Range Optimization for DSRC and 5G Millimeter-Wave Vehicle-to-Vehicle Communication Link

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***Abstract*— The Dedicated Short Range Communications (DSRC) band (5.85-5.925 GHz) allocated for vehicle-to-vehicle (V2V) communication provides limited opportunities for high speed data transfer. Alternatively, high speed communication of at least 1Gbps is possible in the millimeter-wave (mm-wave) bands. To overcome the propagation losses associated with mm-wave frequencies, high gain radio architectures are required. In this paper, we present a novel dual-band V2V receiver architecture for both DSRC and 28GHz communications. For each band, we optimized antenna gain and number of elements to maximize range and data rate. For simplicity, free space path loss model was used for link budget estimation. Results show that an antenna array of at least 9×9 element is required to achieve a maximum data rate of 27Mbps at 5.9GHz and a range of 867m. At 28GHz, the same 9×9 dual band array is capable of transmitting high speed signals at a rate of 1Gbps with coverage of 688m.**

Keywords—link budget; V2V; antenna gain; DSRC; millimeter-wave

I. INTRODUCTION

In the U.S., road accidents claim at least 100 lives daily [1]. Today's cars have various technologies to improve the safety of drivers such as RADAR, LIDAR, global positioning systems (GPS), and cameras. However, these technologies have few challenges. For instance, LIDAR and RADAR require Line-of-Sight (LoS) for accurate positioning and hence fail to detect hidden vehicles. Also, cameras and LIDAR risk to provide false information during extreme weather conditions. Further, connected vehicles cannot solely depend on their own collected measurements.

The Federal Communications Commission (FCC) allocated 5.85-5.925 GHz for Dedicated Short Range Communications (DSRC) Vehicle-to-Vehicle (V2V) communication in Intelligent Transportation Systems (ITS) Radio Service [2]. Vehicular communication offers solution for traffic congestion using virtual traffic light (VTL) algorithm which allows traffic to flow smoothly in busy cities without using traffic lights. Studies showed that VTL can potentially reduce the average commute from 30.7 minutes to 18.3 minutes in Pittsburgh [3]. Also current V2V communication technologies at 5.9GHz include sudden braking warning, intersection movement warning, hard braking, and motor cycle warning among others (see Fig. 1). Although DSRC enables communication and information sharing among nearby vehicles, it only provide a maximum data rate of ~27Mbps [4]. This rate cannot accommodate high speed communication such as video streaming of traffic and road accidents.

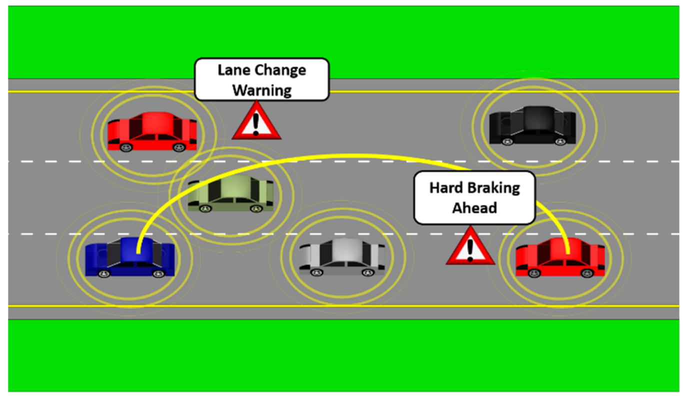

Fig. 1. An example of vehicle-to-vehicle communication

Alternatively, FCC plans to allocate bands in the millimeter-wave (mm-wave) spectrum for 5G V2V communication. Indeed, high speed communication of at least 1Gbps is possible at mm-wave frequencies. Also, mm-wave RF radios are smaller in size, implying inconspicuous integration on cars. However, communication in the mm-waves requires overcoming the high path losses and attenuation due to rain [5]. Therefore, there is need to develop V2V radios for future 5G mm-wave communication without sacrificing the well-established capabilities at 5.9GHz.

To address the abovementioned requirements, we present a novel dual-band RF transceiver architecture, operating at both 5.9GHz (DSRC) and 28GHz (5G V2V) using a single antenna aperture. Notably, implementing a single platform for dual-band operation implies reduction in the number of radios on a single vehicle. In this paper, a dual-band array is designed and optimized for maximum range and data transfer at both 5.9GHz and 28GHz.

