HPA MMIC to W/G Antenna Transition Loss Analysis and Development Results of W-band Transmitter Module

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Abstract

This paper will read about a multichannel frequency-modulated continuous wave (FMCW) radar sensor with switching transmit (TX) antennas is developed at W-band. To achieve a high angular resolution, a uniform linear array consisting of 5 switching-TX and 12 receive (RX) antennas is employed with the digital beamforming technique. The overall radar front-end module comprises a W-band transceiver and TX/RX antennas. A multichannel transceiver module consists of 5 up-conversion and 12 down-conversion channels, where one of the TX channels is sequentially switched ON. For developing transmitter, we developed an HPA (high power amplified) MMIC chip for W-band radar system and fabricated a transmitter module using this chip. In order to develop the W-band transmitter, we analyzed the important antenna transition structure from HPA MMIC line to W/G (Waveguide)antenna via M/S(microstrip) and fabricated it with 5 transmission channels. As a result, the output power of the transmitter was within 1 dB of the error range after analysis and measurement under normal temperature and environmental conditions.

1. INTRODUCTION

Frequency-Modulated Continuous Wave (FMCW) radars at millimeter-wave frequencies have been widely used for industrial and military applications. They include automotive radars for a driver assistant system at 77/79 GHz and sensors for aircraft landing and obstacle avoidance at 94 GHz. In recent years, FMCW radar sensors for unmanned ground vehicles (UGVs) have attracted interest owing to their ability to accurately extract range and velocity information [1], [2]. They can also capture images around the vehicle by using angular data. Even in adverse conditions such as fog, rain, and dusty environments.

On this papet, we present a W-band FMCW radar sensor for UGV applications, where the switching-antenna technique is adopted in the TX to reduce the number of RX channels. At first, we developed an HPA(High Power Amplified) MMIC chip for transmission to FMCW radar. Second, we developed a W-band transceiver by applying these chips and analyzed transmission and characteristic structures from HPA MMIC line to W/G (Waveguide)antenna via M/S(microstrip). Also, electrical characteristics were compared with both room temperature and high environmental conditions.

2. ANALYSIS

Considering the characteristics of W-band radar development system, DDS (Direct Digital Synthesis) was used to generate FMCW waveform suitable for the system.
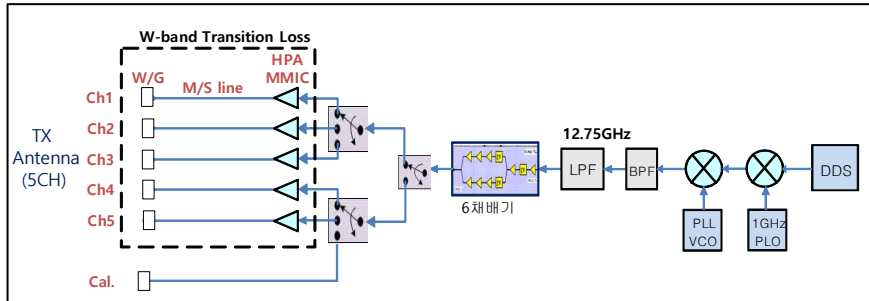

Figure 1. Block diagram of W-band transmitter module including w-band transition loss

Figure 1 Block diagram of W-band transmitter module including W-band transition loss and this block diagram uses the HPA MMIC of the W-band used for transmission output to transmit a signal of 10dBm or more at the transmission antenna output.[4] In addition, PDLRO to up-convert the IF signal (183.33MHz~216.67MHz) input from the DDS signal generator and uses a 6 multiplier to produce the desired output frequency.

