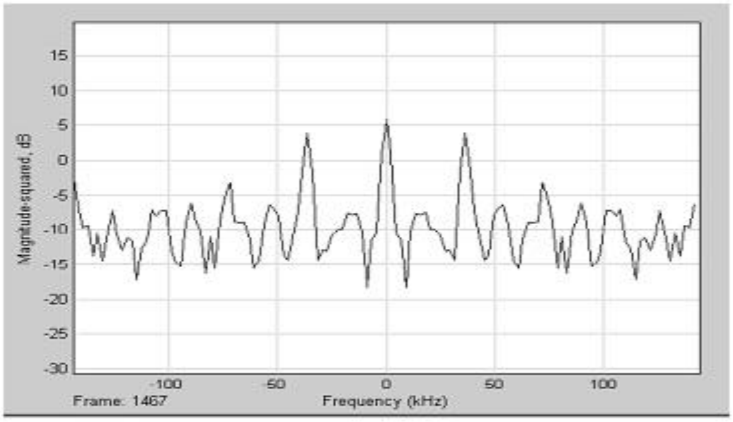

Fig. 5: Spectrum after spreading.

IV. Hardware Implementation of the 60 GHz System

The block diagram of a 60 GHZ transmitter and receiver Sub System can be shown (Fig. 6) as follows.

A. Description of Transmitter Section

The prototype model of the 60 GHz transmitter is shown in Fig. 7 and Fig. 8 shows the final transmit spectrum. The PC is used to program the VSG using MATLAB/ SIMULINK for the generation of two orthogonal basis functions. In the base band section we programmed the ARB section of the VSG to generate the base band WiMAX signal and it is then up converted to IF level of 1 GHz and fed to the 60 GHz varactor tuned Gunn oscillator, which is supplied with 4.7-volt dc voltage obtained from a combination of regulated power supply and precision regulator. The basic block diagram is shown in the Fig. 9. The varactor terminal is connected with the signal to be transmitted so that the desired signal is up converted to millimeter wave by this process. The Gunn oscillator is followed by 60 GHz attenuator and frequency meter for the control and frequency measurement of 60 GHz transmitted signal respectively. The 2 feet parabolic disc antenna is connected at the output for radiation of 60 GHz signal.

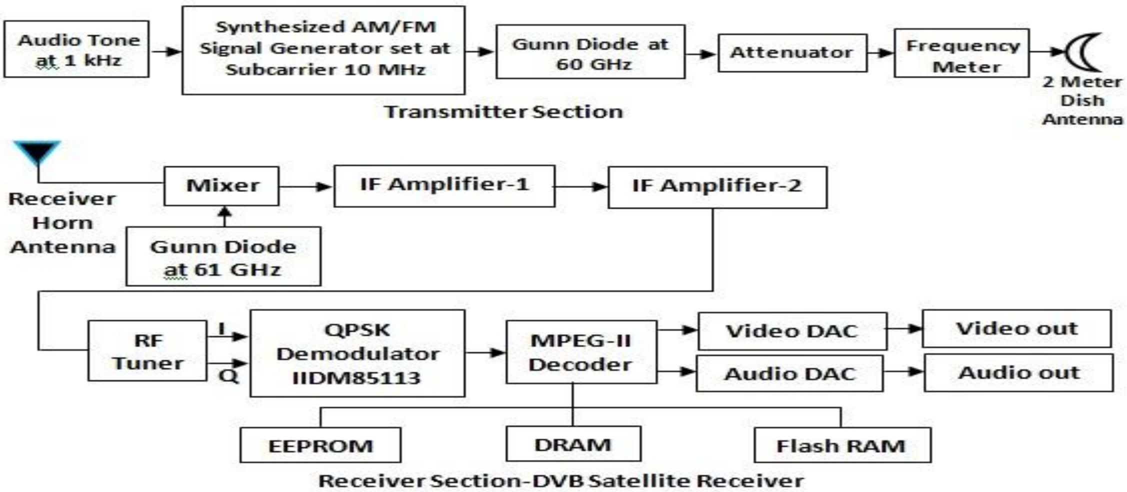

Fig. 6: Block Diagram of a 60 GHZ TX-RX Sub System.

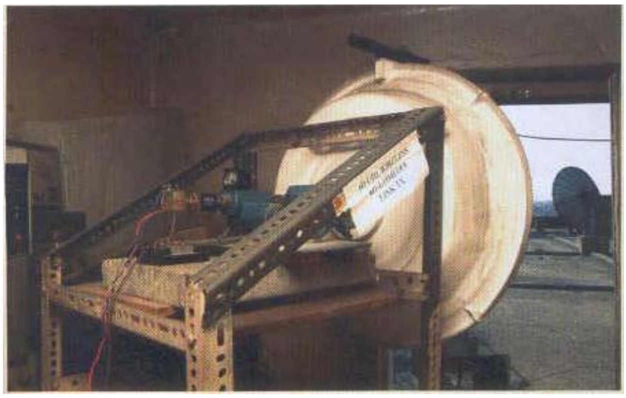

Fig. 7: The 60 GHz Transmitter.

