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# Design of a 120–220 GHz Fourth-Harmonic Mixer

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**Abstract**—In this letter, a 120–220 GHz fourth-harmonic mixer based on Schottky diodes is presented. To broaden the bandwidth, a novel diplexer is proposed, which consists of two low-pass filters (LPFs) and a beam lead capacitor. Thanks to the high-pass characteristic of capacitor, the 30–55 GHz local oscillator (LO) signal is efficiently pumped to the diodes. Moreover, a two-level hammer-head configuration is adopted at the LO LPF to block the 120–220 GHz radio frequency (RF) signal. Finally, a 120–220 GHz fourth-harmonic mixer is fabricated and measured. The measurement results show that the conversion loss ranges from 12 to 18 dB within a wide RF relative bandwidth of 58.8%.

## 1. INTRODUCTION

In millimeter wave and terahertz bands, mixer plays an indispensable role in transmitter and receiver systems for communication, imaging, and measurement applications, whose performance and reliability show significant influence on the entire system. Especially, in spectrum analyzer measurement systems, mixers work with fixed intermediate frequency (IF) while the RF bandwidth directly decides the bandwidth of the entire measurement system. Therefore, it is essential to develop a wideband, high performance, and easy-fabrication mixer to broaden the bandwidth of systems.

For the fundamental mixer with RF frequency above 100 GHz, it is difficult to obtain high quality LO signal. In contrast, harmonic mixers reduce the LO signal frequency to $1/n$ of RF signal frequency ($n$ is the harmonic order). Therefore, harmonic mixer becomes a solution in high frequency. However, increasing harmonic order will introduce worse conversion loss. Then, the harmonic order should be chosen according to the actual needs. In [1], a 164–192 GHz sub-harmonic mixer was presented in which a step impedance was adopted to design IF LPF. Compared with hammer-head LPF, this configuration extended the circuit structure and increased the loss of the IF signal. Reference [2] introduced a 198–238 GHz sub-harmonic mixer, whose RF probe was extended into the waveguide cavity to achieve circuit grounding. Reference [3] presented a wideband sub-harmonic mixer by using GaAs monolithic integration technology. The RF frequency of such presented mixer is 185–255 GHz. Moreover, G-band (140–220 GHz) is between millimeter wave and terahertz band, which has been widely used in communication, measurement, and other fields. However, up to now, few mixers based on Schottky diodes in the reported researches can cover the full 140–220 GHz band.

In this letter, a 120–220 GHz fourth-harmonic mixer is presented, whose RF signal bandwidth is beyond the G-band. It reduces the LO signal frequency to only 30–55 GHz, which is important for cost reduction and system miniaturization. In the mixer design, a chip of series Schottky diodes is positioned on the cavity and microstrip circuit. It not only simplifies the circuit grounding but also realizes the balance of the diodes. Two LPFs and a beam lead capacitor are adopted to design the diplexer. It can transmit LO and IF signals and increase the isolation among the three ports. Finally, the mixer is realized on a quartz-glass substrate with a dielectric constant of 4.4 and tangent loss of 0.01.

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## 2. DESIGN OF MIXER CIRCUIT

Figure 1(a) shows a traditional topology of mixer, which consists of a diode and a diplexer. In the diplexer, LO LPF transmits the LO signal and blocks the RF signal, while IF LPF transmits the IF signal and blocks the LO signal. The band-pass filter (BPF) transmits the LO signal and blocks the IF signal at LO port. However, the bandwidth of the band-pass filter is limited by manufacture.