II. RF TRANSCEIVER ARCHITECTURE

Our system consists of dual-band phased array, dual-band RF transceiver architecture, and digital beamformer, operating at both 5.9GHz and 28GHz. The RF front-end of our dual-band system is depicted in Fig. 2. The focus of this paper is to optimize array dimensions for maximum range and data rate. The link budget of the V2V communication link is estimated using free space path loss model, for simplicity.

A. Antenna Gain

We designed a simple dual-band dipole antenna array operating at both DSRC 5.9GHz and 5G V2V 28GHz, as illustrated in Fig. 3. As shown, the array is well-matched (S_{11}< -10dB) from 5.66GHz to 6.74GHz, and from 18.58GHz to 33.9GHz. Also, the realized gain of the simulated array's unit cell is -9.2dBi at 5.9GHz and 4.4 dBi at 28GHz, which is near theoretical in both cases, as shown in Fig. 4.

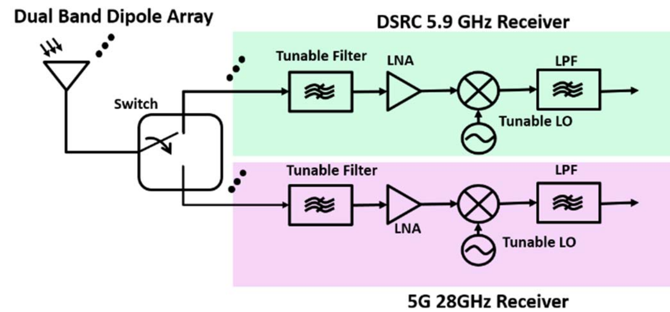

Fig. 2. Novel dual-band RF front-end for DSRC 5.9GHz and 5G 28GHz V2V communication

The total number of antenna elements and hence the total required array gain is computed by conducting link budget at both 5.9GHz and 28GHz. Our aim is to design V2V communication links that are capable of transmitting information over distance >500 m at both frequency bands. We note that DSRC is limited to 10MHz. Hence, the maximum data rate that can be accommodated in this frequency band is 27Mbps, assuming 64-quadrature amplitude modulation (QAM) with coding rate of 3/4 [4].

B. Link Budget Analysis

To compute the link margin (M) we use [6]

$$M = \frac{G_t G_r P_t}{\kappa T_S R L_0 L_S \left(\frac{E_b}{N_0}\right)_{req}} \tag{1}$$

where G_r ,G_t are the gain of receive and transmit antennas, respectively. P_t is the transmitted power (dBm). R is the data rate. L_0 represents circuit losses as well as other losses. κ is the Boltzmann's constant ($1.38 \times 10^{-23}\, J/K$). T_s is the effective system noise temperature. $\left(\frac{E_b}{N_0}\right)_{req}$ is the required $\frac{E_b}{N_0}$ (energy per bit to noise spectral density ratio) that is based on the modulation scheme. Finally, L_s is the free space path loss, represented as [6]

$$\textit{Free Space Path Loss } (L_s) = \left[\frac{4\pi d}{\lambda}\right]^2 \tag{2}$$

