A 60 GHz Planar Phased Array Integrated with Even-Harmonic I/Q Mixers

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***Abstract* — A 60 GHz-band four-element integrated planar phased array is proposed. Each antenna element is integrated with even-harmonic I/Q mixer compromised of anti-parallel diode pairs (APDPs) for the adaptive beamforming systems.**

I. Introduction

The 60 GHz-band has been utilized for short-range and indoor broadband wireless communications. Oxygen absorbs this frequency band, leading to high atmospheric attenuation. However, Brankovic et al. suggested outdoor, underground, and large hall types of environment applications [1]. In order to effectively employ this frequency band in those complex environments, adaptive beamformers are one of the solutions because their antenna arrays can not only generate desirable radiation patterns, but also improve the capacity of systems with multi-channels including high data rates [2].

In this paper, a 60 GHz-band single integrated even-harmonic in-phase and quadrature (I/Q) mixer is designed and extended to a four-element integrated phased array for adaptive beamforming systems at 60 GHz-band frequencies [3]-[5].

There are three main advantages in the proposed phased array. First, RF circuits are integrated with a planar antenna to reduce interconnection losses that are a significant issue at millimeter frequencies. Moreover, compact and low-cost millimeter-wave RF modules can be realized [6]-[7]. Secondly, the even-harmonic I/Q mixers with anti-parallel diode pairs (APDPs) are employed. They can be operated using LO frequency, half of the RF frequency instead of an expensive millimeter-wave source. APDPs enable LO noise suppression and require no bias circuit [7]. Therefore the 60 GHz phased array integrated with the even-harmonic I/Q mixers can be easily implemented. Lastly, I/Q output channels can provide high system throughput for adaptive beamforming system applications as well as reduce the post-stage signal processing [3]-[6].

II. 60 GHz-Band Integrated Antenna Array Design

A. 60 GHz-Band Single Integrated Antenna with Even-Harmonic I/Q Mixer

In order to design a four-element integrated phased array, a single integrated planar antenna with even-harmonic I/Q mixer on alumina substrate (ε_r = 9.8 and h = 5 mils) is first designed as shown in Fig. 1.

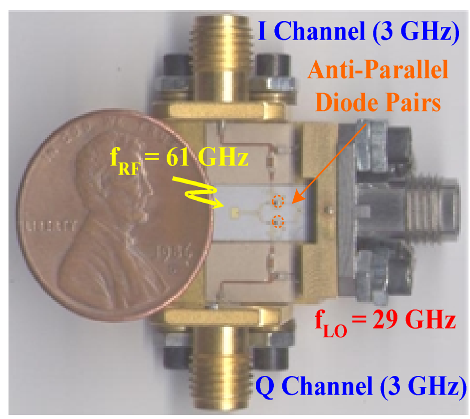

Fig. 1. The photograph of the single Integrated even-harmonic I/Q mixer at 61 GHz.

The operating RF and LO frequencies are 61 GHz and 29 GHz, respectively. The even-harmonic I/Q mixer consists of two pairs of APDPs (Agilent HSCH-9251), open and short stubs, a 45° phase delay line at 29 GHz, and Wilkinson power dividers for the RF of 61 GHz and the LO of 29 GHz, respectively. The two-stage low pass filters with cutoff frequency of 4.5 GHz on duroid substrate (ε_r = 10.2 and h = 10 mils) are connected to IF ports to prevent LO and RF leakages from flowing into I and Q output channels. In order to block the RF and the LO leakages and obtain lowest conversion loss, open and short stubs around the even-harmonic mixer are optimized to be a $\lambda/4$ length at the LO and a $\lambda/2$ length at the RF [6]. Bandpass filters at both the RF and the LO paths are designed for IF decoupling.

Figure 2 shows the phase deviation of 3.5° from the reference of the quadrature phase, while Figure 3 shows the power imbalance of 1.6 dB in the frequency range of 60.5 GHz and 61.5 GHz. Two graph show good balance between I and Q channels.

