International Journal of Advanced Smart Convergence Vol.11 No.2 53-58 (2022)
http://dx.doi.org/10.7236/IJASC.2022.11.2.53

IJASC 22-2-8

W-band Frequency Synthesizer Development Based on Interposer Technology Using MMIC Chip Design and Fabrication Results

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Abstract

In this paper, w-band frequency synthesizer was developed for frequency-modulated continuous wave (FMCW) radar sensors. To achieve a small size and high performance, We designed and manufactured w-band MMIC chips such as up-converter one-chip, multiplier, DA (Drive Amplifier) MMIC (Monolithic Microwave Integrated Circuit), etc. And interposer technology was applied between the W-band multiplier and the DA MMIC chip. As a result, the measured phase noise was -106.10 dBc @1MHz offset, and the frequency switching time of the frequency synthesizer was less than 0.1 usec. Compared with the w-band frequency synthesizer using purchased chips, the developed frequency synthesizer showed better performance.

Keywords: *W-band, Frequency Synthesizer, MMIC, FMCW*

1. INTRODUCTION

FMCW (Frequency-Modulated Continuous Wave) radars at millimeter-wave frequencies have been widely used for industrial and military applications. These include automotive radars for a driver assistant system at 77/79 GHz and sensors for aircraft landing and obstacle avoidance. 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] - [9].

On this paper, we developed an up-converter one chip, multiplier and DA(Drive Amplifier) MMIC chips for w-band frequency synthesizer. In this article for up-converter one chip, which was designed and fabricated up-converter one chip MMIC for 2 port output power and it is located between DDS and W-band multiplier. The up-conversion MMIC includes an MMIC that receives a 2.5 GHz IF (Intermediate Frequency) value and up-converts it to an X-band signal and amplifiers the signal. In addition, it is integrated into one-chip for RF (Radio Frequency) and LO (Local frequency) paths, and high isolation is maintained within the one-chip. A 5-bit attenuator is included at the input stage so that it can operate flexibly according to the change of the input signal, and a switch is installed at the output stage to remove unwanted and harmonic waves using a filter

Manuscript Received: March. 25, 2022 / Revised: March. 29, 2022 / Accepted: April. 3, 2022
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outside the chip after frequency up-conversion in the mixer. [10]
In this article for multiplier chip, we present a ×8 frequency multiplier which rejects parasitic harmonics in early quadrupler, doubler stage creating a high harmonic suppression frequency multiplier. Amplification stages are added after quadrupler and doubler stage, respectively, for gain and increased output power level. Fabricated in 70-nm GaAs mHEMT process with f_{max}= 250 GHz, the ×8 frequency multiplier has 2.6 dBm output power, above 40 dBc harmonic suppression [11].

And this was fabricated based on interposer technology between multiplier and DA MMIC chip. The embedded IC package can integrate multiple ICs into a single package and the lithography process can be used to create geometrically well controlled short interconnection, which reduces parasitic components in high frequency bands and provides excellent electrical performance as well as excellent reliability. This eventually reduces the whole chip size. Recent research has shown that the combination of a lamination process and a silicon IPD (Integrated Passive Device) can also reduce the almost same size of a SoC (System-on-Chip) [12~13]. In this paper, we report on the design method of interconnection according to the material and structure and analyze the structurally generated parasitic resonance of embedded IC package. Then we conclude that the proposed interconnection, bonding wire and flip chip bump are compared [14~15].

2. DESIGN AND FABRICATION

The w-band frequency synthesizer of FMCW radar system is including such as DDS (Direct Digital Synthesis), Up-converter, multiplier and DA MMIC.

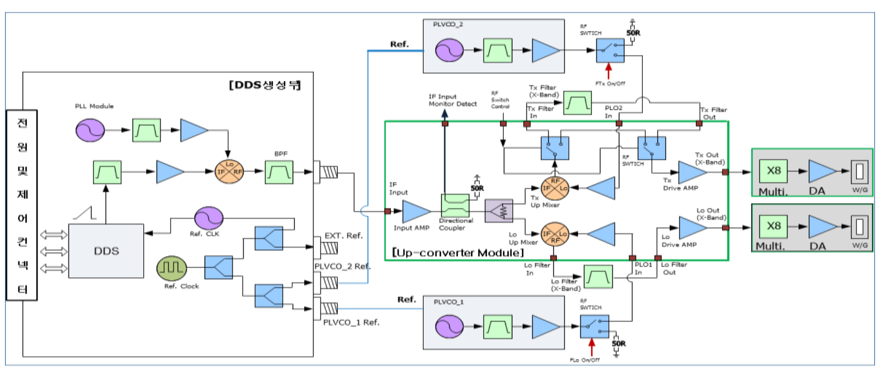

Figure 1. W-band Frequency Synthesizer including purchased MMIC chips (FS Ver. 1)