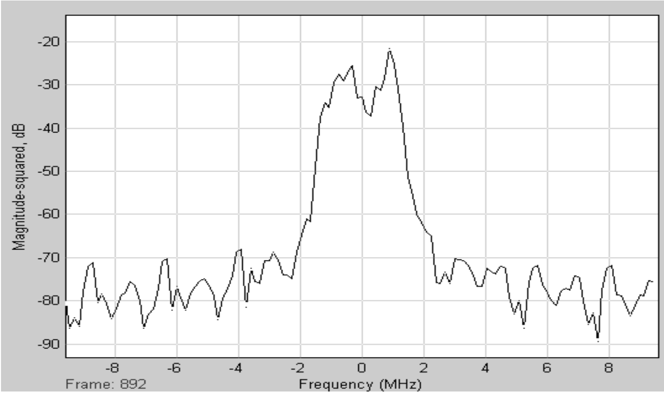

Fig. 8: The final transmit spectrum.

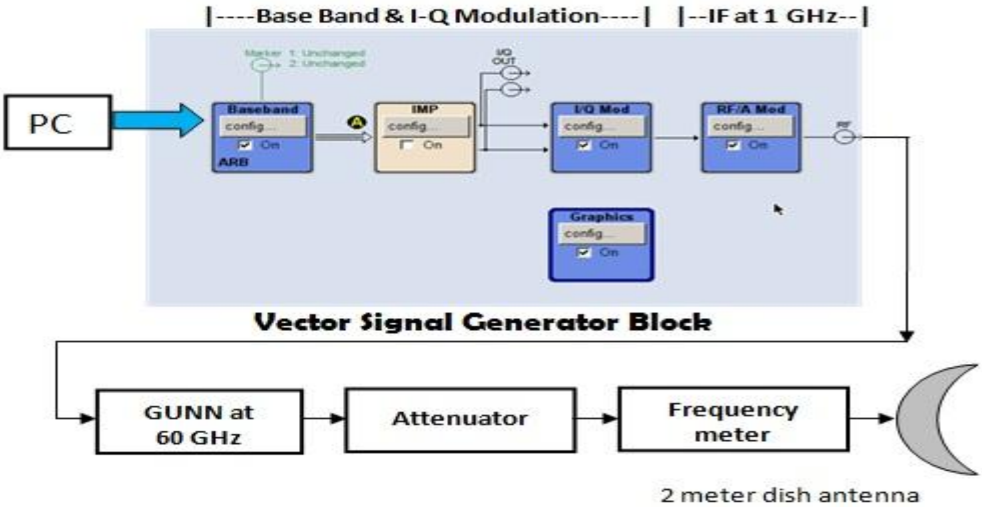

Fig. 9: Block diagram of the WiMAX Transmitter.

B. Performance Analysis of WiMAX Radio Sub System at 60 GHZ

The measurement of various parameters of the 60 GHz LOS link has been determined as follows.

C/N ratio measurement

The modulation source is switched off during this measurement and received IF spectrum having a C/N ratio of 51.89 dB is obtained as in Fig. 10. The obtained C/N ratio is greater than the (C/N) Threshold value which is around 8.4dB.The finer critical adjustment of the antenna is only possible by observing the spectrum and maximizing it and that should be at least the threshold level.

Received I/Q spectrum with/without carrier signal

The demodulated signal at the receiver is reshaped by means of a complementary square root raised cosine filter. In compliance to the filter at the transmitting end, the roll-off factor α is 0.35. This results in an acceptable level of interference with adjacent channels. The I channel spectrum at the output of the RF tuner is shown in Fig. 11. As measured, the one sided bandwidth of this spectrum is 50 MHz which dictates a maximum symbol rate per channel of 74 Ms/s. According to Nyquist criterion, the bandwidth (B) occupied by the pulse spectrum is $B = (rs / 2)(1 + \alpha)$, in which rs represents the symbol rate and α is the filter's roll off factor, where $\alpha = 0.35$. The data rate per channel is 148 Mbps.

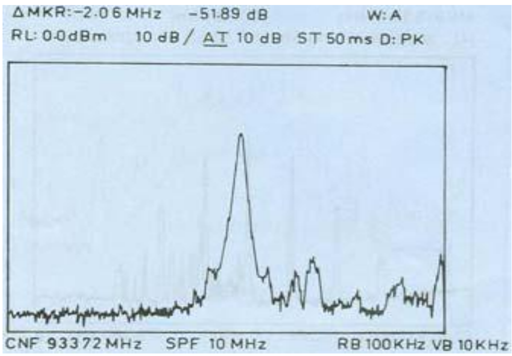

Fig. 10: C/N ratio measurement using spectrum analyzer.

