A High-Dynamic-Range W-band Frequency-Conversion IC for Microwave Dual-Conversion Receivers

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Dual-Conversion Receiver

Classical RF architecture: extend to micro/mm-wave frequencies
- Up-convert to 1\textsuperscript{st} IF (100 GHz), down-convert to 2\textsuperscript{nd} IF (or baseband)
- Image response moved out-of-band
- Very wide tuning range, no image response.

Applications:
- Instrumentation
- Wideband surveillance: 1-25 GHz (possibly 1-50 GHz)
- Single IC serving many applications: application-specific LNA + common module
THz HBTs $\rightarrow$ 1-25 GHz Dual conversion

Teledyne 130 nm InP HBT
1.1 THz $f_{\text{max}}$
CE: 14.4 dB MSG @100 GHz
CB: 18.5 dB MSG @100 GHz

Dual conversion at microwave:
100 GHz 1\textsuperscript{st} IF would enable over 1-60 GHz spur-free tuning
High speed IC technologies: 100 GHz IF feasible

THz transistors enable microwave dual-conversion receivers
Frequency Conversion Blocks

Need high dynamic range & wide tuning range

This presentation: the frequency conversion blocks
High Dynamic Range Mixer

Transistor mixer:
- Low IP3
- High noise figure
- Poor dynamic range

Diode mixer:
- High IP3
- Lower noise figure
- Higher dynamic range

Design challenges:
- High speed diode
- Wide bandwidth balun
- Wide tuning range + high power LO
High Speed DHBT BC Diode

Double-heterojunction base-collector diode
- Hole minority carrier storage is eliminated by large energy barrier to holes
- Electron minority carrier storage time is small

→ Schottky-like high-frequency characteristics
Balun For Diode Mixer

Common-mode impedance $Z_{cm,RF}$ must be zero
IF port is required
Simple center-tapped transformer has wrong $Z_{cm}$
- Two transformers in series.
Ferrite loading gives correct $Z_{cm}$; can't use on IC
Options: two parallel transformers, or balun.

Proposed balun
- Sub-quarter wavelength balun (B1) [3]
- Section B2 provides the IF port and $Z_{cm,RF}=0$

Diode Mixer

Four series-connected BC diode pairs

RF and LO baluns

Balun loss < 4 dB over W-band

Size: 700 um x 300 um (excl. pads)
LO Multiplier Chain

- ECL-gate1
- LC filter
- ECL-gate2
- Stub filter
- ECL-gate3
- Buffer (CE amp.)

- ECL-gate
- Buffer

ECL-gates generate squarewave → Strong third harmonic, wide bandwidth
Chebyshev LC filter: 20-34 GHz
Microstrip line bandpass filter: 60-100 GHz
3-stage ECL pre-amplifier
Buffer: two-stage pseudo-differential common-emitter amplifier > 8 dBm
LO Multiplier Chain

Measured $P_{out}$: 8-11.5 dBm over 75-105 GHz tuning bandwidth
Power consumption: 270 mA from -4 V supply, 64 mA from 2 V supply
High-Power LO Driver

Wide bandwidth > 60-100 GHz, > 19 dBm output power

*Presented in SESSION F on Oct. 25
Frequency Conversion IC

Integrated frequency conversion IC
- Diode mixer
- High power LO driver
- x9 multiplier chain
- 136 emitter fingers
- 326 passive components

Total power consumption: 2 W
- Multiplier chain and LO driver

Size: 4300 um x 1160 um
7 dB conversion loss and 23 dBm IIP3
Down-Conversion Measurements

8 dB conversion loss and 23 dBm IIP3
LO Leakage

- 20 dBm LO power
- 30 dB isolation
- -10 dBm LO leakage into RF

LO Frequency (GHz) vs. Power (dBm)

20 dBm LO power
30 dB isolation
-10 dBm LO leakage into RF
W-band frequency conversion IC