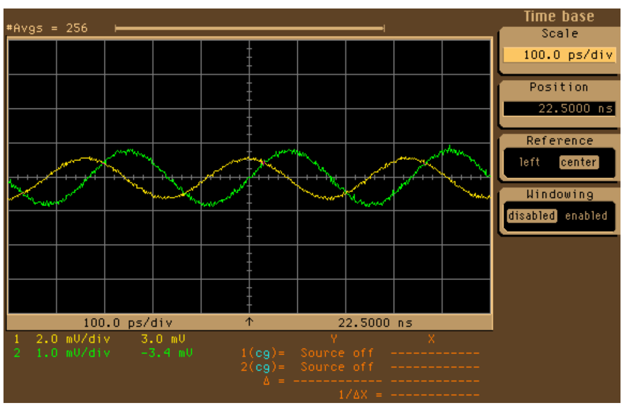

Fig. 2. The waveforms of I and Q channels.

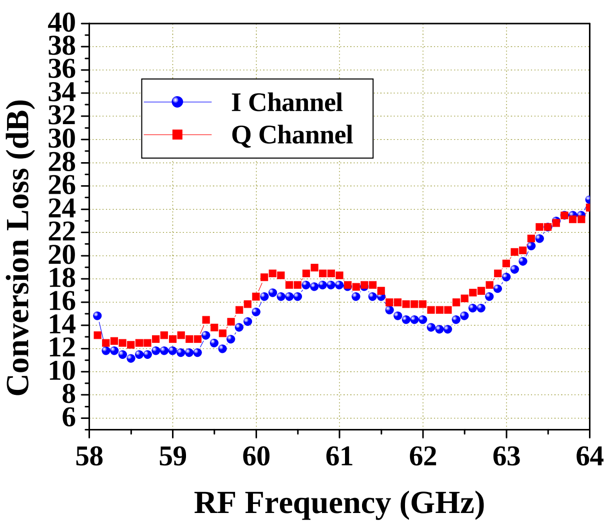

Fig. 3. Conversion loss as a function of RF frequency at I and Q channels.

B. 60 GHz-Band Integrated Phased Array with Even-Harmonic I/Q Mixer

A 60 GHz-band four-element integrated phased array with an array spacing of 0.6 λ based upon the designed single integrated antenna in section I is proposed as shown in Fig. 4. Each even-harmonic mixer is integrated with a microstrip patch antenna. Even-harmonic I/Q mixers and all relevant passive circuits including a microstrip patch antenna are designed at an RF of 61.87 GHz and an LO of 29.56 GHz. Nine-stage low pass filters with a cutoff frequency of 4.5 GHz are designed for suppressing the RF and the LO frequencies. In order to easily measure the array, eight microstrip lines on duroid substrate are connected to each I and Q channel using wire bonding.

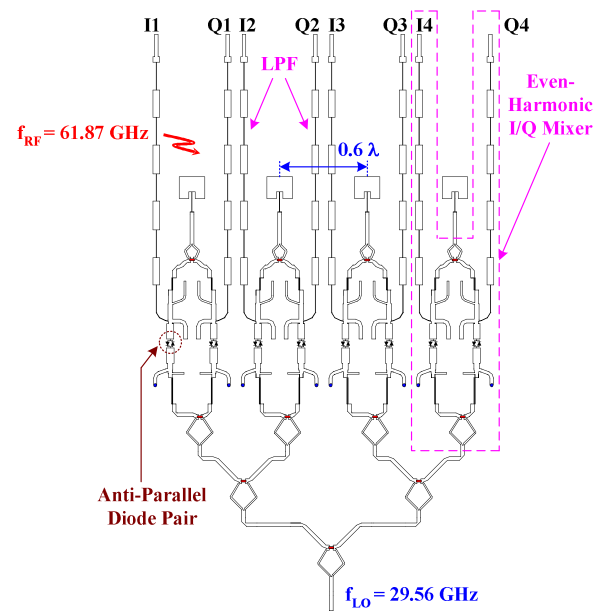

Fig. 4. The 60 GHz four-element integrated phased array.