Figure 2 shows developed HPA MMIC, a compact and broadband impedance transforming 90_ hybrid (from 50 to 25 X) is proposed. Unlike the hybrids proposed in [2], two coupled lines are used to reduce the circuit size, which still provides good return loss across a broad bandwidth. Then, a W-band broadband balanced PA is designed using a 0.15-lm GaAs pHEMT process using the proposed impedance-transforming 90_ hybrids. The designed PA including ITCLCs was fabricated by 0.15-lm GaAs pHEMT process with a 4mm thick substrate. Figure 3 shows the measured Psat and gain versus frequency from 75 to 80 GHz where Psat was over 16.7 dBm with gain of 6.7 dB. The frequency range in the measurement of Psat was limited by the W-band source module. Table 1 reported the performance of the reported W-band HPAs using 0.15-lm GaAs pHEMTs. The designed PA in this work exhibited an excellent BW performance with a high output power (P1dB) owing to the use of the proposed ITCLCs. [3]
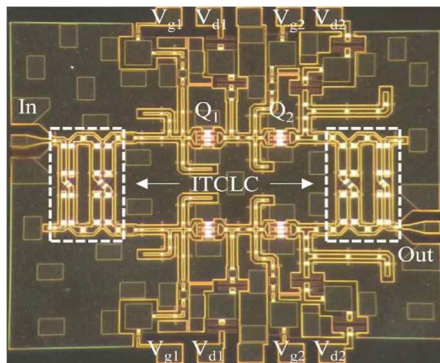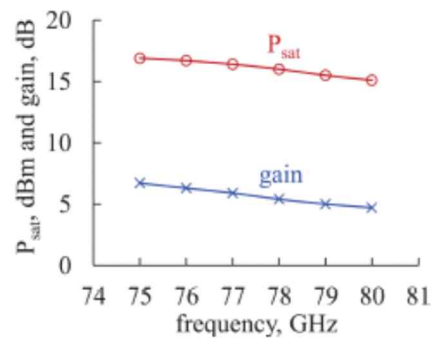

Figure 2. Photograph of fabricated W-band balanced HPA

Figure 3. Measured Psat and gain of balanced HPA versus frequency

Table 1. The development report of W-band HPA using a 0.15-um GaAs pHEMT process

Frequency (GHz)	Gain (dB)	Psat (dBm)	Chip area (mm^2)	3-dB BW (GHz)	
75	12	16.7	2.24	72-89	Room temperature conditions
75	12	13.5	2.24	72-89	(High temperature condition)

Figure 4 shows the design and fabrication results of the W-band micro strip line and the waveguide transition. There are various techniques related to the waveguide transition, but most of them include the Back short.

Here, a 6-layer substrate including Taconic TSM-DS3 and FR4 was used, and the RF power output without the Back short is output to the antenna through the micro strip line and the waveguide as shown in Figure 2. In this case, the physical characteristics are w1=1.91mm, w2=0.15mm, w3=0.30mm, L1=1.01mm and L2=0.815mm. The power from the M/S line radiates through the M/S patch antenna to the W/G. The dimensions of the designed M/S-to-W/G transition are shown in Table 2. The simulation and measurement results of the W-band transition as shown in Figure 4 were obtained. That is the insertion loss of the transition structure from the strip line to the waveguide is 1.5 dB @76.5 GHz, and the error of the loss of about 0.8dB was increased compared to the simulation 0.7dB. On the other hand, S11 shows 28.6 dB @76.5 GHz which is about 10 dB better than simulation. [5]
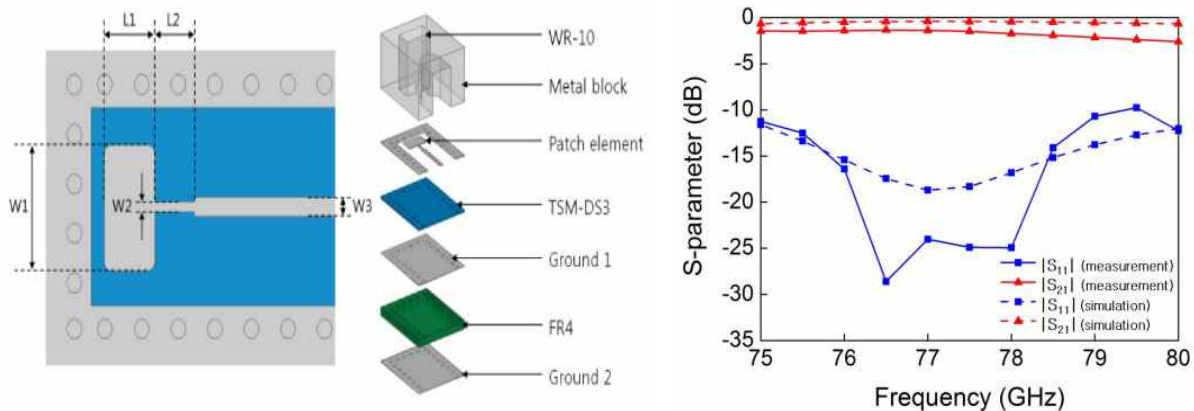