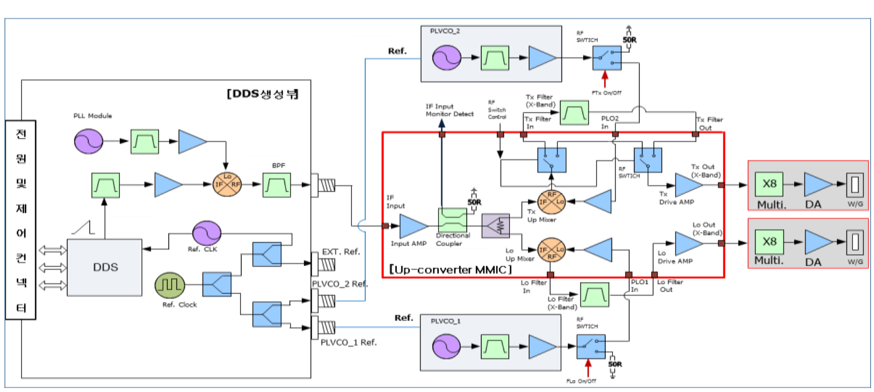

Figure 2. W-band Frequency Synthesizer including design and fabricated MMIC chips (FS Ver. 2)

Figure 1 shows the block diagram of w-band frequency synthesizer which is including the MMIC chips such as DDS, up-converter, multiplier and DA. And this is designed for the purpose of both 2 port output power both the transmitter and local of receiver. The frequency generator has a function of generating an input signal for transmitter of w-band and an LO input signal for a receiver using a reference frequency of 50 MHz. The two signals are branched from the reference signal, have coherent characteristics, and are designed to increase the purity of signal by using PLVCO(Phased Locked Voltage Controlled Oscillator) with low phase noise. By using high-speed DDS, frequency switching time is reduced, and in order to create various waveforms, not only FMCW waveforms and also pulse waveforms are implemented by using switches in the TX and LO paths. The synthesizer was composed of modules using commercial chips such as DDS, up-converter, multiplier, DA and else. Figure 2 shows also same block diagram with Figure 1 which is including domestic designed MMIC chips such as up-converter, multiplier and DA MMIC in red line box, and the rest were composed of modules using commercial chips for new design of synthesizer.

Figure 3 shows the designed and fabricated up-converter one chip MMIC for 2 port output power and it is located between DDS and w-band multiplier. The up-conversion MMIC includes an MMIC that receives a 2.5 GHz IF value and up-converts it to an X-band signal and amplifiers the signal. In addition, it is integrated into one-chip for RF and LO paths, and high isolation is maintained within the one-chip. A 5-bit attenuator is included at the input stage so that it can operate flexibly according to the change of the input signal, and a switch is installed at the output stage to remove unwanted and harmonic waves using a filter outside the chip after frequency up-conversion in the mixer. Figure 4 shows w-band x8 multiplier MMIC. The w-band highly efficient frequency octupler which is composed of a quadrupler followed by a w-band push–push frequency doubler was fabricated using a commercial 65-nm process. A microphotograph of the octupler as 8x multiplier is shown in Figure 4. The area of the chip is 0.74 mm^2, including the dc and RF pads and 0.43 mm^2 excluding pads. Figure 5 shows the fabricated DA MMIC at w-band.

Figure 6 shows fabricated interposer technology between dummy 1 and 2. The cavity is a square with one side of 820 µm and a depth of 120 µm. The bottom GND (ground) was made by Au-plating the entire surface of the cavity. Two dummy chips with a signal line length of 500 µm are mounted in cavity using epoxy. Dummy chip is GCPW (grounded coplanar waveguide) structure and ground is below 20 µ polymer. Chip GND is no direct connection to the cavity bottom GND. Between the chips, there is an interconnection line on the insulator. Interconnection is also GCPW structure and chip GND and bottom GND is connected to top GND by via holes. Figure 7 replaces the two dummy ICs shown in Figure 6 with the domestically developed 8x multiplier and DA MMIC, and applied the fabricated interposer technology between domestic designed 8x multiplier and DA MMIC. So Figure 4 and Figure 5 could be integrated and small the w-band frequency synthesizer.