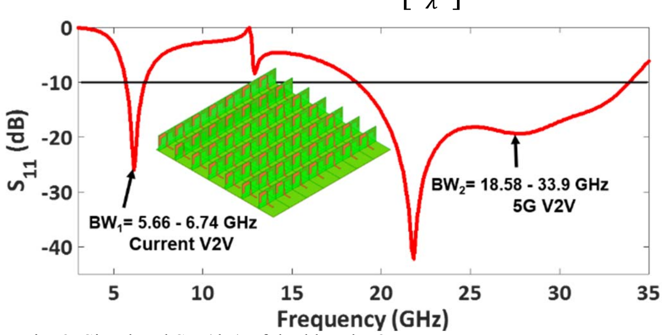

Fig. 3. Simulated S_{11} (dB) of dual band V2V array

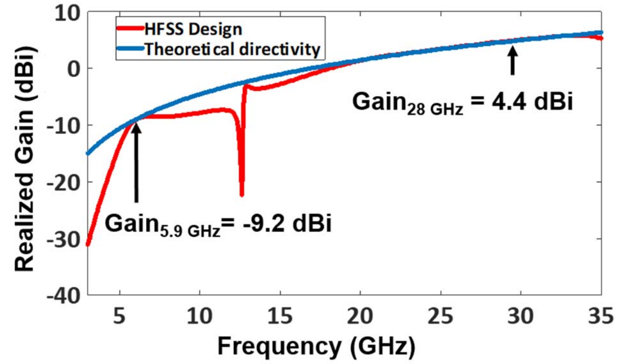

Fig. 4. Simulated and theoretical gain of dual band V2V array

where d is the distance between the transmitter and the receiver. As seen in (2), the path loss increases with frequency. However, such losses can be compensated for by increasing the transmit and receive antenna gain (refer to (1)). For effective communication, we would like to keep the link margin M >10dB. This is usually enough to account for additional and unpredictable losses due to rain and other weather conditions.

In our analysis, we assume the overall circuit losses L_0 = 5dB, receiver front-end noise figure F = 6dB, and receiver antenna temperature T_A = 290K. Considering these values, the overall system's temperature is calculated using formula, $T_s = T_A + (F-1)290$ = 1154.5K or 30.62dB-K.For a 64-QAM, a minimum $\frac{E_b}{N_0}$ of 18.8dB is required to achieve a bit error rate (BER) of 10^{-6} [4].

We note that the maximum allowable Equivalent Isotopically Radiated Power (EIRP) at 5.9GHz is 44. dBm [7]. Therefore, assuming a transmit power of 27dBm (0.5W), our antenna gain should not exceed 17.8dBi. Using (1), we found that, to achieve a link margin M ≥ 10 dB, a data rate transfer of 27Mbps, and a range of 867m at 5.9GHz, the total antenna gain should be 9.9dBi. Since unit cell's gain is -9.2dBi at 5.9GHz (refer to Fig. 4), at least 9×9 (additional 19.08dB) elements are required to achieve a total array gain of 19.08-9.2=9.9dBi. At 28GHz, the 9×9 element array achieves a realized gain of 23.4dBi. Plugging these numbers in (1), we find that, the system is capable of transmitting up to 1Gbps at 28GHz and across a range of 688 m. Table I summarizes the link budget analyses at both 5.9GHz and 28GHz bands.

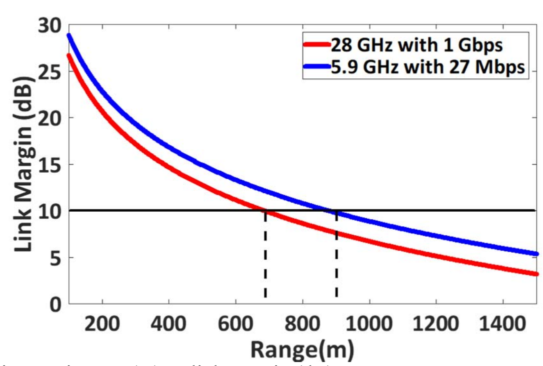

Fig. 5. Distance (m) vs link margin (dB)

III. CONCLUSION

In this paper, a novel dual-band V2V receiver architecture for both DSRC and 28GHz communication is presented. Link budget analyses have been conducted at DSRC 5.9GHz and 5G 28GHz V2V communication assuming free space path loss model. Results showed that our dual band array with at least 9×9 elements can effectively transmit information at a rate of 27Mbps with coverage range of 867m at 5.9GHz. Concurrently, our 9×9 dual-band array is able to achieve a high speed data rate of 1Gbps across a range of 688m.

Table I. *Link Budget Estimation at 5.9 GHz and 28GHz*

	DSRC 5.9GHz	**mm-wave 28GHz**
Transmit Antenna Gain	9.9 dBi	23.4 dBi
Receive Antenna Gain	9.9 dBi	23.4 dBi
Transmit power	27 dBm	27 dBm
EIRP	36.9 dBm	50.4 dBm
Required $\frac{E_b}{N_0}$	18.8 dB	18.8 dB
Free space path loss	-106 .6 dB	-118.1 dB
Data Rate	**27 Mbps**	**1Gbps**
Estimated Range	**867 m**	**688 m**
Link Margin (M)	10 dB	10 dB

ACKNOWLEDGMENT

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