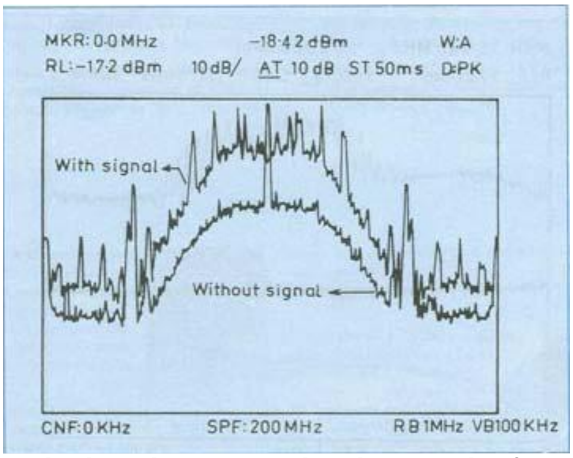

Fig. 11: Received I channel spectrum with/without signal in frequency domain.

<u>Received I/Q waveform with/ without signal in time domain</u>

The received I channel waveform with/without RF signal is shown in the Fig. 12.

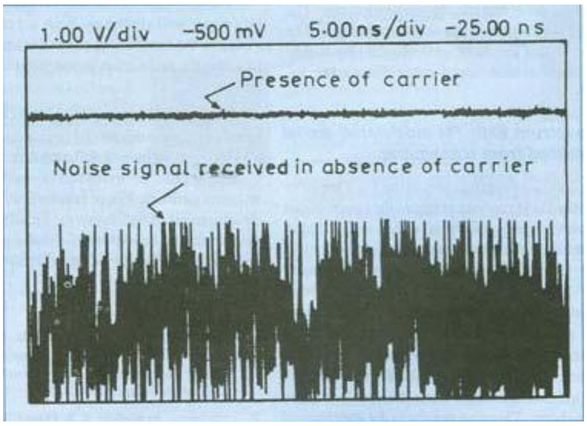

Fig. 12: Received I channel waveform with/without signal in time domain.

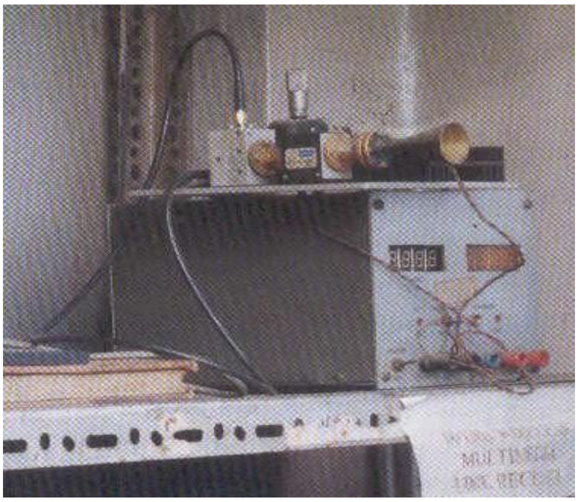

Fig. 13: The 60 GHz Received RF Front End.

C. Description of Receiver Section

The prototype model of the 60 GHz receiver is shown in Fig. 13. The block schematic diagram is shown in Figure 13 where the receiver consists of a front end, which receives signal through a horn antenna. There is another Gunn oscillator generating 61GHz frequency. These two frequencies are fed to a mixer and produces 1GHz signal at the output. This signal is further amplified by two IF amplifiers and is fed to input of the DVB satellite receiver tuner. The I-Q signal from the receiver tuner is connected to the RTSA as shown in Fig. 14. Received spectrum with bandwidth is 1.75 MHz is shown in Fig. 15.We store the received I-Q data in RTSA for further analysis, as shown in Fig. 16.

The Received In-Phase and Quadrature-Phase Signals in Real Time Spectrum Analyzer is shown in Figure 16. Received WiMAX Sub-Carriers in RTSA is shown in Fig. 17.

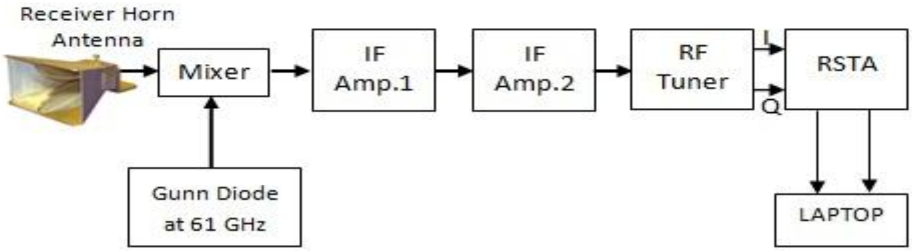

Fig. 14: Block diagram of the 60 GHz WiMAX receiver.