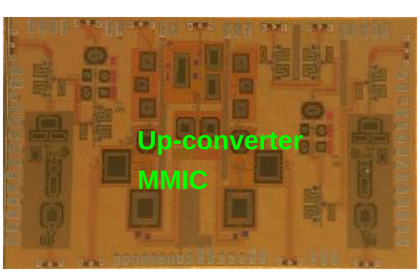

Figure 3. Up-Converter MMIC

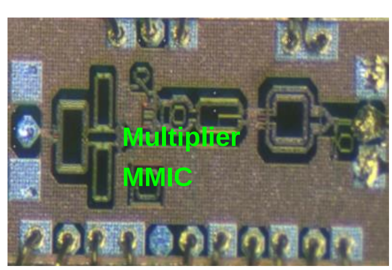

Figure 4. W-band x8 Multiplier MMIC

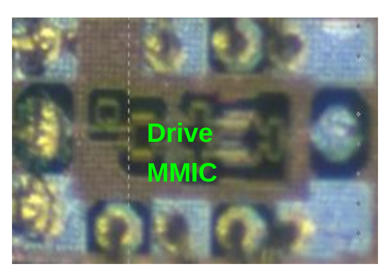

Figure 5. W-band DA MMIC

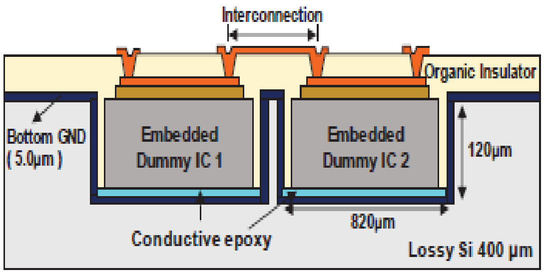

Figure 6. Fabricated interposer technology between Embedded Dummy IC 1 and IC2

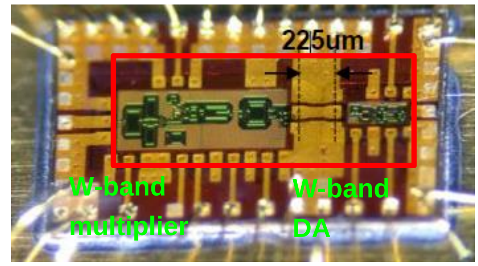

Figure 7. Fabricated interposer technology Between W-band multiplier and DA MMIC

Figure 8(a) shows the internal layout of the frequency synthesizer, and it is composed of a waveform generator module, PLVCO, filter up-conversion module, and w-band generator module including interposer technology. Figure 8(b) shows the overall shape of the frequency synthesizer, developed including the domestically developed up-conversion MMIC and x8 multiplier of Figure 4 and DA MMIC of Figure 5 with interposer technology of Figure 6 (FS Ver.2).

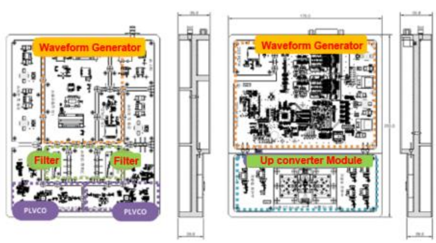

Figure 8. (a). Manufactured W-band DDS and Up-converter module layout of synthesizer (FS Ver.2)

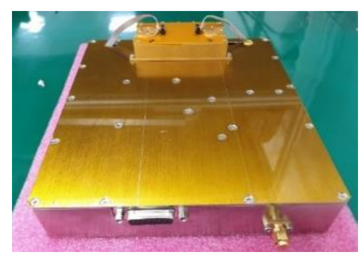

Figure 8. (b). Manufactured W-band frequency synthesizer (FS Ver.2)

3. MEASURED RESULTS

Table 1 compares the electrical characteristics of FS Ver.1 using overseas purchased MMIC and FS Ver.2 using domestically developed MMIC for the results of manufacturing the w-band synthesizer. It includes frequency and bandwidth of w-band, switching time and phase noise and spurious characteristics.

