# A Dual-Conversion Front-End with a W-Band First Intermediate Frequency for 1-30 GHz Reconfigurable Transceivers

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*Abstract* — **We present a microwave dual-conversion front-ends with a W-band first intermediate frequency (IF) for 1-30 GHz reconfigurable transceivers. The front-end consists of frequency up-conversion and down-conversion ICs using base-collector diode mixers and 4:1 local oscillator (LO) frequency multipliers. The front-ends are implemented in a 130 nm InP HBT technology. The IC was designed for a broadly tunable 1-30 GHz dual-conversion receiver using a W-band first IF. The up-conversion IC has 4-7 dB conversion loss and 20-25 dBm IIP3 from 0.1-22 GHz to W-band. Similarly, the down-conversion IC has 4-7 dB conversion loss and 20-25 dBm IIP3 converting from W-band to a 0.1-22 GHz baseband or 2nd IF. The front-end has 30 GHz spurious free RF tuning range, with >6 dBm IIP3 using commercial off the shelf (COTS) off wafer IF filter and IF amplifier. It consumes 2.8W in the down-conversion and 3W in the up-conversion.**

*Index Terms* — **Frequency conversion, dynamic range, InP HBT, millimeter wave integrated circuits, MMICs.**

## I. Introduction

A mixer, together with an LO source, translates signal frequencies in mm-wave transceivers, and can be used in broadly-tunable microwave dual-conversion receivers. The received signal is first up-converted to a very high frequency, then filtered and down-converted to a baseband or to a low 2nd IF frequency. This eliminates spurious image and LO harmonic responses, and permits the RF receivers to tune over a wide frequency range. Using high-performance III-V IC technologies, the first IF can be readily set to even 100 GHz, allowing a spurious-free tuning range as high as 1-50 GHz.

Mixer dynamic range (noise, IP3) and bandwidth limit the performance of such dual-conversion receivers. Passive diode mixers have better noise figure and IP3 than transistor-based mixers. Diode mixers, however, require a high-power LO driver, and in the targeted application, this LO source must be widely tunable. While the lack of a high-speed diode in the technology makes it difficult to implement diode mixers in SiGe BiCMOS [1], the InP HBT base-collector junction has Schottky-diode-like characteristics with small minority carrier storage, and high-dynamic-range mixers are readily designed.

Here we present a microwave dual-conversion front-end with W-band IF for 1-30 GHz spurious-free RF tuning range, using W-band InP based up/down conversion ICs (Fig. 1). We will describe the 1-50 GHz reconfigurable transceiver design, process technology, and provide the performance of circuit blocks and the system.

## II. Microwave Dual-Conversion Front-Ends (for 0.1-50 GHz Reconfigurable Transceivers)

Conversion of the RF to a very high IF frequency allows very broad receiver tuning without in-band image responses. For the given RF front end in Fig. 2a, with a W-band first IF such as 100 GHz, the image lies beyond 150 GHz either for a 1 GHz or 20 GHz RF, enabling 0-50 GHz reception without images (Fig. 2b and 2c). Since the image response is at a very high frequency, it can be very easily rejected. If the front-ends have high-dynamic range, then the RF preselection filter can have bandwidth as large as 0.1-50 GHz to reject out-of-band-jammers from causing IM3 in the RF LNA and first mixer, the system can be tuned/used from 0.1 to 50 GHz.

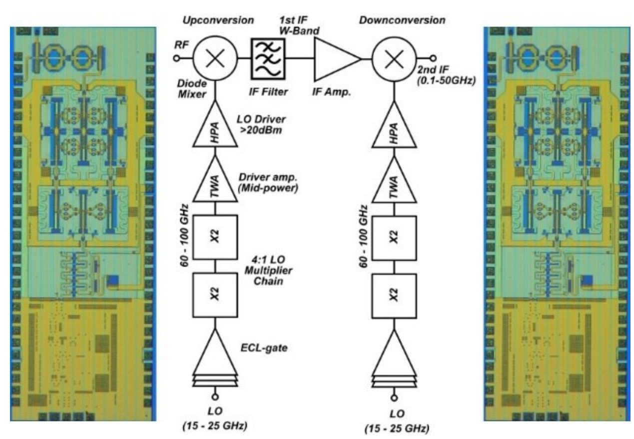


Fig. 1. IC photographs and block diagrams of the dual-conversion receiver. The up-conversion and down-conversion ICs are identical; both are 3.3mm × 1.18mm.