III. Measurements and Discussion

A. 60 GHz-Band integrated Phased Array RF performance

The resonant frequency of a microstrip patch antenna is measured to be 61.43 GHz. The -10 dB bandwidth of the antenna is 2.78 %. In order to measure the RF performance of the proposed array, a transmitter system is positioned at the distance of

25.4 cm from the array for the far field pattern measurement as shown in Fig. 5.

Fig. 6 shows the average conversion losses of each of the mixers as a function of LO power. The conversion loss is defined by the ratio of the RF power right before the microstrip patch antenna array to the IF power at each I and Q channel to reduce measurement errors due to cable losses and other device errors [6], [9]. The average conversion loss of all four channels is lower than 10.6 dB with LO power from 21.5 dBm to 27 dBm at the LO port.

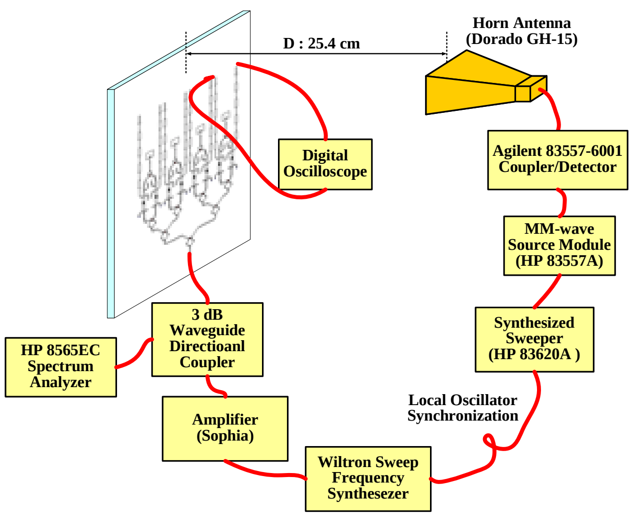

Fig. 5. The test set-up of the proposed integrated phased array.

Fig. 7 shows the measured average conversion losses of each four channel as a function of the RF frequency with LO power of 21.5 dBm. Within the frequency range of 61.5 GHz to 62.2 GHz (700MHz), it has a 1.7 dB power imbalance among four channels. Table 1 and 2 summarize relative power amplitude imbalances of less than 2 dB and phase deviations of less than 3.7° for the reference channel 1 from 61.5 GHz to 62.2 GHz. These slight errors can be compensated for by using digital signal processing which is used to implement digital or hybrid analog-digital beamformers[3]-[5].

Fig. 8 shows IF power as a function of RF power for the I and Q channels. Both the I and Q channels show good power linearity as the RF power is increased.

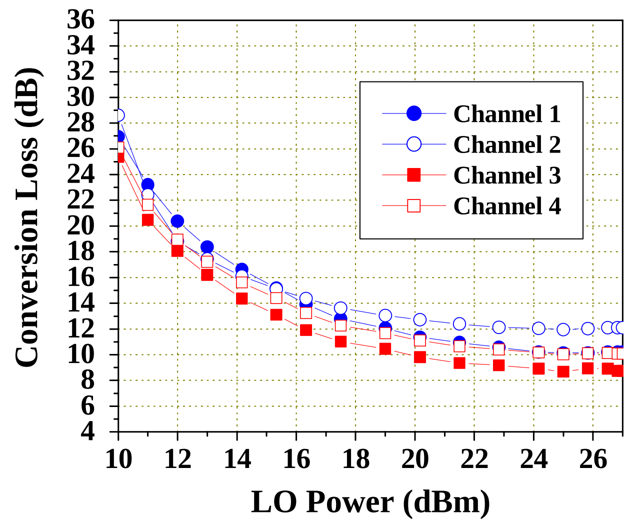

Fig. 6. Measured average conversion losses of each four channel as a function of LO power at IF = 2.75 GHz (The RF power is defined as the power intercepted by the antenna).