Figure 4. M/S(Microstrip) line to W/G(Waveguide) transition structure for W-band antenna connection and simulation results

Table 2. Dimension of waveguide transition structure for W-band antenna connection

W1	W2	W3	L1	L2
1.91 mm	0.15 mm	0.30 mm	1.01 mm	0.815 mm

Figure 5 shows test jig and test result of two wire bonding connection characteristics for 150 um length and 1 mil diameter in W-band. As a result, the insertion loss characteristics of 1.2 dB was confirmed. Figure 6 shows the structure for structural analysis of transition loss when HPA MMIC chip for domestic development transmission is used. The W/G transition structure and MSTL1, 2 (microstrip line1, 2) for connecting the antenna to the 6-layer Taconic substrate were designed. The HPA MMIC used the

transmission carrier to consider the process assembly and environmental conditions for 5 channel fabrication, and W-band transition structure was designed by wire bonding and ribbon bonding. Table 3 shows the shape of the transmitter (Figure 6) and analyzed the W-band transition loss value of the transmitter structure from HPA MMIC line to W/G antenna via M/S by 4.9 dB. As a result, we analyzed 11.8dBm at room temperature condition and 8.6dBm at environmental condition at high temperature using domestic developed HPA MMIC.
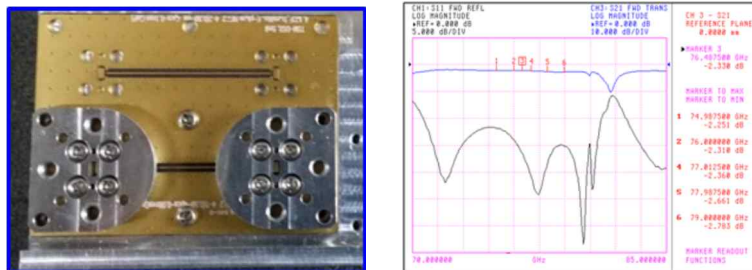

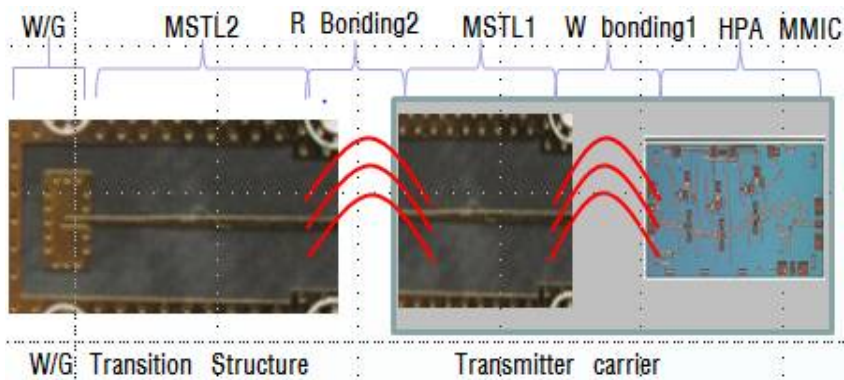
Figure 5. Wire bonding loss test jig and result

Figure 6. W-Band HPA MMIC to W/G transition structure of transmitter

Table 3. Transition structure and loss analysis from W-band HPA MMIC to W/G for antenna

Transition Loss	Detailed Loss Structure	Unit	Transmitter Power budget	Reference
HPA MMIC		[dBm]	16.7	Room temperature conditions
		[dBm]	(13.5)	(High temperature condition)
M/S line To W/G transition Loss	Wire bonding 1	[dBm]	1.2	Fig. 5.
	MSTL1	[dB]	0.5	5 mm length
	Ribbon bonding 2	[dB]	1.2	Fig. 5.
	MSTL2	[dB]	0.5	5 mm length
	Waveguide Loss	[dB]	1.5	Fig. 4.
Analyzed output power		[dBm]	11.8	Room temperature conditions
		[dBm]	(8.6)	(High temperature condition)

3. EXPERIMENTS AND RESULTS

Figure 7 shows manufactured transmitter configuration of W-band module. The multichannel frequency-modulated continuous wave (FMCW) radar sensor with switching transmit (TX) antennas is developed at W-band. To achieve a high angular resolution, a uniform linear array consisting of 5 switching-TX and 12 receive (RX) antennas is employed with the digital beamforming technique. The overall radar front-end module comprises a W-band transceiver and TX/RX antennas. A multichannel transceiver module consists of 5 up-conversion and 12 down-conversion channels, where one of the TX channels is sequentially switched ON.