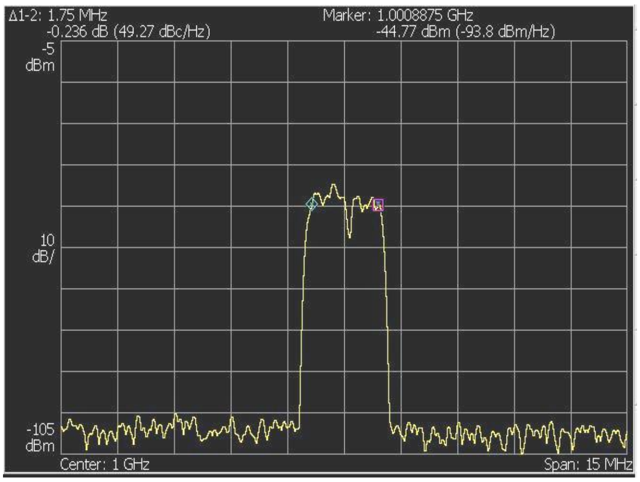

Fig. 15: Received spectrum with bandwidth is 1.75 MHz.

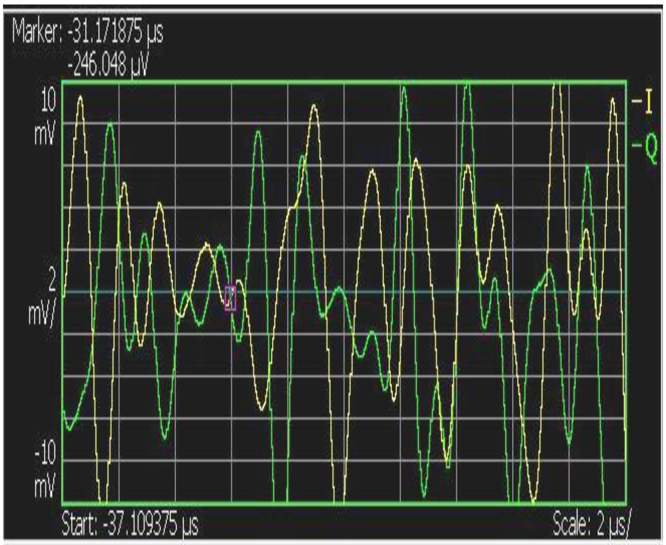

Fig. 16: Received I, Q Signals in RTSA.

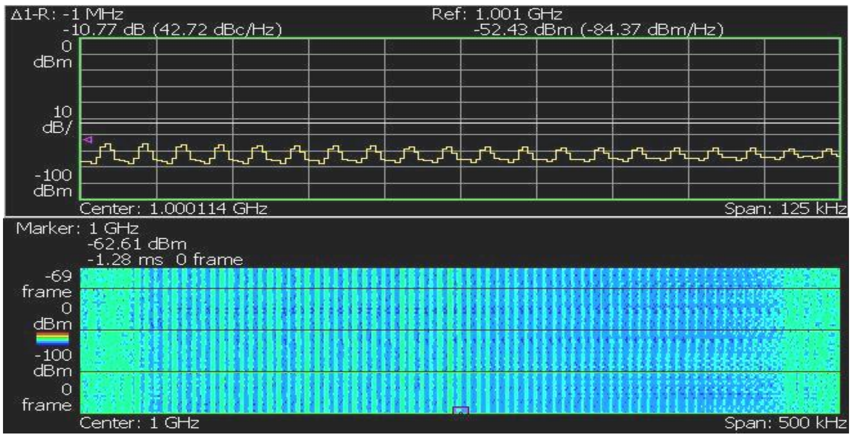

Fig. 17: Received WiMAX Sub-Carriers in RTSA.

V. CONCLUSION

In this study, we have investigated the effect of spectral efficiency of hybrid system with various traditional multiple-access communications schemes. It is then noticed that MC-CDMA - MIMO can approach the capacity of multiple SIMO while OFDM- MIMO cannot do so. Finally Wireless Embedded Systems using WiMAX waveform at 60 GHz Millimeter-Wave is being implemented using VSG and RTSA. Hardware was programmed from Work Station using MATLAB/SIMULINK for its vehicular realization. With proper deployment of this 60 GHz system on vehicles, the existing commercial products for 802.11P will be required to be replaced or updated soon and we look forward for the improved society with intelligent vehicles.

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