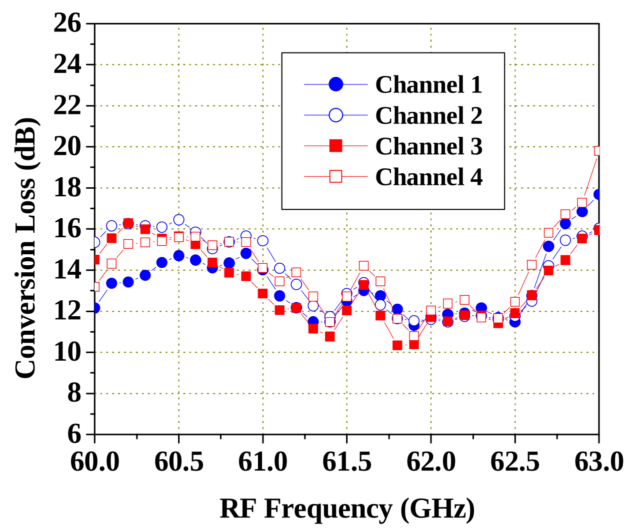

Fig. 7. Measured conversion losses of each four channel vs. RF carrier at LO = 21.5 dBm (The RF power is defined as the power intercepted by the antenna).

Table 2. Relative amplitude balances with the reference channel 1 (Unit : GHz, dB).

RF	61.5	61.6	61.7	61.8	61.9	62.0	62.1	62.2
I1, I2	0.1	0.1	0.8	1.0	0.1	0.4	0.8	0.5
I1, I3	0.1	0.5	0.6	1.8	1.0	0.1	0.6	0.5
I1, I4	1.1	2.0	1.6	0.0	0.1	1.1	1.3	1.3
Q1, Q2	0.6	0.6	0.1	0.3	0.8	0.3	0.3	0.3
Q1, Q3	0.8	0.0	1.3	1.6	0.8	0.1	0.1	0.5
Q1, Q4	0.8	0.3	0.3	1.0	1.3	0.6	0.3	0.1

Table 2. Relative phase deviations with the reference channel 1 (Unit : GHz).

I1, I2	I1, I3	I1, I4	Q1, Q2	Q1, Q3	Q1, Q4
3.3 °	3.7 °	1 °	2.4 °	1.5 °	1 °

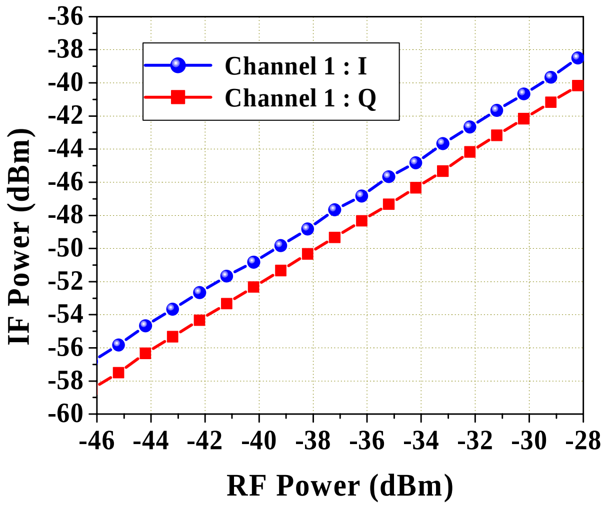

Fig. 8. IF power as a function of RF power.

IV. Conclusion

A 60 GHz-band integrated four-element planar phased array with APDP even-harmonic I/Q mixers for adaptive beamforming system applications has been proposed. In order to predict circuit error, the RF performance of the proposed circuit has been measured. The conversion loss of the overall circuit is less than 10.6 dB and the power imbalance and the phase deviation of each I and Q output are less than 2.5 dB and 7° have been achieved.

Acknowledgement

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