Dual conversion: classic widely-tunable RF receiver design
Extend to microwave (3-30 GHz) → Need ~100 GHz IF

Dual conversion: feasible with wideband (THz) transistors
100 GHz signal frequency is only 10% of transistor $f_{\text{max}}$
Enable high-dynamic-range mixers (amp: next talk)
9:1, 75-100 GHz LO multiplier using digital techniques (ECL-gates)

Present frequency conversion IC
High dynamic range (7-8 dB loss ≈ noise figure, 23 dBm IIP3)
Very wide tuning LO (1-25 GHz ↔ 76-100 GHz)
Application: 1-25 GHz dual-conversion receiver

Complex IC in a 1 THz IC technology
136 HBT emitter fingers, 326 passive components, 16 cascaded stages
1st pass: good correlation between simulation & measurement

We thank Teledyne Scientific & Imaging for IC fabrication
Thank you
RF Balun Design

*Positive LO cycle

Insertion loss < 3.5 dB, phase error < 4° over W-band
LO Balun Design

**Z_{in,ideal} = 0**

*Positive LO cycle*

Insertion Loss (dB) vs Frequency (GHz)

2-4 dB insertion loss over W-band
Multiplier x3

ECL-gate1  LC filter  ECL-gate2

*Ground plane: top metal layer

*Cable loss is not calibrated
LO Multiplier Chain

- Measured $P_{out} > 8$ dBm
- Power consumption:
  - $V_{EE}: 270$ mA @ -4 V
  - $V_{CC}: 64$ mA @ 2 V
Measurement Setup

IIP3 (up-conversion)

Signal gen. → Power combiner (0.1 ~ 22 GHz) → DUT → Quinstar (QMB) → Spectrum Analyzer (70 MHz)

IIP3 (down-conversion)

Signal gen. → x3 → Magic Tee (W-band) → DUT → Spectrum Analyzer

OML module

W-band spectrum and loss

Signal gen. → Coupler (W-band) → OML Harmonic mixer → Power meter → Spectrum Analyzer
IIP3 Measurement Setup

Up-conversion
Measurement Setup

**Up-conversion**
- LO Input (9 dBm)
- Coupler (20 dB)
- Power sensor (Thru)
- Harmonic mixer (Coupled)

**Down-conversion**
- Power sensor (Monitoring LO power)
- Multiplier
- W-band amp.

**Spectrum and gain**
Measurements (UP)

Fixed IF Input @ 200 MHz

- IIP3, w/o Multiplier
- IIP3, Simulated
- IIP3 w/ Multiplier
- Conversion Gain, w/o Multiplier
- Conversion Gain, Simulated
- Conversion Gain, w/ Multiplier
- Conversion Gain, Measured with Power meter

* w/o mul.: LO input power 9 dBm
Measurements (UP)

IIP3 (dBm)

Conversion Gain (dB)

IF Frequency (GHz)

Fixed RF Output @ 100 GHz

*W/o mul.: LO input power 9 dBm
Measurements (Down)

Fixed IF Output @ 100 MHz

- IIP3 (dBm)
- Conversion Gain (dB)
- RF Frequency (GHz)

*IIP3 w/o Multiplier*
*IIP3, Simulated*
*IIP3 w/ Multiplier*
Conversion Gain w/o Multiplier
Conversion Gain w/ Multiplier
Conversion Gain, Simulated

*W/o mul.: LO input power 9 dBm*
Measurements (Down)

Fixed RF Input @ 99 GHz

IIP3 (dBm)

Conversion Gain (dB)

IF Frequency (GHz)

-20
-15
-10
-5
0
5
0 5 10 15 20 25

IIP3 w/o Multiplier
IIP3, Simulated
IIP3 w/ Multiplier
Conversion Gain w/o Multiplier
Conversion Gain, Simulated
Conversion Gain w/ Multiplier
Conversion Gain, Simulated

*w/o mul.: LO input power 9 dBm