Table 1. Test results both FS Ver.1 and FS Ver.2

Items	FS Ver. 1	FS Ver. 2
Frequency	> 90 GHz (W-band)	> 90 GHz (W-band)
Bandwidth	> 1 GHz	> 1 GHz
Switching time	2.2 μsec	0.1 μsec
Phase noise @1Mhz offset	-98.0 dBc/Hz	-106.1 dBc/Hz
Spurious	> 45 dB	> 58 dB
Size	< 200*170*36 mm	< 160*140*31 mm

Figure 9 shows the frequency conversion switching time of the w-band frequency synthesizer. The characteristic result of Figure 9(b) using the domestically developed MMIC was 0.1 µsec, which was superior to the 2.2 µsec of Figure 9(a) using the overseas purchased MMIC. Figure 10 shows the phase noise @1MHz offset characteristics of the w-band frequency synthesizer. The characteristic result of Figure 10(b) using the domestically developed MMIC was -106.1 dBc/Hz, which was superior to the -98.0 dBc/Hz of Figure 10(a) using the overseas purchased MMIC. Figure 11 shows the spurious characteristics of the w-band frequency synthesizer. The characteristic result of Figure 11(b) using the domestically developed MMIC was 58 dB, which was superior to the 45 dB of Figure 11(a) using the overseas purchased MMIC. And the w-band operating frequency and band characteristics of 1 GHz or higher were simultaneously shown.

Figure 9. (a). W-band Switching time of FS Ver.1

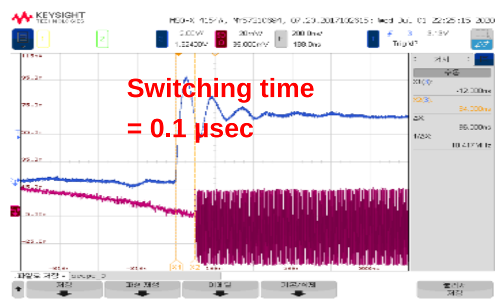

Figure 9. (b). W-band Switching time of FS Ver.2.

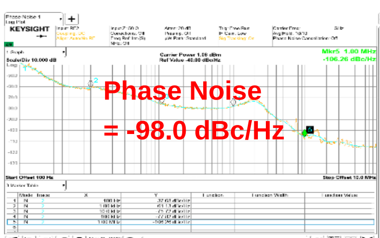

Figure 10. (a). W-band phase noise of FS Ver.1

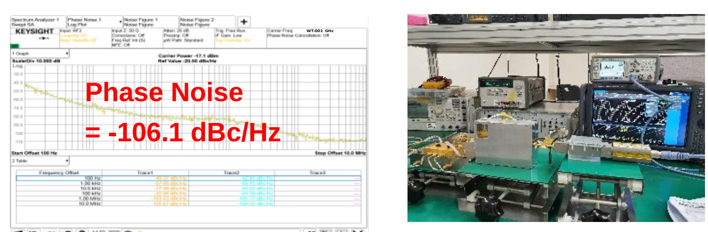

Figure 10. (b). W-band phase noise FS Ver.2

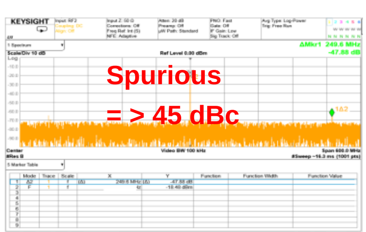

Figure 11. (a). W-band Spurous of FS

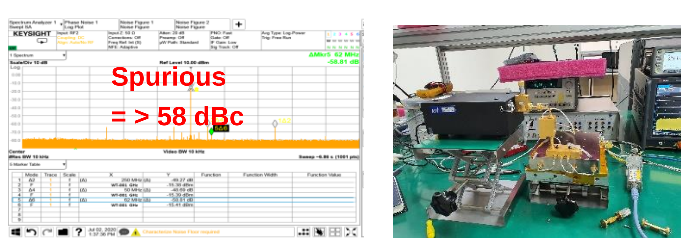

Figure 11. (b). W-band Spurous of FS Ver.2

4. CONCLUSIONS

In this paper, a new w-band frequency synthesizer was developed that includes a domestically desi gned w-band up-conversion one-chip, a multiplier, and a DA MMIC. As a result, as shown in FS Ver 2 in Table 1, it was confirmed that the measurement results of the domestically developed MM

IC and the frequency synthesizer applied with the interposer technology showed excellent electrical performance compared to the results of FS Ver 1 in Table 1.

Based on these results, it was confirmed that the w-band frequency synthesizer to which the dome stically developed MMIC and interposer technology was applied showed suitable characteristics to be applied to a small-sized FMCW radar.

ACKNOWLEDGEMENT

‘This work was supported by Agency for Defense Development under the contract UC170028FD.’

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