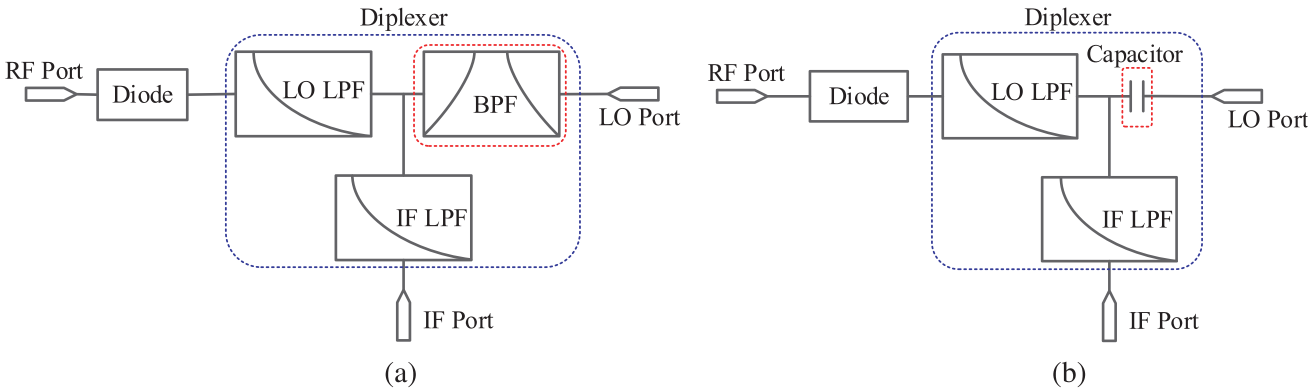


**Figure 1.** Topology diagrams of mixer. (a) Topology of traditional mixer. (b) Topology of proposed mixer.

The parallel coupled microstrip filter is one of the most common band-pass filters in application. The admittance inverter constant $Z_0J_n$, odd-mode line impedance $Z_{0o}$, and even-mode line impedance $Z_{0e}$ are calculated by the equations presented in [4] as

$$Z_0J_1 = \sqrt{\frac{\Delta\pi}{2g_1}}; \quad Z_0J_n = \frac{\Delta\pi}{2\sqrt{g_{n-1}g_n}}, \quad (1 < n \leq N); \quad Z_0J_{N+1} = \sqrt{\frac{\Delta\pi}{2g_Ng_{N+1}}} \tag{1}$$

$$Z_{0o} = Z_0\left[1 - Z_0J + (Z_0J)^2\right] \tag{2}$$

$$Z_{0e} = Z_0\left[1 + Z_0J + (Z_0J)^2\right] \tag{3}$$

where $\Delta$ is the filter relative bandwidth, and $g_n$ is the filter parameter.

With a constant filter order $N$, increasing the relative bandwidth $\Delta$ will dramatically increase $Z_{0e}$, but $Z_{0o}$ only varies a little. This situation will narrow the line width $W$ and gap width $S$. In order to realize the LO signal bandwidth (30–55 GHz), the minimum width of line or gap is about 10 μm, which is extremely difficult to manufacture.

As presented in Figure 1(b), a capacitor is used instead of bandpass filter, which is compact and reduces the manufacturing difficulty. Thanks to its high-pass characteristic, the wideband signal is pumped to diodes, and the low frequency signal is blocked. This is significant for broadening the mixer bandwidth and keeping the compactness of the circuit.

Figure 2 shows the configuration of the proposed mixer, which consists of several diodes, an RF probe, and a diplexer. The RF probe feeds 120–220 GHz RF signal from the waveguide to diodes.

The Schottky diode adopted in this letter is ZT2CL, which is manufactured by The 13th Research Institute of China Electronics Technology Group Corporation. It is connected with the cavity and microstrip by flip-chip, and whose parameters are listed in Table 1.

