

Cost-Effective 60-GHz Modules with Phase-Noise of -110dBc/Hz at 100KHz Offset using Novel Self-Heterodyne Scheme

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Abstract – A novel self-heterodyne scheme was proposed, which transmitted both the RF1 and an additional carrier RF2 produced by an additional single-tone IF2. The feature of this scheme is that the frequency-fluctuation and the phase-noise generated in the local-oscillator of the transmitter can be eliminated, because the RF1 and the RF2 have both the frequency-fluctuation and the phase-noise in phase. It was reported that cost-effective 60-GHz modules with this scheme applied exhibited the phase-noise of -110 dBc/Hz at 100 kHz off-carrier frequency.

I. Introduction

It was reported that cost-effective millimeter-wave modules were proposed and completed, for the drastic reduction in the cost of semiconductor devices used in the millimeter-wave wireless systems such as LAN and Home-Link systems [1][2]. These modules using the conventional heterodyne scheme exhibited the phase-noise of -85 ~ -89 dBc/Hz at 100 kHz off-carrier frequency, but these phase-noise values were not sufficient to meet the requirement of the broadband system as mentioned above.

Especially, Home-Link systems, which transmit several video signals such as BS, CS, VHS-TV etc., need the phase-noise less than -85 dBc/Hz as well as the lowest cost [3]. Additionally, these services require the frequency-stability of ± 1.5 MHz. This means that the highly stabilized local-oscillator such as a PLL has to be used, which results in expensive systems.

In this paper, to cost-effectively solve this problem, a novel self-heterodyne scheme is proposed.

II. A proposed novel self-heterodyne scheme

Figure 1(a) shows the conventional heterodyne scheme. The IF signal at the IF terminal of the receiver has the sum of the frequency-fluctuation and the phase-noise generated in the local-oscillators of both the transmitter and the receiver, which is expressed as $\pm \text{square root} (|\Delta f_{L_o(Tx)}|^2 + |\Delta f_{L_o(Rx)}|^2)$.

Figure 1(b) shows the novel self-heterodyne

scheme. An oscillator with the frequency of f_{IF2} is

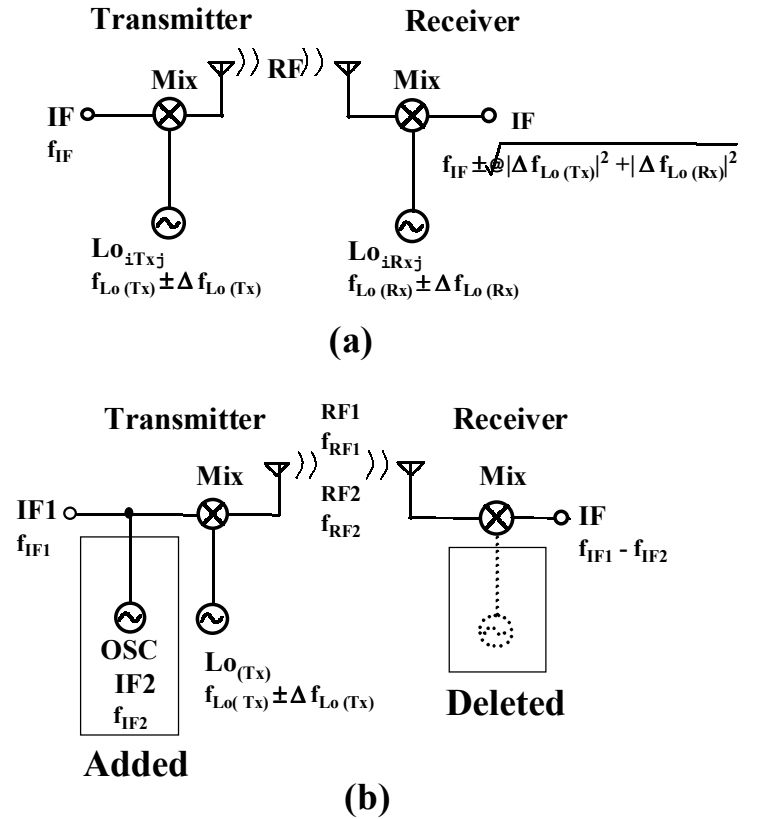


Fig.1

(a) Conventional heterodyne scheme. The sums of the frequency fluctuation and the phase-noise generated in the local-oscillators of the transmitter and the receiver, are symbolically expressed as $\Delta f_{L_o(Tx)}$ and $\Delta f_{L_o(Rx)}$, respectively.