Figure 8 shows the transmitter layout of W-band module that is connected 5 channel antenna by W/G. The total module dimensions are 225 mm×100 mm×57 mm.

Figure 9 shows the output power analysis and measurement results of the transmitter in 5 channels. At room temperature, the output power analysis value was 11.8 dBm while the measured values were at least 11.8 dBm and a maximum of 12.3 dBm. As shown in Table 4, at least 11.8 dBm was predicted at room temperature, with almost no error and it is considered that there were no manufacturing error in the assembling process. Similar results were obtained under the environmental conditions.

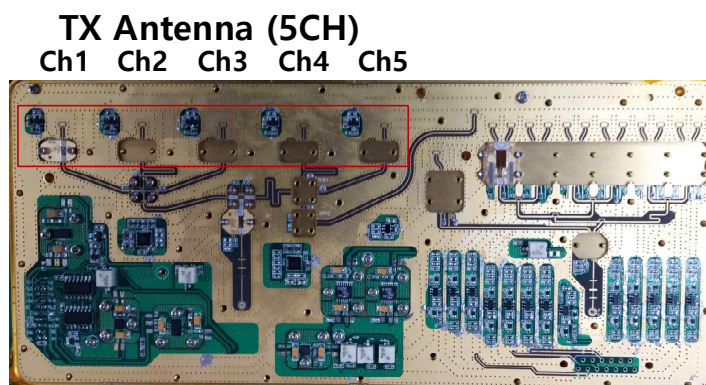**Figure 7. Transmitter configuration of W-band module**

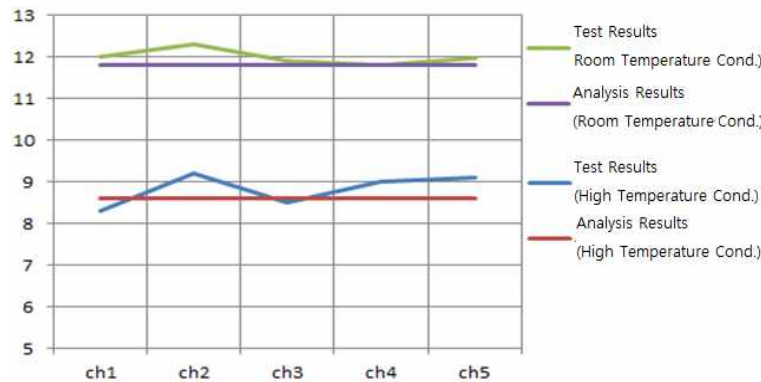**Figure 8. Transmitter Layout of W-band module**

Figure 9. Output power measurement results using domestic developed HPA MMIC chip

Table 4. Output power analysis and measurement comparison of transmitter

Transition Loss	Unit	Output power (Room temperature condition)	Output power (Environmental condition - high temperature)	Reference
Analytical value	[dBm]	11.8	8.6	Table 3
Measurement value	[dBm]	11.8~12.3	8.3~9.2	Fig.8
Analyzed output power	[dB]	Min 0.0	Min -0.3	
	[dB]	Max 0.5	Max 0.6	

4. CONCLUSION

This paper shows that we have developed a HPA (High Power Amplified) MMIC chip for W-band radar system and fabricated a transmitter module using this chip. In order to develop the W-band transmitter, we analyzed the transition structure from HPA MMIC to W/G(Waveguide) Antenna via M/S(microstrip), fabricated it with 5 transmission channels. And as a result, at room temperature, the output power analysis value was 11.8 dBm while the measured values were at least 11.8 dBm and a maximum of 12.3 dBm. The output power of the transmitter was within 1dB of the error range as a result of analysis and measurement under normal temperature and environmental conditions.

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