**Table 1.** The parameters of Schottky diodes.

| Serial Resistance $R_s$ | Zero Voltage Capacity $C_{j0}$ | Ideal Factor $n$ | Built-in Potential $V_j$ |
|---|---|---|---|
| $5\,\Omega$ | 10 fF | 1.2 | 0.75 V |

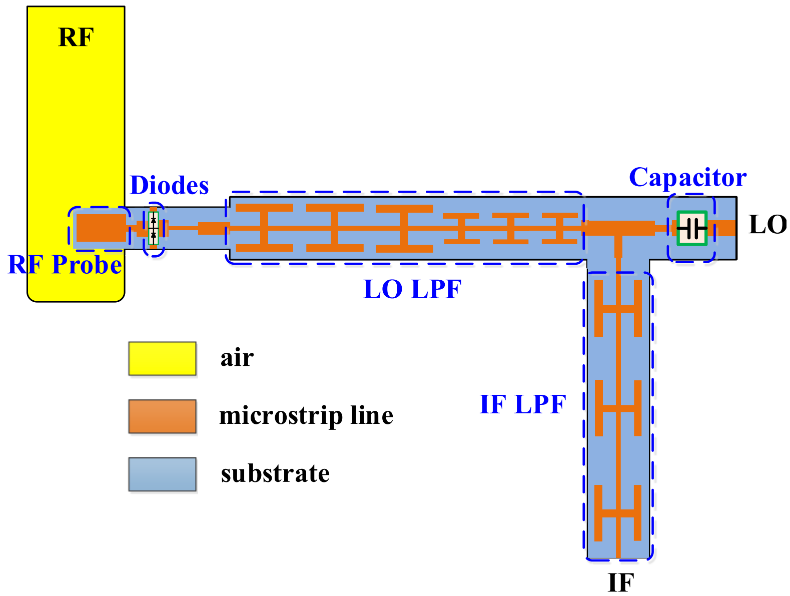


**Figure 2.** Configuration of the proposed mixer.

The diplexer consists of two LPFs and a beam lead capacitor. Thanks to the high-pass characteristic of the capacitor, it simultaneously transmits wide LO signal and blocks low frequency IF signal. Moreover, the IF signal bandwidth is determined by the capacitance. To keep the compactness of the circuit, the hammer-head configuration is adopted to design two LPFs. Their structures and simulation results are shown in Figure 3, to increase the bandwidth of out-of-band rejection, the LO LPF adopts a two-level hammer-head configuration. As can be seen from the simulation results, LO LPF can block RF signal, and IF LPF can block LO signal, both of which have high out-of-band rejection.

Figure 4 indicates the model of the diplexer and simulation results of transmission performance.