(b) Novel self-heterodyne scheme proposed here. An oscillator with the frequency of f_{IF2} is added at the IF port of the transmitter, and the local-oscillator of the receiver is deleted. At the IF port of the receiver, the frequency-fluctuation and the phase-noise generated in the local-oscillator of the transmitter is eliminated. That is, $f_{RF1} - f_{RF2} = (f_{IF1} + f_{L_o(Tx)} \pm \Delta f_{L_o(Tx)}) - (f_{IF2} + f_{L_o(Tx)} \pm \Delta f_{L_o(Tx)}) = f_{IF1} - f_{IF2}$.

added at the IF port of the transmitter, and the local-oscillator of the receiver is deleted. The RF1 and the RF2 corresponding to the IF1 and the IF2, respectively, are radiated from the antenna of the transmitter. The RF1 and the RF2 are heterodyned at the mixer of the receiver to be converted to IF.

The frequency-fluctuation and the phase-noise generated in the local-oscillator of the transmitter is eliminated, because the RF1 and the RF2 have both the frequency-fluctuation and the phase-noise in phase. That is,

$$f_{RF1} - f_{RF2} = (f_{IF1} + f_{Lo(Tx)} \pm \Delta f_{Lo(Tx)}) - (f_{IF2} + f_{Lo(Tx)} \pm \Delta f_{Lo(Tx)}) = f_{IF1} - f_{IF2} .$$

In this novel self-heterodyne scheme, the IF signal of the receiver has no frequency-fluctuation and phase-noise generated in the local-oscillator of the transmitter as shown in Fig. 1(b).

The most important feature of the novel self-heterodyne scheme is that the qualified local-oscillator can be realized inexpensively. Because the oscillator to be added at the IF port of the transmitter is now under mass-production and is available at a low price, and it has the excellent phase-noise characteristics. Moreover, the local-oscillator in the receiver is not needed, which contributes to make the price lower.

III. Review of the millimeter-wave modules with the conventional heterodyne scheme

Before reporting the novel self-heterodyne scheme, the conventional heterodyne scheme is reviewed. Figure 2 shows the block diagrams of the millimeter-wave modules with the conventional heterodyne

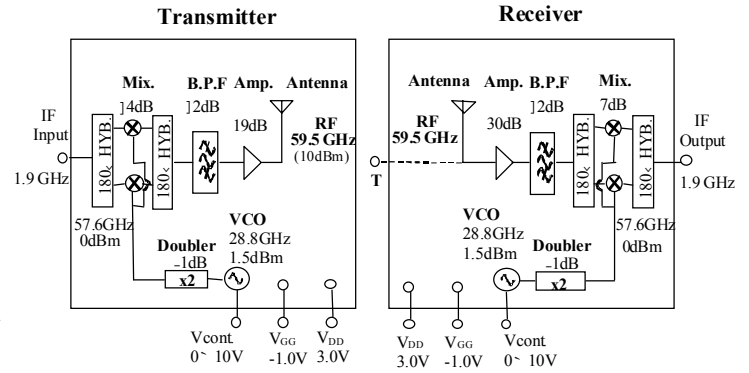


Fig.2 Block diagrams of the cost-effective millimeter-wave modules with the conventional heterodyne scheme, which were reported in GAAS 2000 conference.

scheme, which were reported in GAAS 2000 [2]. The phase-noises obtained at the IF port of the receiver were -60 dBc/Hz at 1kHz, -78 dBc/Hz at 10kHz, and -88.5 dBc/Hz at 100 kHz off-carrier frequency.