## III. InP HBT Technology

The ICs were fabricated using 130 nm InP HBT process, which provides 50 Ω/square thin film resistors, 0.3 fF/μm$^2$ MIM capacitors, and three-levels of gold interconnections (M1-M3). A 0.13 × 2 μm$^2$ HBT has a current gain cutoff

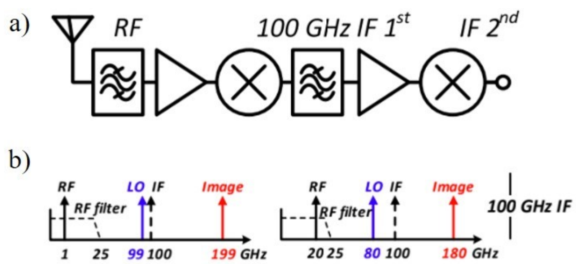


Fig. 2. Dual-conversion receiver front end (a) frequency plan for 1-20 GHz RF tuning with a 100 GHz first IF (b).

frequency $f_\tau$ = 520 GHz and a maximum frequency of oscillation $f_{max}$ = 1.1 THz at $I_C$ = 6.9 mA and $V_{CE}$ = 1.6 V [2]. M2 and M3 with a 5 µm thick BCB layer are used to design low-loss normal and inverted microstrip lines.

## IV. Circuit Blocks and Measurements

The up/down-conversion IC consists of a 4:1 LO frequency multiplier, a traveling wave amplifier (TWA) predriver, a high-power LO diver amplifier, and a high-dynamic-range wideband diode mixer. The multiplier uses two consecutive doublers covering 32-53 GHz and 50-106 GHz. The frequency doublers are based on digital logic and use DC negative feedback to suppress spurious harmonics. This spurious harmonic rejection significantly relaxed the filter requirements. Detailed design of the doublers is provided in [3]. Two doublers are cascaded to realize a 4:1 multiplier.

The multiplier chain's output power and harmonic rejection were measured using V-band and W-band harmonic mixers and a Rohde&Schwarz FSU spectrum analyzer. All cable and probe losses are de-embedded. Fig. 3 shows the multiplier harmonic power vs. input frequency. The desired 4$^{th}$ harmonic output power is 8-10 dBm from 60 GHz to 84 GHz. 3$^{rd}$, and 5$^{th}$ harmonic rejections are both better than 20 dBc. The multiplier chain draws 550 mA from a 3.3 V supply.

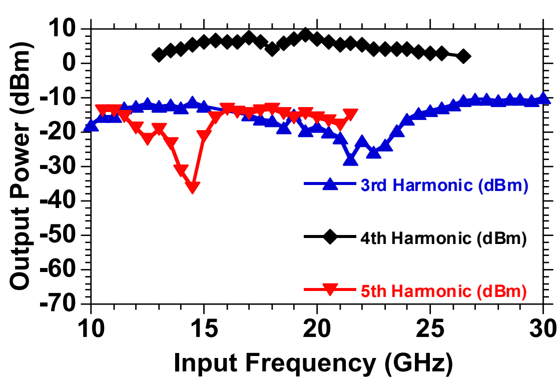


Fig. 3. Harmonic power vs. input frequency for the 4:1 multiplier chain

The diode mixer consists of two baluns and four series-connected diode pairs. The diodes are HBT base-collector junctions. The P-InGaAs/N-InP base-collector heterojunction blocks hole minority carrier diode injection into the InP subcollector, greatly reducing the minority carrier storage. The resulting high-frequency characteristics are similar to a Schottky diode [4]. The LO port driver amplifier provides greater than 20 dBm over its W-band tuning range [5]. The LO pre-driver stage, a TWA [6], has a simulated 80 GHz 3-dB bandwidth and 15 dB peak gain. Compared to the ICs reported in [4] which used a 9:1 LO frequency multiplier with using triplers, the current IC, with its digital/feedback frequency multiplier, uses a smaller die, has broader tuning range, and better spurious rejection.