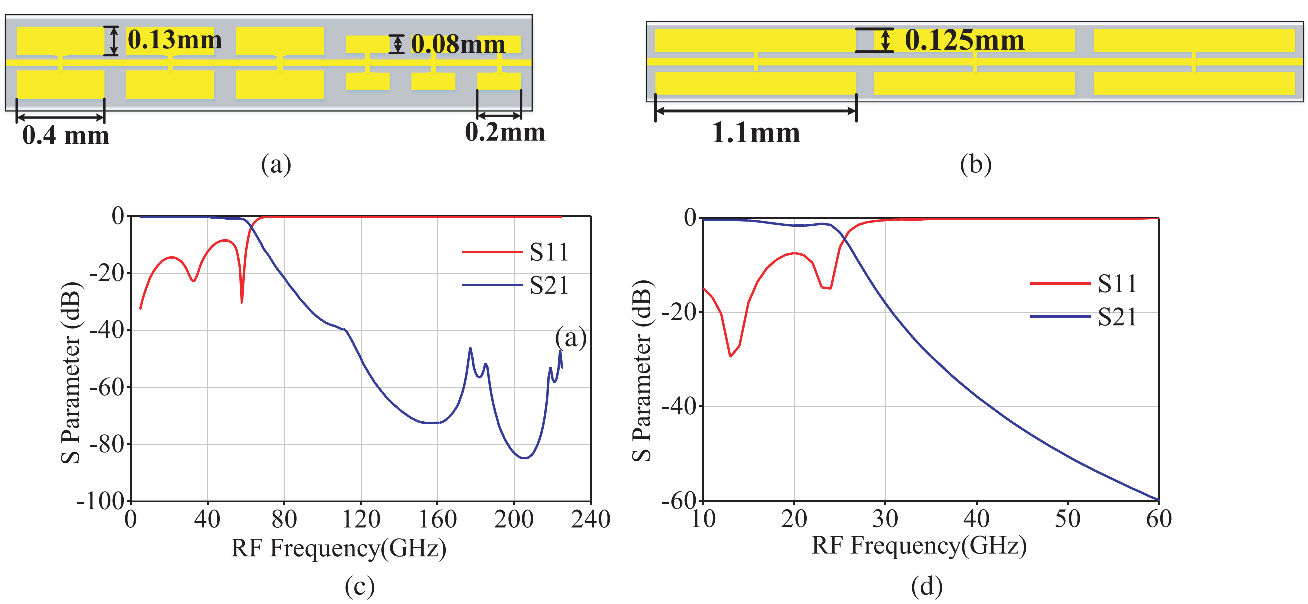


**Figure 3.** Structure of LPFs and simulation results of transmission performance. (a) Structure of LO LPF. (b) Structure of IF LPF. (c) Transmission performance of LO LPF. (d) Transmission performance of IF LPF.

Figure 4(b) shows that the IF signal below 200 MHz only reaches Port 3 from Port 1 by the effect of capacitor with 1 pF, and the isolation between Port 1 and Port 2 is more than 23 dB. Figure 4(c) shows that the 120–220 GHz signal from RF probe is blocked by the effect of LO LPF, and the out-of-band rejection of this band is more than 45 dB. Figure 4(d) shows that the 30–55 GHz LO signal is only fed to Port 1 from Port 2 by the effect of IF LPF, and the isolation between Port 2 and Port 3 is more