IV. Developed 60-GHz modules with the novel self-heterodyne scheme

(1) Block diagram

The block diagrams of the developed cost-effective 60-GHz modules (both the transmitter and the receiver) using the novel self-heterodyne scheme are shown in Fig.3. The package size of one module is 50 x 23 x 6.5 mm³. The local-frequency was 57.6 GHz, and the frequency 2.2 GHz as IF1 and the 1.7 GHz as IF2 were selected. Therefore, the RF1 and the RF2 were 59.8 GHz and 59.3 GHz, respectively.

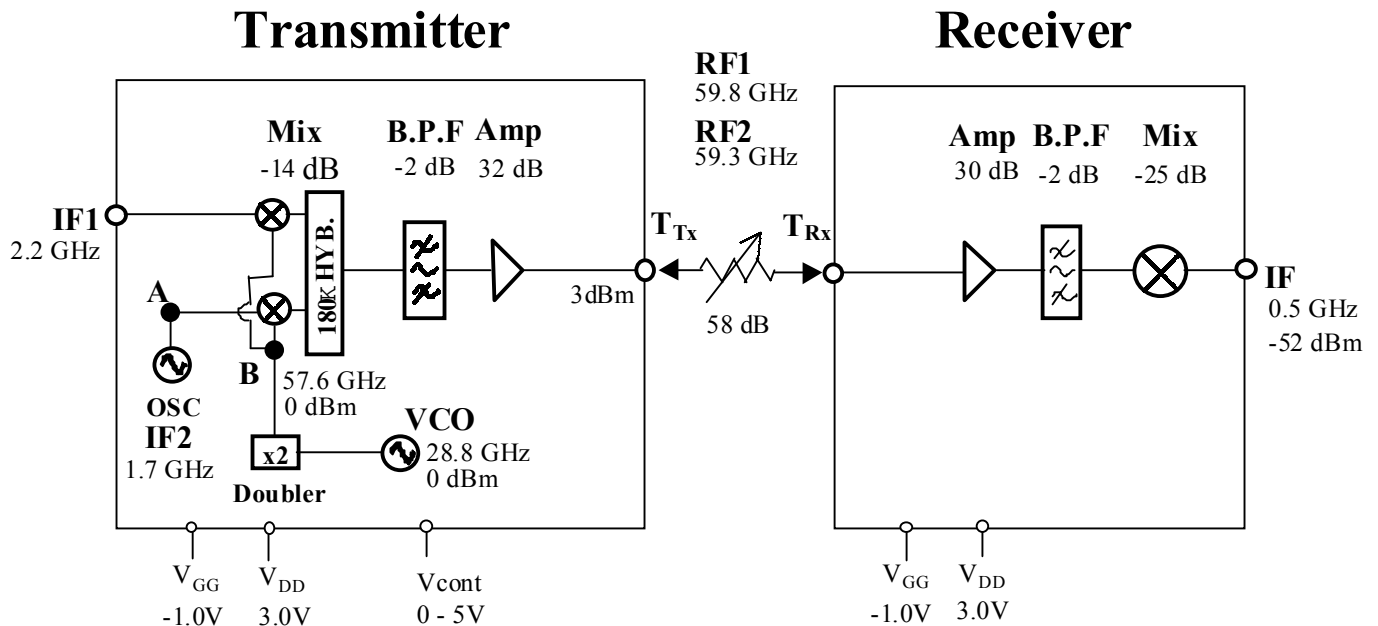


Fig. 3 Block diagrams of developed cost-effective 60-GHz modules with novel self-heterodyne

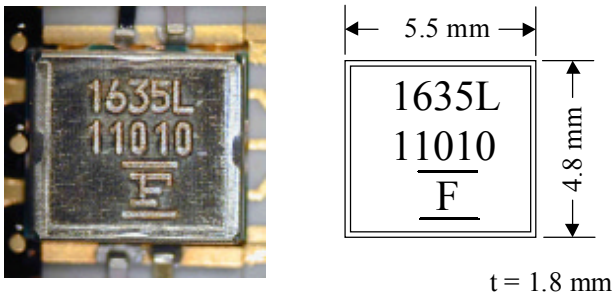
(b)