Key parameters of the frequency conversion IC are IP3, noise figure, and spurious responses. Because the mixer is passive, its noise figure will be very close to its conversion loss. Fig. 4a and 4b shows the IIP3 and conversion gain of up/down conversion ICs respectively. The up-conversion IC has 20-25 dBm IIP3 and 4 to 6 dBm conversion loss. Similarly, operating with a 100 GHz first IF, the down-conversion IC has 20-25 dBm IIP3 and 3 to 6 dB conversion loss as the 2nd IF is tuned from 0.1 GHz to 22 GHz. The frequency conversion ICs each consume 935 mA from a 3.3 V supply.

## IV. Dual-Conversion Receiver Demonstration

A dual-conversion receiver was demonstrated using the up-conversion and down-conversion ICs together with an off-wafer IF section consisting of a 94 GHz bandpass

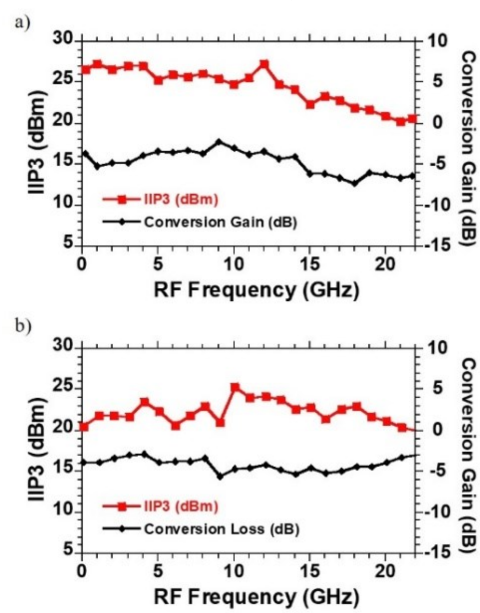


Fig. 4. IIP3 and conversion gain of a) up-conversion IC b) down-conversion IC at constant IF at 100 GHz

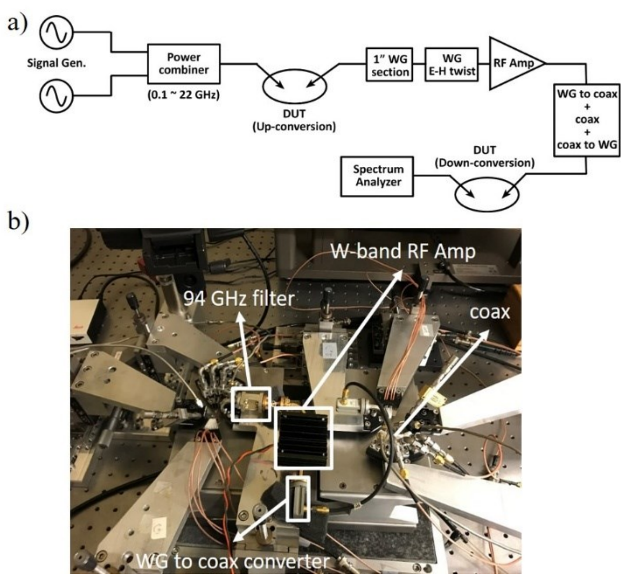


Fig. 5. a) Schematic diagram and b) image of the experimental setup for system measurement.

waveguide filter and a commercial W-band amplifier. The available IF amplifier had relatively high noise figure and low IP3; this will limit the IP3 and noise figure of the resulting receiver to levels well below that of the frequency conversion ICs; the measurements nevertheless demonstrate the spurious tuning responses of the receiver.

In this demonstration, the frequency conversion ICs were connected to the external W-band IF components via W-band waveguide probes and waveguide to coaxial adapters (Fig. 1 and 5). The IF band-pass filter has 1.5 dB conversion loss and 4 GHz bandwidth. The commercial IF amplifier has 16-20 dB gain, and a 4 dBm 1-dB gain-compression point. For IM3 measurements, the receiver was driven by two tones combined at the input using a 0.1-22 GHz power combiner, and the receiver output is measured by a microwave spectrum analyzer. Losses associated with cables and connectors are de-embedded. Because the noise, IP3, and conversion loss of this demonstration are limited by the external IF components to levels much poorer than that of the frequency-conversion ICs, we do not here report these measurements.