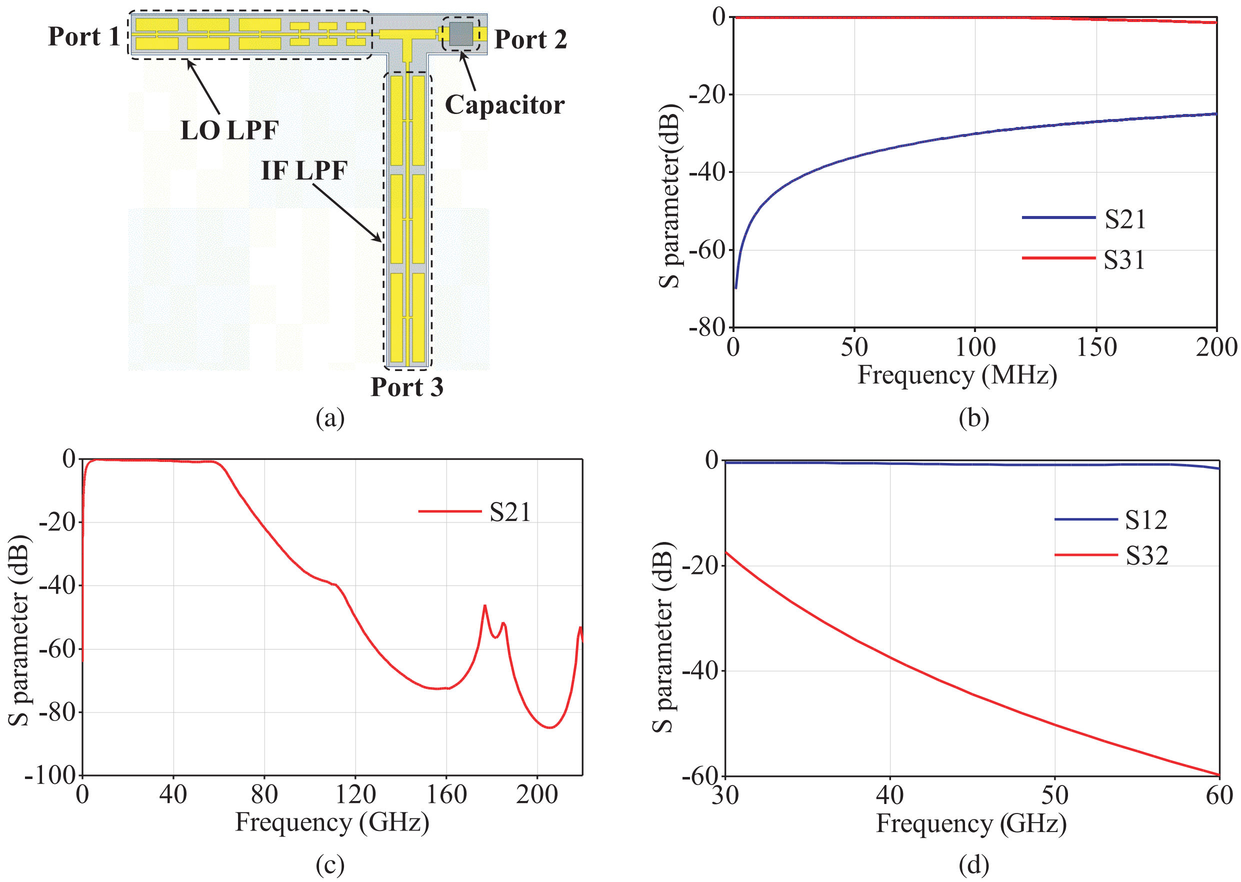


**Figure 4.** Model of the diplexer and simulation results of transmission performance. (a) Model of diplexer circuit. (b) $S_{21}$ and $S_{31}$ with the frequency below 200 MHz. (c) $S_{21}$ with the frequency below 220 GHz. (d) $S_{12}$ and $S_{32}$ with the frequency of 30–60 GHz.

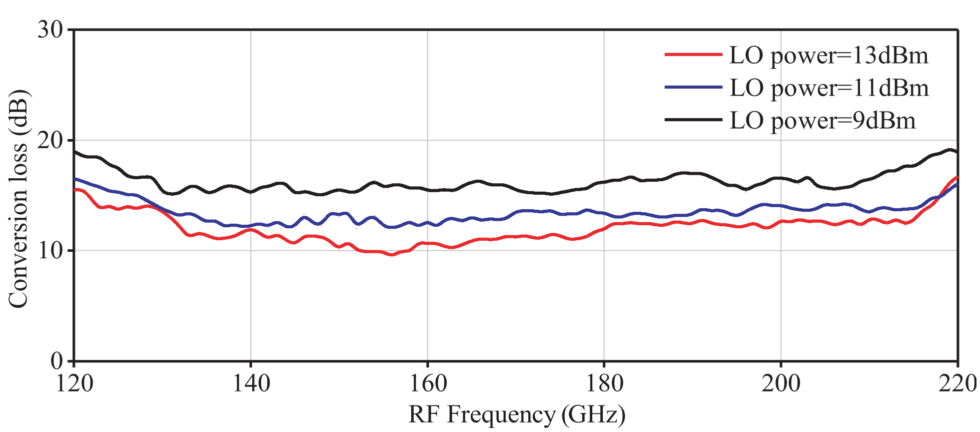


**Figure 5.** Simulation conversion loss with different LO power.

than 18 dB. Observing simulation results, one can find that this diplexer simultaneously transmits the wideband LO signal and the IF signal, and ensures a high isolation among the three ports.

Figure 5 shows that the simulation conversion loss with different LO powers. It can be seen that the conversion loss decreases gradually while increasing the LO power. Furthermore, mixer presents the best conversion loss when the LO power is 13 dBm, which is from 10 to 16 dB with the RF frequency of 120–220 GHz.

## 3. FABRICATION AND MEASUREMENT

Figure 6 shows a photograph of the designed mixer. The RF signal is inputted through a WR-5 waveguide, and both LO input and IF output ports adopt coaxial connector. The mixer is realized on a quartz-glass substrate with a thickness of 60 µm, and the conductor thickness is 3 µm. The adopted diodes chip, ZT2CL, is connected with the cavity and microstrip by flip-chip.