- (2) The oscillator added as IF2
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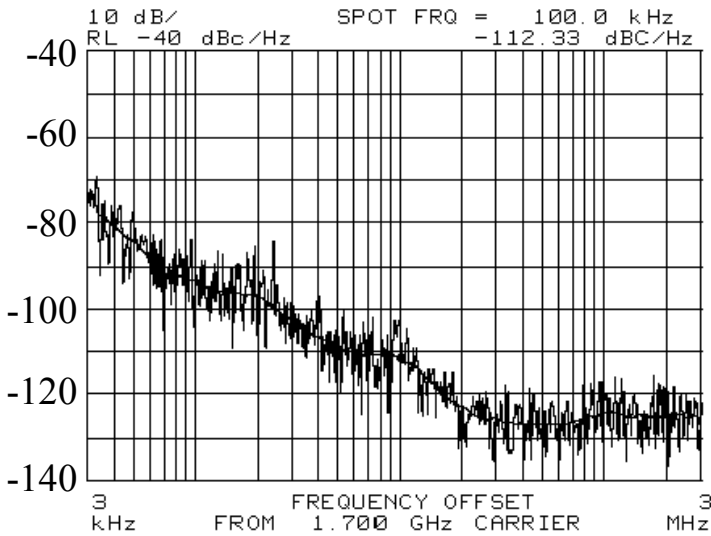
The oscillator added as IF2 is shown in Fig.4 (a). The oscillator is the same VCO (1635L) as used in mobile phones. The oscillation frequency is 1635 ± 70 MHz. Figure 4(b) shows the phase-noise of the VCO itself measured at point A of the transmitter shown in Fig. 3. The phase-noise at 1.7 GHz was -112.3 dB/Hz at 100 kHz off-carrier frequency.

- (3) Phase-noise of the developed modules with the novel self-heterodyne scheme

Figure 5 shows the phase-noise measured at the IF terminal of the receiver module shown in Fig.3. In the measurement, the terminal of the transmitter T_{TX} and that of the receiver T_{RX} were connected with the 58 dB attenuator, which was equivalent to the distance



(a)



(b)

Fig. 4

- (a) An added oscillator, which is mounted in the transmitter of 60 GHz modules. The oscillator is the same VCO as used in mobile phones which is available at low price. The oscillation frequency range of this VCO is 1635 ± 70 MHz.

- (b) Phase-noise of the VCO itself at 1.7 GHz measured at point A of the transmitter block diagram shown in Fig.3. The phase-noise was -112.3 dBc/Hz at 100 kHz off-carrier frequency.

of 10 m when the transmitter-antenna of 5 dBi and the receiver-antenna of 25 dBi were used. The IF frequency of the receiver module is 0.5 GHz, since,

$$f_{IF1} - f_{IF2} = 2.2 \text{ GHz} - 1.7 \text{ GHz} = 0.5 \text{ GHz}.$$

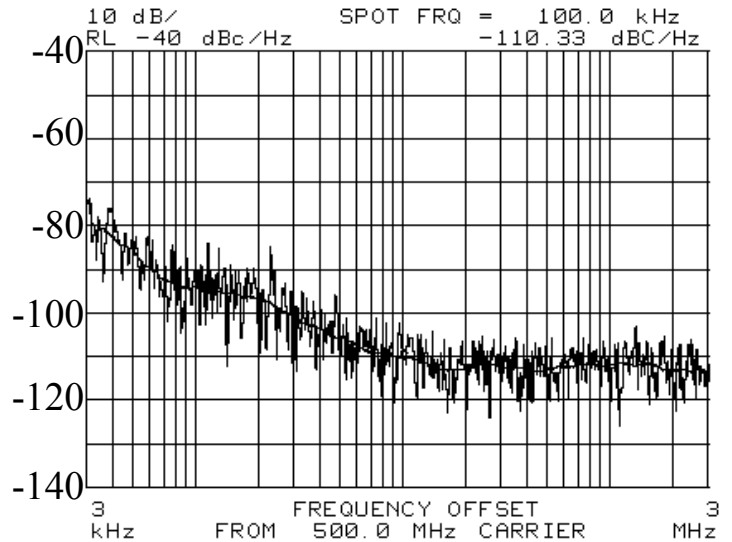
The phase-noise was measured to be -79.0 dBc/Hz at 3 kHz, -94.0 dBc/Hz at 10kHz and -110 dBc/Hz at 100 kHz off-carrier frequency, respectively.