To measure the receiver's spurious tuning response, the receiver is first tuned, by setting the LO frequency, to a particular desired RF frequency, and, with the LO held fixed, the RF is then swept over the targeted DC-40 GHz RF tuning range. Such measurements were performed with the receiver tuned to 2, 5, 10, 20 and 30 GHz. The relative strength of the receiver spurious response was then measured as a function of RF input frequency and spurious input frequency (Fig. 6). Over 2-30 GHz bandwidth, the receiver has better than 20 dBc rejection. Largest spurs are resulted from spurious mixing products from the LO multiplier chain 3rd and 5th harmonics. With correction of a minor design error present on the current ICs, the spurious responses can be reduced to ~35 dB rejection, consistent with the results of [3].

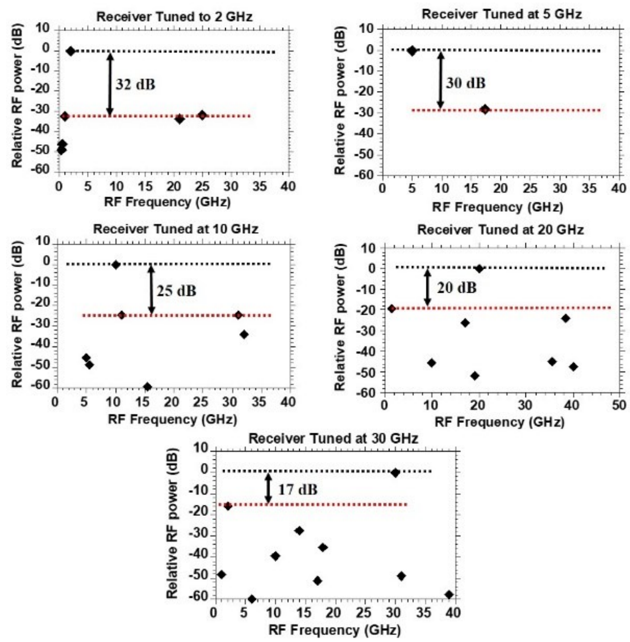


Fig. 6. Spurious free tuning range for the system. Relative power due to the unwanted spurs vs. RF frequency is plotted.

Table 1. Comparison between state-of-the-art designs

| | [7] | [8] | [9] | This Work |
|---|---|---|---|---|
| Technology | 45 nm CMOS | 65 nm CMOS | 90 nm CMOS | 130 nm InP HBT |
| Freq. [GHz] | 0.6-10 | 0-8 | 0.8-6 | 1-30 |
| Conversion Gain [dB] | 14 | 23 | 20 | (-4) – (-7)# |
| IIP3 (dBm) | 0 | -7 | -4 | 20-25 |
| NF [dB] | 7 | 4.5 | 5 | 4 - 7* |
| Pdc [mW] | 90 | 39 | 60 | 3085 |

#: only frequency conversion without pre-amp or LNA
*: estimated from conversion loss for a passive network

## V. Conclusion

We present a high-dynamic-range W-band frequency conversion ICs using a passive diode mixer and an integrated 4:1 frequency multiplier and LO power driver. The circuits were fabricated in a 130 nm InP HBT process. The conversion IC has about 4-7 dB conversion loss and an IIP3 of about 20-25 dBm for both up and down-conversion. Noise figure has not yet been measured but the noise figure of a passive diode mixer is usually very close to its insertion loss. We therefore expect 4-7 dB noise figure in either frequency up or down-conversion.

We than demonstrate a dual-conversion super-heterodyne receiver with a 94 GHz first IF and a 1–30 GHz RF tuning range using both up and down-conversion ICs. State of the art results are provided in Table 1 for broadband receivers for comparison. The receiver in this work can be tuned over 1-30 GHz bandwidth, which is the best compared to the previous broadband receivers according to the authors' best of knowledge.

## VI. Acknowledgement

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