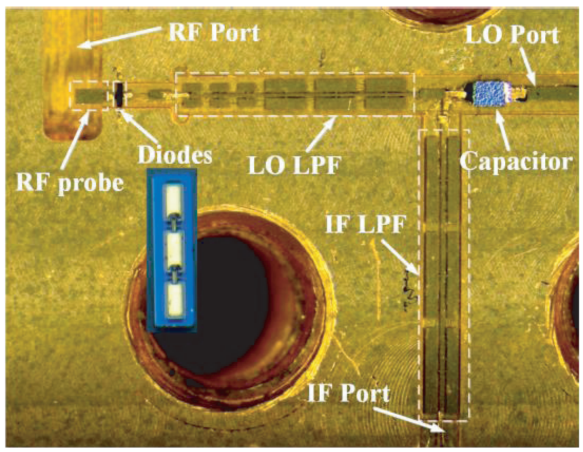


**Figure 6.** Photograph of the proposed mixer.

### 3.1. Isolation and Port Matching of Mixer

The isolation and port matching of mixer needs to be measured by a vector network analyzer. The LO-IF isolation measurement result is shown in Figure 7. Under the influence of IF LPF, the isolation between the two ports is higher than 25 dB in the full frequency band. The port matching measurement

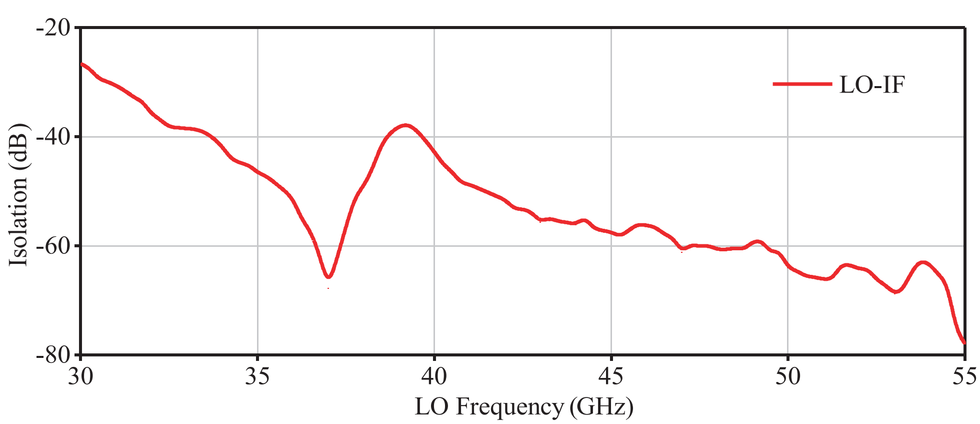


**Figure 7.** Isolation of LO-IF Port.

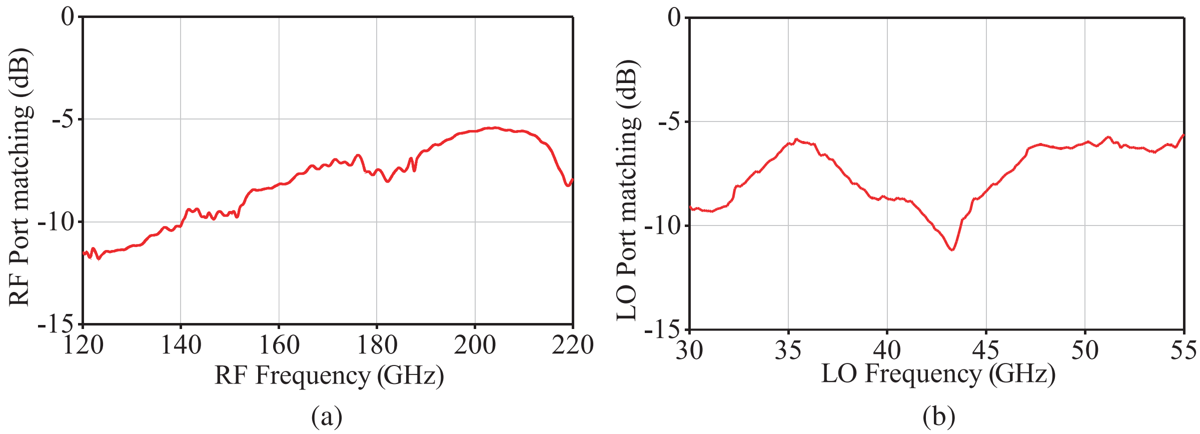


**Figure 8.** (a) RF Port matching of mixer. (b) LO Port matching of mixer.

results are shown in Figure 8. RF port matching is 5.4–12 dB, and LO port matching is 6–11 dB in the full frequency band.

### 3.2. Harmonic Contents and Conversion Loss of Mixer

Harmonic contents and conversion loss can be measured by the same system. As shown in Figure 9, the measurement system of the proposed mixer consists of two Signal Generators 1465L (100 kHz-67 GHz), a Spectrum Analyzer 4051L (3 Hz-67 GHz), an amplifier with the frequency of 30–60 GHz, convert waveguides, a 110–170 GHz RF