This is the phase-noise of the cost-effective 60-GHz modules with the novel self-heterodyne scheme. In the novel self-heterodyne scheme, the worse phase-noise in the IF1 or IF2 is obtained, but the obtained phase-noise is good by a large margin, compared the phase-noise of -88.5 dBc/Hz at 100 kHz off-carrier frequency in the conventional heterodyne scheme reported in GAAS 2000 [2].

- (4) Pout-Pin characteristics of the transmitter module

The output powers P_{RF1} , P_{RF2} of RF1, RF2 vs. the input power of IF1 measured at the terminal T_{TX} of the transmitter module are shown in Fig.6. The local frequency $f_{Lo(Tx)}$ is 57.6 GHz, and the frequencies of f_{RF1} and f_{RF2} are 59.8 GHz, 59.3 GHz, respectively. The parameters P_{IF2} for RF2 are the powers of IF2 measured at point A shown in Fig3.

In the novel self-heterodyne scheme, the optimized C/N ratio of the total system can be obtained at the intersecting points of the solid-line of



- Fig.5 Phase-noise of the modules with the novel self-heterodyne scheme. This was measured at the IF terminal of the receiver module shown in Fig.3. The IF frequency is 0.5 GHz. The phase-noise was measured to be -79.0 dBc/Hz at 3 kHz, -94.0

dBc/Hz at 10kHz and -110dBc/Hz at 100 kHz off-carrier frequency, respectively.

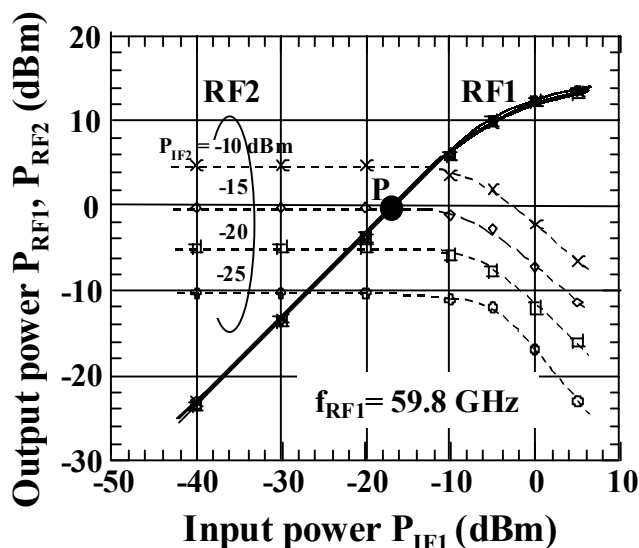


Fig.6 Output powers P_{RF1} , P_{RF2} vs. P_{IF1} input power at the frequency $f_{RF1} = 59.8$ GHz. The parameters P_{IF2} for RF2 are the powers of IF2 measured at point A shown in Fig3.

RF1 and the dotted-line of RF2 for each P_{IF2} . In other ward, when the P_{RF1} and the P_{RF2} become equal, the optimized C/N ratio is obtained [4]. For example, at the input power P_{IF1} of -17dBm, the P_{RF1} is 0 dBm and the P_{RF2} becomes 0 dBm if the P_{IF2} is selected to be -15 dBm (point P), where the total output power is 3 dBm. When the P_{IF1} is - 12 dBm and the P_{IF2} is - 10 dBm, the P_{RF1} is still in the linear range, and the P_{RF1} and the P_{RF2} are 5 dBm, respectively. That is, the total output power of this transmitter is 8 dBm.

V. Conclusion

A novel self-heterodyne scheme which could eliminate the frequency-fluctuation and the phase-noise generated in the local-oscillator of the transmitter was proposed. The feature of this scheme is that millimeter-wave modules with the lowest phase-noise can be made easily and cost-effectively. The developed 60-GHz modules with the novel self-heterodyne scheme exhibited the output power of 8 dBm with the phase-noise of -110 dBc/Hz at 100 kHz off-carrier frequency.

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