Source, and a 170–220 GHz RF source. These two RF sources provide the RF signal (120–220 GHz) together. The LO signal (30–55 GHz) is provided by a 1465L Signal Generator and an amplifier, which output the power of more than 13 dBm.

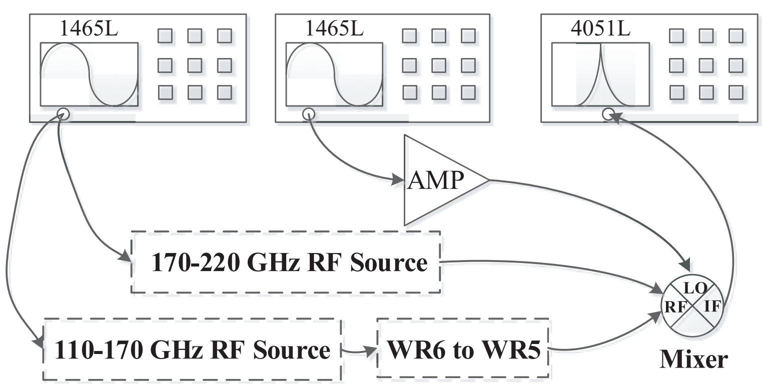


**Figure 9.** Measurement system of the mixer.

According to the filter designed in this letter and the input signal frequency, the harmonic frequency of IF signal is an integer multiple of its own frequency. The measurement results of harmonic contents are shown in Figure 10. The harmonics of 200 MHz and 300 MHz can be measured during the IF signal 100 MHz, and the harmonic suppression is higher than 30 dBc.

Figure 11 shows the comparison of simulation and measurement conversion losses of the mixer, which agree with each other well. It is observed that the measurement conversion loss is 12–18 dB with full RF frequency and is 12–15 dB with the frequency of 140–180 GHz. The measurement conversion loss decreases gradually with higher LO power. The RF signal frequency of the proposed mixer is 120–220 GHz, which means that the operational bandwidth is up to 100 GHz.

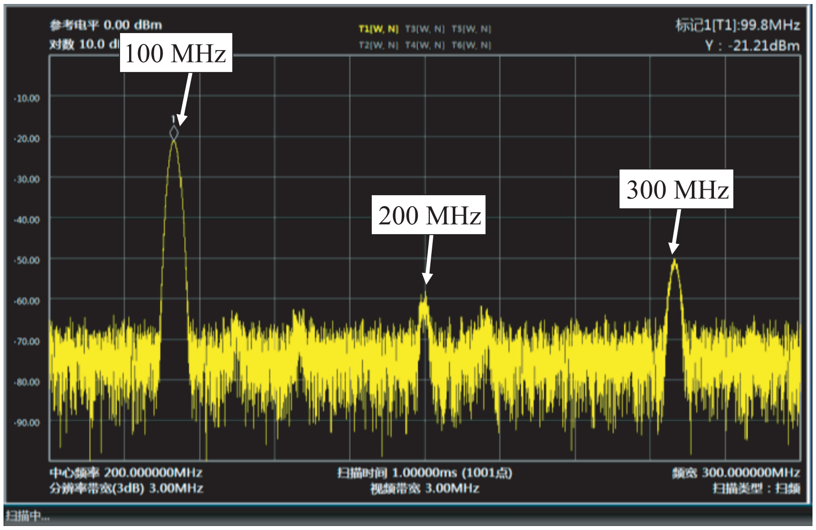


**Figure 10.** Measured harmonic contents of the mixer.

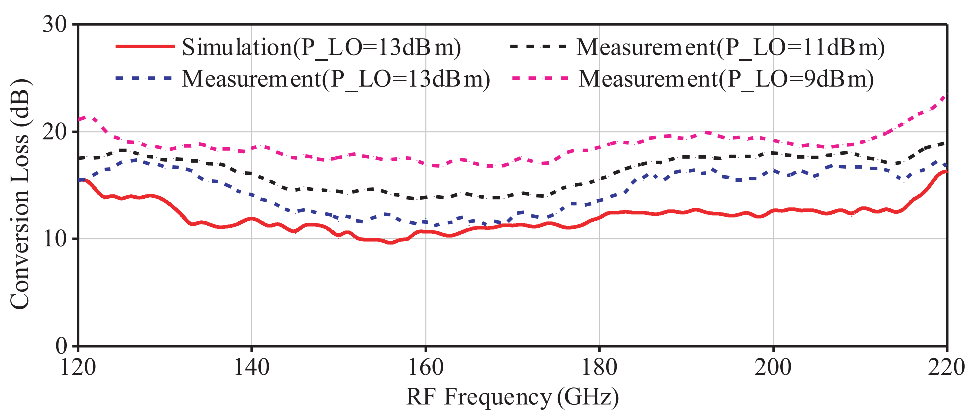


**Figure 11.** Simulated and measured conversion loss of the mixer.

**Table 2.** Summary of previously published mixers.

| Ref. | Harmonic Order | Single side band Conversion Loss (dB) | RF Frequency (GHz) | Relative Bandwidth |
|---|---|---|---|---|
| [1] | 2nd | 8–11.5 | 164–192 | 15.7% |
| [2] | 2nd | 8–11 | 198–238 | 18.3% |
| [3] | 2nd | 7.5–10.7 | 185–255 | 31.8% |
| [5] | 2nd | 9.5–13 | 188–244 | 25.9% |
| [6] | 2nd | 10–16 | 200–250 | 22.2% |
| [7] | 2nd | 7–14 | 190–250 | 27.3% |
| **This work** | **4th** | **12–18**<br>**12–15** | **120–220**<br>**140–180** | **58.8%** |

To indicate the advantages of the proposed mixer, Table 2 summarizes the comparisons with some similar published literatures. The proposed fourth-harmonic mixer shows the merits of wide relative bandwidth and acceptable conversion loss.

## 4. CONCLUSION

In this letter, a 120–220 GHz wideband fourth-harmonic mixer based on Schottky diodes is realized. A capacitor and two LPFs are used to design a novel diplexer. Using this diplexer, the bandwidth of the mixer is broadened. The measurement results show that the conversion loss is 12–18 dB in the frequency of 120–220 GHz and is 12–15 dB in the frequency of 140–180 GHz, respectively. Compared with the previously published mixers, the relative bandwidth of this mixer increases by approximately 30%. This mixer can be used in the spectrum analyzer to broaden the bandwidth of the measurement system. In addition, different capacitances can be selected according to the required IF bandwidth in actual applications.

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